

## SUPPORTING FILES:

### 3.1 Thermal stepping

Table S3.1: thermal stepping data of 2 MAPbI<sub>3</sub> devices.

| T (°C) | MAPbI <sub>3</sub> DEVICE 1 |         |        |                           | MAPbI <sub>3</sub> DEVICE 2 |         |        |                           | MAPbI <sub>3</sub> STEPPING AVERAGE |         |        |                           |
|--------|-----------------------------|---------|--------|---------------------------|-----------------------------|---------|--------|---------------------------|-------------------------------------|---------|--------|---------------------------|
|        | PCE (%)                     | Voc (V) | FF (%) | Jsc (mA/Cm <sup>2</sup> ) | PCE (%)                     | Voc (V) | FF (%) | Jsc (mA/Cm <sup>2</sup> ) | PCE (%)                             | Voc (V) | FF (%) | Jsc (mA/Cm <sup>2</sup> ) |
| 20     | 12.35                       | 1       | 56.3   | 12.02                     | 13.07                       | 1.01    | 59.02  | 12.03                     | 12.71                               | 1.005   | 57.66  | 12.03                     |
| 10     | 12.43                       | 1       | 56.29  | 12.04                     | 13.04                       | 1.01    | 58.83  | 12.02                     | 12.74                               | 1.005   | 57.56  | 12.03                     |
| 0      | 12.23                       | 1.01    | 55.07  | 12.08                     | 12.83                       | 1.01    | 57.85  | 12.03                     | 12.53                               | 1.010   | 56.46  | 12.06                     |
| -10    | 11.88                       | 1.01    | 53.32  | 12.11                     | 12.59                       | 1.01    | 56.67  | 12.05                     | 12.24                               | 1.010   | 55.00  | 12.08                     |
| -20    | 11.49                       | 1.01    | 51.31  | 12.17                     | 12.16                       | 1.01    | 54.79  | 12.07                     | 11.83                               | 1.010   | 53.05  | 12.12                     |
| -30    | 11                          | 1.01    | 49.07  | 12.19                     | 11.86                       | 1.01    | 53.4   | 12.09                     | 11.43                               | 1.010   | 51.24  | 12.14                     |
| -40    | 10.28                       | 1       | 46.07  | 12.17                     | 11.46                       | 1       | 51.6   | 12.1                      | 10.87                               | 1.00    | 48.84  | 12.14                     |
| -50    | 9.63                        | 1       | 43.34  | 12.18                     | 10.82                       | 1       | 48.78  | 12.09                     | 10.23                               | 1.00    | 46.06  | 12.14                     |
| -60    | 8.78                        | 0.99    | 39.79  | 12.17                     | 10.1                        | 0.99    | 44.11  | 12.07                     | 9.44                                | 0.99    | 41.95  | 12.12                     |
| -70    | 7.65                        | 0.98    | 35.44  | 12.03                     | 9.2                         | 0.99    | 40.87  | 12.02                     | 8.43                                | 0.99    | 38.16  | 12.03                     |
| -80    | 6.5                         | 0.97    | 31.43  | 11.66                     | 8.1                         | 0.98    | 36.75  | 12.01                     | 7.30                                | 0.98    | 34.09  | 11.84                     |
| -90    | 5.31                        | 0.96    | 27.89  | 10.86                     | 7.16                        | 0.97    | 32.66  | 11.84                     | 6.24                                | 0.97    | 30.28  | 11.35                     |
| -100   | 4.42                        | 0.95    | 25.65  | 9.93                      | 5.81                        | 0.95    | 28.86  | 11.57                     | 5.12                                | 0.95    | 27.26  | 10.75                     |
| -110   | 3.6                         | 0.94    | 23.87  | 8.74                      | 4.99                        | 0.94    | 26.94  | 10.74                     | 4.30                                | 0.94    | 25.41  | 9.74                      |
| -120   | 2.63                        | 0.94    | 22.04  | 6.96                      | 3.91                        | 0.93    | 24.78  | 9.27                      | 3.27                                | 0.94    | 23.41  | 8.12                      |
| -125   | 2.09                        | 0.93    | 21.18  | 5.78                      | 3.2                         | 0.93    | 23.38  | 8.09                      | 2.65                                | 0.93    | 22.28  | 6.94                      |

Table S3.2: MAPbI<sub>3</sub> J-V data.

| MAPbI3 (DEVICE 2)    |                          |                        |                          |
|----------------------|--------------------------|------------------------|--------------------------|
| 20 °C (FORWARD SCAN) |                          | -125 °C (FORWARD SCAN) |                          |
| Voltage (V)          | Current density (mA/Cm²) | Voltage (V)            | Current density (mA/Cm²) |
| 1.2                  | -12.29673                | 1.2                    | -2.455464                |
| 1.185                | -12.05124                | 1.185                  | -2.300941                |
| 1.17                 | -10.97198                | 1.17                   | -2.148592                |
| 1.155                | -9.832873                | 1.155                  | -1.997477                |
| 1.14                 | -8.678786                | 1.14                   | -1.848889                |
| 1.125                | -7.576759                | 1.125                  | -1.702217                |
| 1.11                 | -6.49125                 | 1.11                   | -1.558524                |
| 1.095                | -5.421165                | 1.095                  | -1.417216                |
| 1.08                 | -4.399896                | 1.08                   | -1.278386                |
| 1.065                | -3.416652                | 1.065                  | -1.142762                |
| 1.05                 | -2.463295                | 1.05                   | -1.009919                |
| 1.035                | -1.547205                | 1.035                  | -0.8803673               |
| 1.02                 | -0.756445                | 1.02                   | -0.753718                |
| 1.005                | 0.1430479                | 1.005                  | -0.6254916               |
| 0.99                 | 0.965807                 | 0.99                   | -0.5030265               |
| 0.975                | 1.842824                 | 0.975                  | -0.3831032               |
| 0.96                 | 2.629091                 | 0.96                   | -0.2671028               |
| 0.945                | 3.3664                   | 0.945                  | -0.1521163               |
| 0.93                 | 4.055875                 | 0.93                   | -3.52E-02                |
| 0.915                | 4.711619                 | 0.915                  | 8.56E-02                 |
| 0.9                  | 5.32537                  | 0.9                    | 0.1983889                |
| 0.885                | 5.902345                 | 0.885                  | 0.308694                 |
| 0.87                 | 6.437292                 | 0.87                   | 0.4190597                |
| 0.855                | 6.935289                 | 0.855                  | 0.5292783                |
| 0.84                 | 7.30786                  | 0.84                   | 0.6391131                |
| 0.825                | 7.798457                 | 0.825                  | 0.7537406                |
| 0.81                 | 8.212886                 | 0.81                   | 0.8664536                |
| 0.795                | 8.583326                 | 0.795                  | 0.9786083                |
| 0.78                 | 8.912149                 | 0.78                   | 1.090912                 |
| 0.765                | 9.210373                 | 0.765                  | 1.204155                 |
| 0.75                 | 9.47865                  | 0.75                   | 1.318175                 |
| 0.735                | 9.715076                 | 0.735                  | 1.433647                 |
| 0.72                 | 9.92084                  | 0.72                   | 1.549937                 |
| 0.705                | 10.12737                 | 0.705                  | 1.667292                 |
| 0.69                 | 10.28676                 | 0.69                   | 1.785029                 |
| 0.675                | 10.43988                 | 0.675                  | 1.90634                  |
| 0.66                 | 10.57361                 | 0.66                   | 2.028091                 |
| 0.645                | 10.69477                 | 0.645                  | 2.151129                 |
| 0.63                 | 10.79059                 | 0.63                   | 2.275664                 |
| 0.615                | 10.88837                 | 0.615                  | 2.401947                 |
| 0.6                  | 10.97465                 | 0.6                    | 2.529606                 |
| 0.585                | 11.04506                 | 0.585                  | 2.65917                  |
| 0.57                 | 11.11241                 | 0.57                   | 2.789244                 |
| 0.555                | 11.16913                 | 0.555                  | 2.921552                 |
| 0.54                 | 11.21884                 | 0.54                   | 3.054889                 |
| 0.525                | 11.26935                 | 0.525                  | 3.189371                 |
| 0.51                 | 11.31206                 | 0.51                   | 3.326052                 |
| 0.495                | 11.35248                 | 0.495                  | 3.463592                 |
| 0.48                 | 11.37009                 | 0.48                   | 3.601831                 |
| 0.465                | 11.41343                 | 0.465                  | 3.74138                  |
| 0.45                 | 11.4486                  | 0.45                   | 3.88254                  |
| 0.435                | 11.48036                 | 0.435                  | 4.02531                  |
| 0.42                 | 11.52284                 | 0.42                   | 4.167066                 |
| 0.405                | 11.55383                 | 0.405                  | 4.31146                  |
| 0.39                 | 11.57342                 | 0.39                   | 4.454745                 |
| 0.375                | 11.59035                 | 0.375                  | 4.599129                 |
| 0.36                 | 11.62675                 | 0.36                   | 4.744092                 |
| 0.345                | 11.64675                 | 0.345                  | 4.890006                 |
| 0.33                 | 11.67341                 | 0.33                   | 5.035379                 |
| 0.315                | 11.70424                 | 0.315                  | 5.180928                 |
| 0.3                  | 11.71646                 | 0.3                    | 5.325484                 |
| 0.285                | 11.73057                 | 0.285                  | 5.470288                 |
| 0.27                 | 11.75495                 | 0.27                   | 5.615258                 |
| 0.255                | 11.77291                 | 0.255                  | 5.758969                 |
| 0.24                 | 11.79289                 | 0.24                   | 5.902632                 |
| 0.225                | 11.81555                 | 0.225                  | 6.046187                 |
| 0.21                 | 11.83023                 | 0.21                   | 6.187833                 |
| 0.195                | 11.85519                 | 0.195                  | 6.330041                 |
| 0.18                 | 11.86114                 | 0.18                   | 6.470111                 |
| 0.165                | 11.87695                 | 0.165                  | 6.61059                  |
| 0.15                 | 11.89896                 | 0.15                   | 6.748864                 |
| 0.135                | 11.91779                 | 0.135                  | 6.886406                 |
| 0.12                 | 11.9279                  | 0.12                   | 7.041473                 |
| 0.105                | 11.95432                 | 0.105                  | 7.169954                 |
| 0.09                 | 11.94574                 | 0.09                   | 7.30489                  |
| 0.075                | 11.97049                 | 0.075                  | 7.440433                 |
| 0.06                 | 11.97813                 | 0.06                   | 7.57217                  |
| 0.045                | 11.98975                 | 0.045                  | 7.704243                 |
| 0.03                 | 12.00083                 | 0.03                   | 7.833469                 |
| 0.015                | 12.01142                 | 0.015                  | 7.964                    |
| 0                    | 12.03366                 | 0                      | 8.091264                 |
| -0.015               | 12.03762                 | -0.015                 | 8.217986                 |
| -0.03                | 12.04752                 | -0.03                  | 8.344143                 |
| -0.045               | 12.05307                 | -0.045                 | 8.469823                 |
| -0.06                | 12.07057                 | -0.06                  | 8.59357                  |
| -0.075               | 12.08455                 | -0.075                 | 8.718697                 |
| -0.09                | 12.08334                 | -0.09                  | 8.839999                 |
| -0.1                 | 12.08775                 | -0.1                   | 8.919643                 |

| MAPbI3 (DEVICE 2)    |                          |                        |                          |
|----------------------|--------------------------|------------------------|--------------------------|
| 20 °C (REVERSE SCAN) |                          | -125 °C (REVERSE SCAN) |                          |
| Voltage (V)          | Current density (mA/Cm²) | Voltage (V)            | Current density (mA/Cm²) |
| 1.2                  | -12.1397                 | 1.2                    | -1.588307                |
| 1.2                  | -12.26225                | 1.2                    | -1.598143                |
| 1.185                | -11.18949                | 1.185                  | -1.453883                |
| 1.17                 | -10.13194                | 1.17                   | -1.312045                |
| 1.155                | -9.093583                | 1.155                  | -1.173081                |
| 1.14                 | -8.085874                | 1.14                   | -1.037144                |
| 1.125                | -7.048473                | 1.125                  | -0.9039356               |
| 1.11                 | -6.222437                | 1.11                   | -0.7726687               |
| 1.095                | -5.294948                | 1.095                  | -0.6530771               |
| 1.08                 | -4.393743                | 1.08                   | -0.5284514               |
| 1.065                | -3.515364                | 1.065                  | -0.4068631               |
| 1.05                 | -2.659107                | 1.05                   | -0.2869247               |
| 1.035                | -1.811149                | 1.035                  | -0.1688185               |
| 1.02                 | -0.9332116               | 1.02                   | -6.40E-02                |
| 1.005                | -0.3053077               | 1.005                  | 3.62E-02                 |
| 0.99                 | 0.5188165                | 0.99                   | 0.1379154                |
| 0.975                | 1.105582                 | 0.975                  | 0.2433248                |
| 0.96                 | 1.785285                 | 0.96                   | 0.3463833                |
| 0.945                | 2.441952                 | 0.945                  | 0.4489945                |
| 0.93                 | 3.071468                 | 0.93                   | 0.5506623                |
| 0.915                | 3.657215                 | 0.915                  | 0.6519063                |
| 0.9                  | 4.228864                 | 0.9                    | 0.7411206                |
| 0.885                | 4.78222                  | 0.885                  | 0.839406                 |
| 0.87                 | 5.289317                 | 0.87                   | 0.9353816                |
| 0.855                | 5.771223                 | 0.855                  | 1.030854                 |
| 0.84                 | 6.242176                 | 0.84                   | 1.126202                 |
| 0.825                | 6.78116                  | 0.825                  | 1.22234                  |
| 0.81                 | 6.987776                 | 0.81                   | 1.318522                 |
| 0.795                | 7.354003                 | 0.795                  | 1.414225                 |
| 0.78                 | 7.699426                 | 0.78                   | 1.509608                 |
| 0.765                | 8.015473                 | 0.765                  | 1.606228                 |
| 0.75                 | 8.298926                 | 0.75                   | 1.702939                 |
| 0.735                | 8.569336                 | 0.735                  | 1.799285                 |
| 0.72                 | 8.805666                 | 0.72                   | 1.896897                 |
| 0.705                | 9.023606                 | 0.705                  | 1.995521                 |
| 0.69                 | 9.229712                 | 0.69                   | 2.093677                 |
| 0.675                | 9.416869                 | 0.675                  | 2.193748                 |
| 0.66                 | 9.58064                  | 0.66                   | 2.292047                 |
| 0.645                | 9.73172                  | 0.645                  | 2.391152                 |
| 0.63                 | 9.864163                 | 0.63                   | 2.491658                 |
| 0.615                | 9.992526                 | 0.615                  | 2.594579                 |
| 0.6                  | 10.11122                 | 0.6                    | 2.69634                  |
| 0.585                | 10.21954                 | 0.585                  | 2.801564                 |
| 0.57                 | 10.34012                 | 0.57                   | 2.905213                 |
| 0.555                | 10.40057                 | 0.555                  | 3.010689                 |
| 0.54                 | 10.47135                 | 0.54                   | 3.117459                 |
| 0.525                | 10.55108                 | 0.525                  | 3.225272                 |
| 0.51                 | 10.64562                 | 0.51                   | 3.335179                 |
| 0.495                | 10.69631                 | 0.495                  | 3.445704                 |
| 0.48                 | 10.75408                 | 0.48                   | 3.558515                 |
| 0.465                | 10.81558                 | 0.465                  | 3.674049                 |
| 0.45                 | 10.88086                 | 0.45                   | 3.790803                 |
| 0.435                | 10.94098                 | 0.435                  | 3.910839                 |
| 0.42                 | 10.98441                 | 0.42                   | 4.032307                 |
| 0.405                | 11.04651                 | 0.405                  | 4.156101                 |
| 0.39                 | 11.08608                 | 0.39                   | 4.283223                 |
| 0.375                | 11.13588                 | 0.375                  | 4.412372                 |
| 0.36                 | 11.18168                 | 0.36                   | 4.543722                 |
| 0.345                | 11.2249                  | 0.345                  | 4.676737                 |
| 0.33                 | 11.2611                  | 0.33                   | 4.812599                 |
| 0.315                | 11.30374                 | 0.315                  | 4.952771                 |
| 0.3                  | 11.341                   | 0.3                    | 5.092552                 |
| 0.285                | 11.38581                 | 0.285                  | 5.235898                 |
| 0.27                 | 11.43091                 | 0.27                   | 5.382447                 |
| 0.255                | 11.44743                 | 0.255                  | 5.530979                 |
| 0.24                 | 11.48752                 | 0.24                   | 5.679387                 |
| 0.225                | 11.5316                  | 0.225                  | 5.830943                 |
| 0.21                 | 11.55251                 | 0.21                   | 5.984345                 |
| 0.195                | 11.58647                 | 0.195                  | 6.136075                 |
| 0.18                 | 11.60776                 | 0.18                   | 6.290905                 |
| 0.165                | 11.63962                 | 0.165                  | 6.447728                 |
| 0.15                 | 11.67448                 | 0.15                   | 6.619227                 |
| 0.135                | 11.69932                 | 0.135                  | 6.736149                 |
| 0.12                 | 11.72325                 | 0.12                   | 6.889773                 |
| 0.105                | 11.73185                 | 0.105                  | 7.043232                 |
| 0.09                 | 11.76989                 | 0.09                   | 7.19591                  |
| 0.075                | 11.7912                  | 0.075                  | 7.348263                 |
| 0.06                 | 11.81292                 | 0.06                   | 7.49849                  |
| 0.045                | 11.84707                 | 0.045                  | 7.649416                 |
| 0.03                 | 11.86781                 | 0.03                   | 7.794676                 |
| 0.015                | 11.88762                 | 0.015                  | 7.940569                 |
| 0                    | 11.92955                 | 0                      | 8.081976                 |
| -0.01                | 11.92193                 | -0.01                  | 8.177369                 |
| -0.025               | 11.94939                 | -0.025                 | 8.317766                 |
| -0.04                | 11.97493                 | -0.04                  | 8.45793                  |
| -0.055               | 11.99934                 | -0.055                 | 8.594379                 |
| -0.07                | 12.03725                 | -0.07                  | 8.731093                 |
| -0.085               | 12.09809                 | -0.085                 | 8.86838                  |
| -0.1                 | 12.26957                 | -0.1                   | 9.021664                 |

Table S3.3: thermal stepping data of 2 triple cation devices.

| T (°C) | TRIPLE CATION DEVICE 1 |         |        |                           | TRIPLE CATION DEVICE 2 |         |        |                           | TRIPLE CATION STEPPING AVERAGE |         |        |                           |
|--------|------------------------|---------|--------|---------------------------|------------------------|---------|--------|---------------------------|--------------------------------|---------|--------|---------------------------|
|        | PCE (%)                | Voc (V) | FF (%) | Jsc (mA/Cm <sup>2</sup> ) | PCE (%)                | Voc (V) | FF (%) | Jsc (mA/Cm <sup>2</sup> ) | PCE (%)                        | Voc (V) | FF (%) | Jsc (mA/Cm <sup>2</sup> ) |
| 20     | 15.46                  | 1.1     | 67.12  | 11.48                     | 15.98                  | 1.1     | 65.46  | 12.18                     | 15.72                          | 1.1     | 66.29  | 11.83                     |
| 10     | 15.17                  | 1.1     | 65.93  | 11.45                     | 15.36                  | 1.09    | 64.18  | 12.18                     | 15.265                         | 1.095   | 65.055 | 11.815                    |
| 0      | 14.77                  | 1.1     | 64.24  | 11.46                     | 14.62                  | 1.08    | 63.01  | 12.2                      | 14.695                         | 1.09    | 63.625 | 11.83                     |
| -10    | 14.46                  | 1.1     | 63.1   | 11.41                     | 13.71                  | 1.05    | 61.5   | 12.18                     | 14.085                         | 1.075   | 62.3   | 11.795                    |
| -20    | 14.01                  | 1.09    | 62.8   | 11.19                     | 12.88                  | 1.03    | 59.49  | 12.18                     | 13.445                         | 1.06    | 61.145 | 11.685                    |
| -30    | 12.71                  | 1.07    | 58.44  | 11.11                     | 11.6                   | 1       | 55.07  | 12.13                     | 12.155                         | 1.035   | 56.755 | 11.62                     |
| -40    | 10.72                  | 1.03    | 51.23  | 11.06                     | 10.4                   | 0.98    | 51.84  | 12.06                     | 10.56                          | 1.005   | 51.535 | 11.56                     |
| -50    | 8.84                   | 1       | 43.65  | 11.03                     | 9.17                   | 0.97    | 45.24  | 12.03                     | 9.005                          | 0.985   | 44.445 | 11.53                     |
| -60    | 7.22                   | 0.99    | 36.67  | 10.89                     | 8.01                   | 0.96    | 39.34  | 12.03                     | 7.615                          | 0.975   | 38.005 | 11.46                     |
| -70    | 5.7                    | 0.97    | 29.94  | 10.68                     | 6.64                   | 0.95    | 33.91  | 11.96                     | 6.17                           | 0.96    | 31.925 | 11.32                     |
| -80    | 4.63                   | 0.97    | 26.02  | 10.03                     | 5.78                   | 0.95    | 30.22  | 11.69                     | 5.205                          | 0.96    | 28.12  | 10.86                     |
| -90    | 3.77                   | 0.97    | 24.04  | 8.86                      | 5.1                    | 0.95    | 27.91  | 11.13                     | 4.435                          | 0.96    | 25.975 | 9.995                     |
| -100   | 3.03                   | 0.97    | 22.89  | 7.47                      | 4.44                   | 0.95    | 26.35  | 10.2                      | 3.735                          | 0.96    | 24.62  | 8.835                     |
| -110   | 2.38                   | 0.97    | 22.11  | 6.06                      | 3.92                   | 0.94    | 25.64  | 9.18                      | 3.15                           | 0.955   | 23.875 | 7.62                      |
| -120   | 1.83                   | 0.97    | 21.52  | 4.78                      | 3.36                   | 0.93    | 24.78  | 8.09                      | 2.595                          | 0.95    | 23.15  | 6.435                     |
| -125   | 1.71                   | 0.99    | 21.37  | 4.42                      | 3.09                   | 0.92    | 24.39  | 7.52                      | 2.4                            | 0.955   | 22.88  | 5.97                      |

Table S3.4: triple cation J-V data.

| TRIPLE CATION (DEVICE 2) |                          |                        |                          |
|--------------------------|--------------------------|------------------------|--------------------------|
| 20 °C (FORWARD SCAN)     |                          | -125 °C (FORWARD SCAN) |                          |
| Voltage (V)              | Current density (mA/Cm²) | Voltage (V)            | Current density (mA/Cm²) |
| 1.2                      | -10.74941                | 1.2                    | -2.578339                |
| 1.185                    | -8.485773                | 1.185                  | -2.394257                |
| 1.17                     | -6.446378                | 1.17                   | -2.221487                |
| 1.155                    | -4.818397                | 1.155                  | -2.057798                |
| 1.14                     | -3.447642                | 1.14                   | -1.899489                |
| 1.125                    | -2.197582                | 1.125                  | -1.745825                |
| 1.11                     | -1.022944                | 1.11                   | -1.597186                |
| 1.095                    | 0.1185591                | 1.095                  | -1.452731                |
| 1.08                     | 1.239096                 | 1.08                   | -1.312608                |
| 1.065                    | 2.249966                 | 1.065                  | -1.175931                |
| 1.05                     | 3.169913                 | 1.05                   | -1.04229                 |
| 1.035                    | 4.045239                 | 1.035                  | -0.911864                |
| 1.02                     | 4.855264                 | 1.02                   | -0.7840586               |
| 1.005                    | 5.605411                 | 1.005                  | -0.6596159               |
| 0.99                     | 6.29713                  | 0.99                   | -0.5340794               |
| 0.975                    | 6.934183                 | 0.975                  | -0.4120128               |
| 0.96                     | 7.468752                 | 0.96                   | -0.2915973               |
| 0.945                    | 7.994486                 | 0.945                  | -0.1723707               |
| 0.93                     | 8.472719                 | 0.93                   | -0.0570517               |
| 0.915                    | 8.83933                  | 0.915                  | 6.39E-02                 |
| 0.9                      | 9.298456                 | 0.9                    | 0.1772606                |
| 0.885                    | 9.579373                 | 0.885                  | 0.2967991                |
| 0.87                     | 9.845676                 | 0.87                   | 0.4133424                |
| 0.855                    | 10.16944                 | 0.855                  | 0.5288199                |
| 0.84                     | 10.38121                 | 0.84                   | 0.6436127                |
| 0.825                    | 10.55671                 | 0.825                  | 0.7535143                |
| 0.81                     | 10.75505                 | 0.81                   | 0.8710803                |
| 0.795                    | 10.91612                 | 0.795                  | 0.9863936                |
| 0.78                     | 11.05808                 | 0.78                   | 1.101442                 |
| 0.765                    | 11.15087                 | 0.765                  | 1.215967                 |
| 0.75                     | 11.23735                 | 0.75                   | 1.33047                  |
| 0.735                    | 11.35178                 | 0.735                  | 1.447111                 |
| 0.72                     | 11.4348                  | 0.72                   | 1.562314                 |
| 0.705                    | 11.49741                 | 0.705                  | 1.677547                 |
| 0.69                     | 11.56385                 | 0.69                   | 1.795061                 |
| 0.675                    | 11.62597                 | 0.675                  | 1.911361                 |
| 0.66                     | 11.67288                 | 0.66                   | 2.028892                 |
| 0.645                    | 11.71488                 | 0.645                  | 2.147                    |
| 0.63                     | 11.7432                  | 0.63                   | 2.26699                  |
| 0.615                    | 11.77983                 | 0.615                  | 2.386806                 |
| 0.6                      | 11.81784                 | 0.6                    | 2.505563                 |
| 0.585                    | 11.84488                 | 0.585                  | 2.627374                 |
| 0.57                     | 11.85964                 | 0.57                   | 2.750326                 |
| 0.555                    | 11.87533                 | 0.555                  | 2.874044                 |
| 0.54                     | 11.90187                 | 0.54                   | 2.997366                 |
| 0.525                    | 11.90922                 | 0.525                  | 3.122808                 |
| 0.51                     | 11.93821                 | 0.51                   | 3.248513                 |
| 0.495                    | 11.93809                 | 0.495                  | 3.375096                 |
| 0.48                     | 11.95982                 | 0.48                   | 3.503132                 |
| 0.465                    | 11.97163                 | 0.465                  | 3.631196                 |
| 0.45                     | 11.97778                 | 0.45                   | 3.758743                 |
| 0.435                    | 11.98842                 | 0.435                  | 3.889201                 |
| 0.42                     | 11.99404                 | 0.42                   | 4.019605                 |
| 0.405                    | 12.00865                 | 0.405                  | 4.152025                 |
| 0.39                     | 12.01403                 | 0.39                   | 4.282067                 |
| 0.375                    | 12.02633                 | 0.375                  | 4.414338                 |
| 0.36                     | 12.02989                 | 0.36                   | 4.546219                 |
| 0.345                    | 12.03803                 | 0.345                  | 4.677017                 |
| 0.33                     | 12.04201                 | 0.33                   | 4.809932                 |
| 0.315                    | 12.05043                 | 0.315                  | 4.941931                 |
| 0.3                      | 12.05753                 | 0.3                    | 5.073447                 |
| 0.285                    | 12.06046                 | 0.285                  | 5.205064                 |
| 0.27                     | 12.05787                 | 0.27                   | 5.333105                 |
| 0.255                    | 12.0819                  | 0.255                  | 5.46525                  |
| 0.24                     | 12.0867                  | 0.24                   | 5.592297                 |
| 0.225                    | 12.09781                 | 0.225                  | 5.722891                 |
| 0.21                     | 12.11226                 | 0.21                   | 5.848047                 |
| 0.195                    | 12.1127                  | 0.195                  | 5.975582                 |
| 0.18                     | 12.12529                 | 0.18                   | 6.103305                 |
| 0.165                    | 12.12448                 | 0.165                  | 6.22798                  |
| 0.15                     | 12.12976                 | 0.15                   | 6.352383                 |
| 0.135                    | 12.13701                 | 0.135                  | 6.475156                 |
| 0.12                     | 12.14442                 | 0.12                   | 6.593957                 |
| 0.105                    | 12.15479                 | 0.105                  | 6.714612                 |
| 0.09                     | 12.15153                 | 0.09                   | 6.836349                 |
| 0.075                    | 12.15305                 | 0.075                  | 6.953703                 |
| 0.06                     | 12.16122                 | 0.06                   | 7.112724                 |
| 0.045                    | 12.16847                 | 0.045                  | 7.191879                 |
| 0.03                     | 12.17894                 | 0.03                   | 7.29824                  |
| 0.015                    | 12.17506                 | 0.015                  | 7.40804                  |
| 0                        | 12.17504                 | 0                      | 7.518666                 |
| -0.015                   | 12.19019                 | -0.015                 | 7.631013                 |
| -0.03                    | 12.1901                  | -0.03                  | 7.738556                 |
| -0.045                   | 12.21244                 | -0.045                 | 7.847897                 |
| -0.06                    | 12.20827                 | -0.06                  | 7.950837                 |
| -0.075                   | 12.21731                 | -0.075                 | 8.051737                 |
| -0.09                    | 12.21561                 | -0.09                  | 8.153586                 |
| -0.1                     | 12.21107                 | -0.1                   | 8.217797                 |

| TRIPLE CATION (DEVICE 2) |                          |                        |                          |
|--------------------------|--------------------------|------------------------|--------------------------|
| 20 °C (REVERSE SCAN)     |                          | -125 °C (REVERSE SCAN) |                          |
| Voltage (V)              | Current density (mA/Cm²) | Voltage (V)            | Current density (mA/Cm²) |
| 1.2                      | -6.090316                | 1.2                    | -2.478914                |
| 1.2                      | -6.165758                | 1.2                    | -2.481766                |
| 1.185                    | -5.020037                | 1.185                  | -2.317708                |
| 1.17                     | -3.909458                | 1.17                   | -2.156391                |
| 1.155                    | -2.825953                | 1.155                  | -1.9989                  |
| 1.14                     | -1.771548                | 1.14                   | -1.844658                |
| 1.125                    | -0.7131696               | 1.125                  | -1.694206                |
| 1.11                     | 0.2266929                | 1.11                   | -1.546589                |
| 1.095                    | 1.002341                 | 1.095                  | -1.403224                |
| 1.08                     | 1.845877                 | 1.08                   | -1.262624                |
| 1.065                    | 2.706956                 | 1.065                  | -1.125017                |
| 1.05                     | 3.353436                 | 1.05                   | -0.9898649               |
| 1.035                    | 4.168733                 | 1.035                  | -0.857172                |
| 1.02                     | 4.758912                 | 1.02                   | -0.724276                |
| 1.005                    | 5.444255                 | 1.005                  | -0.6036714               |
| 0.99                     | 6.060088                 | 0.99                   | -0.4797889               |
| 0.975                    | 6.629655                 | 0.975                  | -0.3575455               |
| 0.96                     | 7.09876                  | 0.96                   | -0.2369978               |
| 0.945                    | 7.574426                 | 0.945                  | -0.1137076               |
| 0.93                     | 7.981276                 | 0.93                   | -3.30E-03                |
| 0.915                    | 8.349873                 | 0.915                  | 0.1022551                |
| 0.9                      | 8.695286                 | 0.9                    | 0.2136652                |
| 0.885                    | 8.99267                  | 0.885                  | 0.3233964                |
| 0.87                     | 9.269883                 | 0.87                   | 0.4314736                |
| 0.855                    | 9.522943                 | 0.855                  | 0.5392014                |
| 0.84                     | 9.747683                 | 0.84                   | 0.6536076                |
| 0.825                    | 9.949373                 | 0.825                  | 0.7417463                |
| 0.81                     | 10.14399                 | 0.81                   | 0.8426166                |
| 0.795                    | 10.3275                  | 0.795                  | 0.9421072                |
| 0.78                     | 10.45849                 | 0.78                   | 1.041743                 |
| 0.765                    | 10.59818                 | 0.765                  | 1.140228                 |
| 0.75                     | 10.73032                 | 0.75                   | 1.237151                 |
| 0.735                    | 10.84253                 | 0.735                  | 1.331337                 |
| 0.72                     | 10.94518                 | 0.72                   | 1.426576                 |
| 0.705                    | 11.04345                 | 0.705                  | 1.521838                 |
| 0.69                     | 11.11541                 | 0.69                   | 1.615818                 |
| 0.675                    | 11.21274                 | 0.675                  | 1.710821                 |
| 0.66                     | 11.27507                 | 0.66                   | 1.805748                 |
| 0.645                    | 11.33032                 | 0.645                  | 1.899893                 |
| 0.63                     | 11.38559                 | 0.63                   | 1.994546                 |
| 0.615                    | 11.44655                 | 0.615                  | 2.09237                  |
| 0.6                      | 11.47543                 | 0.6                    | 2.188692                 |
| 0.585                    | 11.52789                 | 0.585                  | 2.289216                 |
| 0.57                     | 11.56423                 | 0.57                   | 2.391322                 |
| 0.555                    | 11.61244                 | 0.555                  | 2.495169                 |
| 0.54                     | 11.63195                 | 0.54                   | 2.602465                 |
| 0.525                    | 11.67781                 | 0.525                  | 2.710479                 |
| 0.51                     | 11.69151                 | 0.51                   | 2.821057                 |
| 0.495                    | 11.72382                 | 0.495                  | 2.936116                 |
| 0.48                     | 11.73928                 | 0.48                   | 3.051797                 |
| 0.465                    | 11.76262                 | 0.465                  | 3.170105                 |
| 0.45                     | 11.784                   | 0.45                   | 3.292184                 |
| 0.435                    | 11.80354                 | 0.435                  | 3.416701                 |
| 0.42                     | 11.82279                 | 0.42                   | 3.543139                 |
| 0.405                    | 11.83853                 | 0.405                  | 3.672276                 |
| 0.39                     | 11.85567                 | 0.39                   | 3.802377                 |
| 0.375                    | 11.86056                 | 0.375                  | 3.935861                 |
| 0.36                     | 11.88785                 | 0.36                   | 4.074293                 |
| 0.345                    | 11.89331                 | 0.345                  | 4.211518                 |
| 0.33                     | 11.90747                 | 0.33                   | 4.352892                 |
| 0.315                    | 11.92385                 | 0.315                  | 4.493976                 |
| 0.3                      | 11.94137                 | 0.3                    | 4.6347                   |
| 0.285                    | 11.96185                 | 0.285                  | 4.778473                 |
| 0.27                     | 11.98145                 | 0.27                   | 4.922393                 |
| 0.255                    | 11.99085                 | 0.255                  | 5.066702                 |
| 0.24                     | 12.00765                 | 0.24                   | 5.214032                 |
| 0.225                    | 12.02329                 | 0.225                  | 5.359722                 |
| 0.21                     | 12.02673                 | 0.21                   | 5.506574                 |
| 0.195                    | 12.03365                 | 0.195                  | 5.651681                 |
| 0.18                     | 12.04133                 | 0.18                   | 5.796669                 |
| 0.165                    | 12.05908                 | 0.165                  | 5.942531                 |
| 0.15                     | 12.07195                 | 0.15                   | 6.087083                 |
| 0.135                    | 12.07283                 | 0.135                  | 6.232839                 |
| 0.12                     | 12.0924                  | 0.12                   | 6.378793                 |
| 0.105                    | 12.10226                 | 0.105                  | 6.52504                  |
| 0.09                     | 12.11514                 | 0.09                   | 6.707739                 |
| 0.075                    | 12.13338                 | 0.075                  | 6.772883                 |
| 0.06                     | 12.13872                 | 0.06                   | 6.908913                 |
| 0.045                    | 12.15022                 | 0.045                  | 7.042102                 |
| 0.03                     | 12.14609                 | 0.03                   | 7.172649                 |
| 0.015                    | 12.1623                  | 0.015                  | 7.30429                  |
| 0                        | 12.18114                 | 0                      | 7.437146                 |
| -0.01                    | 12.17957                 | -0.01                  | 7.516796                 |
| -0.025                   | 12.18292                 | -0.025                 | 7.641956                 |
| -0.04                    | 12.21184                 | -0.04                  | 7.770327                 |
| -0.055                   | 12.21101                 | -0.055                 | 7.899                    |
| -0.07                    | 12.23081                 | -0.07                  | 8.025187                 |
| -0.085                   | 12.25706                 | -0.085                 | 8.16381                  |
| -0.1                     | 12.37979                 | -0.1                   | 8.368306                 |

Table S3.5: average cooling compared to heating PCEs of TC and MAPbI<sub>3</sub> devices.

| TRIPLE CATION   |         |  | MAPbI <sub>3</sub> |         |
|-----------------|---------|--|--------------------|---------|
| AVERAGE PCE (%) |         |  | AVERAGE PCE (%)    |         |
| COOLING         | HEATING |  | COOLING            | HEATING |
| 15.72           | 15.25   |  | 12.71              | 13.16   |
| 15.27           | 14.86   |  | 12.74              | 12.96   |
| 14.70           | 14.19   |  | 12.53              | 12.59   |
| 14.09           | 13.55   |  | 12.24              | 12.19   |
| 13.45           | 12.74   |  | 11.83              | 11.71   |
| 12.16           | 11.55   |  | 11.43              | 11.16   |
| 10.56           | 10.21   |  | 10.87              | 10.46   |
| 9.01            | 8.60    |  | 10.23              | 9.65    |
| 7.62            | 7.29    |  | 9.44               | 8.67    |
| 6.17            | 6.30    |  | 8.43               | 7.62    |
| 5.21            | 5.20    |  | 7.30               | 6.45    |
| 4.44            | 4.30    |  | 6.24               | 5.23    |
| 3.74            | 3.76    |  | 5.12               | 4.15    |
| 3.15            | 3.10    |  | 4.30               | 3.27    |
| 2.60            | 2.69    |  | 3.27               | 2.72    |
| 2.40            | 2.40    |  | 2.65               | 2.65    |

Table S3.6: series resistance extracted from J-V curves of MAPbI<sub>3</sub> and triple cation.

| MAPbI <sub>3</sub> series resistance |             |          |                         |  | Triple cation series resistance |             |          |                         |
|--------------------------------------|-------------|----------|-------------------------|--|---------------------------------|-------------|----------|-------------------------|
| T (°C)                               | Slope (A/V) | 1/Slope  | Rs (Ω cm <sup>2</sup> ) |  | T (°C)                          | Slope (A/V) | 1/Slope  | Rs (Ω cm <sup>2</sup> ) |
| 20                                   | -0.06051    | 16.52619 | 110.17                  |  | 20                              | -0.08829    | 11.32631 | 75.51                   |
| 10                                   | -0.06079    | 16.45007 | 109.67                  |  | 10                              | -0.07849    | 12.74048 | 84.94                   |
| 0                                    | -0.05917    | 16.90046 | 112.67                  |  | 0                               | -0.07142    | 14.00168 | 93.34                   |
| -10                                  | -0.05607    | 17.83485 | 118.90                  |  | -10                             | -0.06444    | 15.51831 | 103.46                  |
| -20                                  | -0.05168    | 19.34985 | 129.00                  |  | -20                             | -0.05805    | 17.22653 | 114.84                  |
| -30                                  | -0.04839    | 20.66543 | 137.77                  |  | -30                             | -0.04268    | 23.43018 | 156.20                  |
| -40                                  | -0.04604    | 21.72024 | 144.80                  |  | -40                             | -0.02889    | 34.61405 | 230.76                  |
| -50                                  | -0.043      | 23.25581 | 155.04                  |  | -50                             | -0.02327    | 42.97379 | 286.49                  |
| -60                                  | -0.03568    | 28.02691 | 186.85                  |  | -60                             | -0.01849    | 54.08329 | 360.56                  |
| -70                                  | -0.03017    | 33.14551 | 220.97                  |  | -70                             | -0.01363    | 73.36757 | 489.12                  |
| -80                                  | -0.02377    | 42.06984 | 280.47                  |  | -80                             | -0.01114    | 89.76661 | 598.44                  |
| -90                                  | -0.01878    | 53.24814 | 354.99                  |  | -90                             | -0.00889    | 112.4859 | 749.91                  |
| -100                                 | -0.01451    | 68.91799 | 459.45                  |  | -100                            | -0.00702    | 142.4501 | 949.67                  |
| -110                                 | -0.01246    | 80.25682 | 535.05                  |  | -110                            | -0.00536    | 186.5672 | 1243.78                 |
| -120                                 | -0.00993    | 100.7049 | 671.37                  |  | -120                            | -0.00426    | 234.7418 | 1564.95                 |
| -125                                 | -0.00808    | 123.7624 | 825.08                  |  | -125                            | -0.00373    | 268.0965 | 1787.31                 |

## 3.2 Open-Circuit Photoluminescence

Table S3.7: PL<sub>OC</sub> cooling parameters of the MAPI-based device.

| Temperature (°C) | Peak Position (nm) | Peak Shift (nm) | Optical Band Gap (eV) | FWHM (nm) |
|------------------|--------------------|-----------------|-----------------------|-----------|
| 20               | 778.39             | 0               | 1.59                  | 44        |
| 10               | 779.15             | 0.76            | 1.59                  | 43        |
| 0                | 780.04             | 1.65            | 1.59                  | 41        |
| -10              | 780.92             | 2.54            | 1.59                  | 40        |
| -20              | 781.92             | 3.53            | 1.59                  | 39        |
| -30              | 783.00             | 4.61            | 1.58                  | 38        |
| -40              | 784.02             | 5.63            | 1.58                  | 37        |
| -50              | 785.16             | 6.77            | 1.58                  | 36        |
| -60              | 786.33             | 7.94            | 1.58                  | 34        |
| -70              | 787.56             | 9.17            | 1.57                  | 33        |
| -80              | 788.81             | 10.42           | 1.57                  | 32        |
| -90              | 790.08             | 11.69           | 1.57                  | 31        |
| -100             | 791.39             | 13.00           | 1.57                  | 29        |
| -110             | 792.78             | 14.39           | 1.56                  | 28        |
| -120             | 794.15             | 15.76           | 1.56                  | 27        |
| -125             | 794.83             | 16.45           | 1.56                  | 26        |

Table S3.8: PL<sub>OC</sub> cooling parameters of the triple cation-based device.

| Temperature (°C) | Peak Position (nm) | Peak Shift (nm) | Optical Band Gap (eV) | FWHM (nm) |
|------------------|--------------------|-----------------|-----------------------|-----------|
| 20               | 768.97             | 0               | 1.61                  | 38        |
| 10               | 768.36             | -0.62           | 1.61                  | 34        |
| 0                | 767.18             | -1.79           | 1.62                  | 35        |
| -10              | 767.06             | -1.91           | 1.62                  | 33        |
| -20              | 766.86             | -2.11           | 1.62                  | 32        |
| -30              | 767.53             | -1.45           | 1.62                  | 33        |
| -40              | 768.71             | -0.27           | 1.61                  | 31        |
| -50              | 769.71             | 0.74            | 1.61                  | 30        |
| -60              | 770.81             | 1.84            | 1.61                  | 29        |
| -70              | 771.83             | 2.86            | 1.61                  | 28        |
| -80              | 772.86             | 3.89            | 1.6                   | 27        |
| -90              | 773.85             | 4.88            | 1.6                   | 26        |
| -100             | 774.76             | 5.79            | 1.6                   | 25        |
| -110             | 775.60             | 6.63            | 1.6                   | 25        |
| -120             | 776.34             | 7.37            | 1.6                   | 24        |
| -125             | 776.68             | 7.71            | 1.6                   | 23        |

## 4.1 Thermal Cycling

Table S4.1: data of the MAPI device that experienced ice forming on device.

| Cycle | PCE (%) | Voc (V) | Fill Factor (%) | Jsc (mA/Cm <sup>2</sup> ) |
|-------|---------|---------|-----------------|---------------------------|
| 0     | 12.97   | 1.04    | 66.08           | 11.89                     |
| 1     | 12.1    | 1.03    | 63.01           | 11.68                     |
| 2     | 11.53   | 1.02    | 61.08           | 11.68                     |
| 4     | 3.77    | 1.02    | 43.6            | 5.31                      |
| 7     | 2.24    | 1.02    | 42.36           | 2.23                      |
| 11    | 2.45    | 1.02    | 43.16           | 2.39                      |

Table S4.2: MAPbI<sub>3</sub> thermal cycling data.

| Cycle | MAPbI <sub>3</sub> DEVICE 1 |         |                 |                           | MAPbI <sub>3</sub> DEVICE 2 |         |                 |                           | MAPbI <sub>3</sub> CYCLING AVERAGE |         |                 |                           |
|-------|-----------------------------|---------|-----------------|---------------------------|-----------------------------|---------|-----------------|---------------------------|------------------------------------|---------|-----------------|---------------------------|
|       | PCE (%)                     | Voc (V) | Fill Factor (%) | Jsc (mA/Cm <sup>2</sup> ) | PCE (%)                     | Voc (V) | Fill Factor (%) | Jsc (mA/Cm <sup>2</sup> ) | PCE (%)                            | Voc (V) | Fill Factor (%) | Jsc (mA/Cm <sup>2</sup> ) |
| 0     | 13.6                        | 0.97    | 65.93           | 11.55                     | 12.98                       | 0.96    | 61.02           | 12.1                      | 13.29                              | 0.97    | 63.48           | 11.83                     |
| 1     | 13.41                       | 0.97    | 65.72           | 11.54                     | 12.3                        | 0.95    | 58.62           | 12.12                     | 12.86                              | 0.96    | 62.17           | 11.83                     |
| 2     | 12.74                       | 0.96    | 61.33           | 11.81                     | 12.57                       | 0.95    | 59.56           | 12.13                     | 12.66                              | 0.96    | 60.45           | 11.97                     |
| 4     | 12.97                       | 0.96    | 61.97           | 11.9                      | 12.66                       | 0.95    | 59.9            | 12.13                     | 12.82                              | 0.96    | 60.94           | 12.02                     |
| 7     | 12.95                       | 0.96    | 61.26           | 12.03                     | 12.66                       | 0.95    | 59.81           | 12.14                     | 12.81                              | 0.96    | 60.54           | 12.09                     |
| 11    | 12.71                       | 0.96    | 59.85           | 12.12                     | 12.69                       | 0.95    | 59.83           | 12.16                     | 12.70                              | 0.96    | 59.84           | 12.14                     |
| 16    | 12.34                       | 0.96    | 57.79           | 12.22                     | 12.76                       | 0.95    | 60.16           | 12.16                     | 12.55                              | 0.96    | 58.98           | 12.19                     |

Table S4.3: Triple cation thermal cycling data.

| Cycle | TRIPLE CATION DEVICE 1 |         |                 |                           | TRIPLE CATION DEVICE 2 |         |                 |                           | TRIPLE CATION CYCLING AVERAGE |         |                 |                           |
|-------|------------------------|---------|-----------------|---------------------------|------------------------|---------|-----------------|---------------------------|-------------------------------|---------|-----------------|---------------------------|
|       | PCE (%)                | Voc (V) | Fill Factor (%) | Jsc (mA/Cm <sup>2</sup> ) | PCE (%)                | Voc (V) | Fill Factor (%) | Jsc (mA/Cm <sup>2</sup> ) | PCE (%)                       | Voc (V) | Fill Factor (%) | Jsc (mA/Cm <sup>2</sup> ) |
| 0     | 14.99                  | 1.08    | 62.99           | 12.04                     | 15.38                  | 1.09    | 63.91           | 12.11                     | 15.19                         | 1.09    | 63.45           | 12.08                     |
| 1     | 14.69                  | 1.07    | 62.08           | 12.04                     | 15.05                  | 1.08    | 62.72           | 12.11                     | 14.87                         | 1.08    | 62.40           | 12.08                     |
| 2     | 14.66                  | 1.07    | 62.09           | 12.04                     | 15.06                  | 1.08    | 62.74           | 12.14                     | 14.86                         | 1.08    | 62.42           | 12.09                     |
| 4     | 14.7                   | 1.07    | 62.32           | 12.02                     | 15.01                  | 1.08    | 62.54           | 12.13                     | 14.86                         | 1.08    | 62.43           | 12.08                     |
| 7     | 14.67                  | 1.07    | 62.43           | 11.98                     | 14.94                  | 1.08    | 62.7            | 12.05                     | 14.81                         | 1.08    | 62.57           | 12.02                     |
| 11    | 14.66                  | 1.07    | 62.41           | 11.98                     | 14.88                  | 1.08    | 62.39           | 12.08                     | 14.77                         | 1.08    | 62.40           | 12.03                     |
| 16    | 14.73                  | 1.07    | 62.69           | 11.96                     | 14.93                  | 1.08    | 62.74           | 12.07                     | 14.83                         | 1.08    | 62.72           | 12.02                     |

Table S4.4: thermal cycling J-V data of the MAPbI<sub>3</sub>-based device.

| MAPbI3 DEVICE 1 |                                       |             |                                       | MAPbI3 DEVICE 2 |                                       |             |                                       | AVERAGE       |                                       |                                       |
|-----------------|---------------------------------------|-------------|---------------------------------------|-----------------|---------------------------------------|-------------|---------------------------------------|---------------|---------------------------------------|---------------------------------------|
| Initial cycle   | Initial cycle                         | 16th cycle  | 16th cycle                            | Initial cycle   | Initial cycle                         | 16th cycle  | 16th cycle                            | Initial cycle | 16th cycle                            | 16th cycle                            |
| Voltage (V)     | Current density (mA/Cm <sup>2</sup> ) | Voltage (V) | Current density (mA/Cm <sup>2</sup> ) | Voltage (V)     | Current density (mA/Cm <sup>2</sup> ) | Voltage (V) | Current density (mA/Cm <sup>2</sup> ) | Voltage (V)   | Current density (mA/Cm <sup>2</sup> ) | Current density (mA/Cm <sup>2</sup> ) |
| 1.2             | -23.58253                             | 1.2         | -23.53996                             | 1.2             | -12.99121                             | 1.2         | -12.50113                             | 1.2           | -18.28687                             | -18.020545                            |
| 1.185           | -20.07038                             | 1.185       | -21.41648                             | 1.185           | -14.10935                             | 1.185       | -12.90798                             | 1.185         | -17.089865                            | -17.16223                             |
| 1.17            | -18.26143                             | 1.17        | -19.32378                             | 1.17            | -14.764                               | 1.17        | -13.30266                             | 1.17          | -16.512715                            | -16.31322                             |
| 1.155           | -16.63915                             | 1.155       | -17.40793                             | 1.155           | -14.51734                             | 1.155       | -13.30603                             | 1.155         | -15.578245                            | -15.35698                             |
| 1.14            | -15.05231                             | 1.14        | -15.55421                             | 1.14            | -13.7228                              | 1.14        | -12.86452                             | 1.14          | -14.387555                            | -14.209365                            |
| 1.125           | -13.47651                             | 1.125       | -13.74158                             | 1.125           | -12.65053                             | 1.125       | -12.08466                             | 1.125         | -13.06352                             | -12.91312                             |
| 1.11            | -11.93095                             | 1.11        | -11.98383                             | 1.11            | -11.46851                             | 1.11        | -11.09081                             | 1.11          | -11.69973                             | -11.53732                             |
| 1.095           | -10.40354                             | 1.095       | -10.3476                              | 1.095           | -10.22819                             | 1.095       | -9.99031                              | 1.095         | -10.315865                            | -10.168955                            |
| 1.08            | -8.94655                              | 1.08        | -8.81437                              | 1.08            | -8.99228                              | 1.08        | -8.85887                              | 1.08          | -8.969415                             | -8.83662                              |
| 1.065           | -7.56857                              | 1.065       | -7.40427                              | 1.065           | -7.76174                              | 1.065       | -7.71448                              | 1.065         | -7.665155                             | -7.559375                             |
| 1.05            | -6.22552                              | 1.05        | -6.08887                              | 1.05            | -6.52654                              | 1.05        | -6.55949                              | 1.05          | -6.37603                              | -6.32418                              |
| 1.035           | -4.93448                              | 1.035       | -4.87066                              | 1.035           | -5.29698                              | 1.035       | -5.40988                              | 1.035         | -5.11573                              | -5.14027                              |
| 1.02            | -3.73809                              | 1.02        | -3.75356                              | 1.02            | -4.1417                               | 1.02        | -4.31917                              | 1.02          | -3.939895                             | -4.036365                             |
| 1.005           | -2.60252                              | 1.005       | -2.75691                              | 1.005           | -2.9942                               | 1.005       | -3.26226                              | 1.005         | -2.79836                              | -3.009585                             |
| 0.99            | -1.51312                              | 0.99        | -1.84555                              | 0.99            | -1.90464                              | 0.99        | -2.238                                | 0.99          | -1.70888                              | -2.041775                             |
| 0.975           | -0.66605                              | 0.975       | -0.977                                | 0.975           | -0.82334                              | 0.975       | -1.25401                              | 0.975         | -0.744695                             | -1.115505                             |
| 0.96            | 0.51295                               | 0.96        | -0.20706                              | 0.96            | 0.14567                               | 0.96        | -0.36958                              | 0.96          | 0.32931                               | -0.28832                              |
| 0.945           | 1.68469                               | 0.945       | 0.57568                               | 0.945           | 1.10545                               | 0.945       | 0.59684                               | 0.945         | 1.39507                               | 0.58626                               |
| 0.93            | 2.60666                               | 0.93        | 1.28288                               | 0.93            | 2.06124                               | 0.93        | 1.40876                               | 0.93          | 2.33395                               | 1.34582                               |
| 0.915           | 3.56267                               | 0.915       | 2.00792                               | 0.915           | 2.98203                               | 0.915       | 2.31544                               | 0.915         | 3.27235                               | 2.16168                               |
| 0.9             | 4.44579                               | 0.9         | 2.6878                                | 0.9             | 3.80264                               | 0.9         | 3.13163                               | 0.9           | 4.124215                              | 2.909715                              |
| 0.885           | 5.27061                               | 0.885       | 3.34805                               | 0.885           | 4.6029                                | 0.885       | 3.89884                               | 0.885         | 4.936755                              | 3.623445                              |
| 0.87            | 6.00156                               | 0.87        | 3.98466                               | 0.87            | 5.32134                               | 0.87        | 4.62239                               | 0.87          | 5.66145                               | 4.303525                              |
| 0.855           | 6.67794                               | 0.855       | 4.61367                               | 0.855           | 5.99293                               | 0.855       | 5.30613                               | 0.855         | 6.335435                              | 4.9599                                |
| 0.84            | 7.22575                               | 0.84        | 5.23048                               | 0.84            | 6.60602                               | 0.84        | 5.94084                               | 0.84          | 6.915885                              | 5.58566                               |
| 0.825           | 7.80615                               | 0.825       | 5.81522                               | 0.825           | 7.02083                               | 0.825       | 6.54183                               | 0.825         | 7.41349                               | 6.178525                              |
| 0.81            | 8.31139                               | 0.81        | 6.38139                               | 0.81            | 7.61121                               | 0.81        | 6.97449                               | 0.81          | 7.9613                                | 6.67794                               |
| 0.795           | 8.7473                                | 0.795       | 6.9167                                | 0.795           | 8.09181                               | 0.795       | 7.56141                               | 0.795         | 8.419555                              | 7.239055                              |
| 0.78            | 9.17575                               | 0.78        | 7.357                                 | 0.78            | 8.54414                               | 0.78        | 8.05849                               | 0.78          | 8.859945                              | 7.707745                              |
| 0.765           | 9.47312                               | 0.765       | 7.85764                               | 0.765           | 8.93831                               | 0.765       | 8.5035                                | 0.765         | 9.205715                              | 8.18057                               |
| 0.75            | 9.73956                               | 0.75        | 8.30633                               | 0.75            | 9.27051                               | 0.75        | 8.9019                                | 0.75          | 9.505035                              | 8.604115                              |
| 0.735           | 9.96216                               | 0.735       | 8.71559                               | 0.735           | 9.5867                                | 0.735       | 9.23537                               | 0.735         | 9.77443                               | 8.97548                               |
| 0.72            | 10.15372                              | 0.72        | 9.07565                               | 0.72            | 9.83455                               | 0.72        | 9.5704                                | 0.72          | 9.994135                              | 9.323025                              |
| 0.705           | 10.31661                              | 0.705       | 9.4163                                | 0.705           | 10.05662                              | 0.705       | 9.85635                               | 0.705         | 10.186615                             | 9.636325                              |
| 0.69            | 10.45112                              | 0.69        | 9.72941                               | 0.69            | 10.29667                              | 0.69        | 10.10896                              | 0.69          | 10.373895                             | 9.919185                              |
| 0.675           | 10.57143                              | 0.675       | 9.97814                               | 0.675           | 10.48928                              | 0.675       | 10.31689                              | 0.675         | 10.530355                             | 10.147515                             |
| 0.66            | 10.67182                              | 0.66        | 10.22774                              | 0.66            | 10.66048                              | 0.66        | 10.51818                              | 0.66          | 10.66615                              | 10.37296                              |
| 0.645           | 10.76297                              | 0.645       | 10.4344                               | 0.645           | 10.78391                              | 0.645       | 10.70191                              | 0.645         | 10.77344                              | 10.568155                             |
| 0.63            | 10.84956                              | 0.63        | 10.63822                              | 0.63            | 10.91445                              | 0.63        | 10.84725                              | 0.63          | 10.882005                             | 10.742735                             |
| 0.615           | 10.92388                              | 0.615       | 10.81651                              | 0.615           | 11.05529                              | 0.615       | 10.96894                              | 0.615         | 10.989585                             | 10.892725                             |
| 0.6             | 10.96728                              | 0.6         | 10.96431                              | 0.6             | 11.16779                              | 0.6         | 11.07895                              | 0.6           | 11.067535                             | 11.02163                              |
| 0.585           | 11.01893                              | 0.585       | 11.08483                              | 0.585           | 11.19785                              | 0.585       | 11.18128                              | 0.585         | 11.10839                              | 11.133055                             |
| 0.57            | 11.07936                              | 0.57        | 11.22154                              | 0.57            | 11.26848                              | 0.57        | 11.27377                              | 0.57          | 11.17392                              | 11.249455                             |
| 0.555           | 11.12691                              | 0.555       | 11.33776                              | 0.555           | 11.33178                              | 0.555       | 11.3372                               | 0.555         | 11.229345                             | 11.33748                              |
| 0.54            | 11.16176                              | 0.54        | 11.42006                              | 0.54            | 11.43346                              | 0.54        | 11.39662                              | 0.54          | 11.29761                              | 11.40834                              |
| 0.525           | 11.18438                              | 0.525       | 11.49436                              | 0.525           | 11.45261                              | 0.525       | 11.45625                              | 0.525         | 11.318495                             | 11.475305                             |
| 0.51            | 11.22191                              | 0.51        | 11.56346                              | 0.51            | 11.53281                              | 0.51        | 11.51748                              | 0.51          | 11.37736                              | 11.54047                              |
| 0.495           | 11.25502                              | 0.495       | 11.62662                              | 0.495           | 11.56938                              | 0.495       | 11.58118                              | 0.495         | 11.41122                              | 11.6039                               |
| 0.48            | 11.27458                              | 0.48        | 11.68567                              | 0.48            | 11.59531                              | 0.48        | 11.62728                              | 0.48          | 11.434945                             | 11.656475                             |
| 0.465           | 11.29504                              | 0.465       | 11.72887                              | 0.465           | 11.61595                              | 0.465       | 11.66333                              | 0.465         | 11.47727                              | 11.6961                               |
| 0.45            | 11.31486                              | 0.45        | 11.79119                              | 0.45            | 11.61633                              | 0.45        | 11.69301                              | 0.45          | 11.465595                             | 11.7421                               |
| 0.435           | 11.33123                              | 0.435       | 11.81469                              | 0.435           | 11.72581                              | 0.435       | 11.7015                               | 0.435         | 11.52852                              | 11.758095                             |
| 0.42            | 11.34332                              | 0.42        | 11.84822                              | 0.42            | 11.74037                              | 0.42        | 11.75453                              | 0.42          | 11.541845                             | 11.801375                             |
| 0.405           | 11.35767                              | 0.405       | 11.86896                              | 0.405           | 11.72673                              | 0.405       | 11.78188                              | 0.405         | 11.5422                               | 11.82542                              |
| 0.39            | 11.37594                              | 0.39        | 11.90351                              | 0.39            | 11.74764                              | 0.39        | 11.80716                              | 0.39          | 11.56179                              | 11.855335                             |
| 0.375           | 11.39325                              | 0.375       | 11.93846                              | 0.375           | 11.7509                               | 0.375       | 11.83184                              | 0.375         | 11.572075                             | 11.88515                              |
| 0.36            | 11.4079                               | 0.36        | 11.9585                               | 0.36            | 11.67495                              | 0.36        | 11.85774                              | 0.36          | 11.541425                             | 11.90812                              |
| 0.345           | 11.40687                              | 0.345       | 11.97454                              | 0.345           | 11.69228                              | 0.345       | 11.87598                              | 0.345         | 11.549835                             | 11.92526                              |
| 0.33            | 11.42471                              | 0.33        | 12.00046                              | 0.33            | 11.80496                              | 0.33        | 11.8936                               | 0.33          | 11.614835                             | 11.94703                              |
| 0.315           | 11.42635                              | 0.315       | 12.02031                              | 0.315           | 11.77599                              | 0.315       | 11.91635                              | 0.315         | 11.60117                              | 11.96833                              |
| 0.3             | 11.44202                              | 0.3         | 12.02761                              | 0.3             | 11.80501                              | 0.3         | 11.9252                               | 0.3           | 11.623515                             | 11.976405                             |
| 0.285           | 11.44312                              | 0.285       | 12.04852                              | 0.285           | 11.87656                              | 0.285       | 11.95501                              | 0.285         | 11.65984                              | 12.001765                             |
| 0.27            | 11.45857                              | 0.27        | 12.06576                              | 0.27            | 11.83651                              | 0.27        | 11.97456                              | 0.27          | 11.64754                              | 12.02016                              |
| 0.255           | 11.456                                | 0.255       | 12.07871                              | 0.255           | 11.90366                              | 0.255       | 11.98384                              | 0.255         | 11.67983                              | 12.031275                             |
| 0.24            | 11.47206                              | 0.24        | 12.09312                              | 0.24            | 11.89161                              | 0.24        | 11.99035                              | 0.24          | 11.681835                             | 12.041735                             |
| 0.225           | 11.48245                              | 0.225       | 12.0969                               | 0.225           | 11.89296                              | 0.225       | 12.01593                              | 0.225         | 11.687705                             | 12.056415                             |
| 0.21            | 11.47717                              | 0.21        | 12.1163                               | 0.21            | 11.90034                              | 0.21        | 12.02115                              | 0.21          | 11.688755                             | 12.068725                             |
| 0.195           | 11.49295                              | 0.195       | 12.11917                              | 0.195           | 11.91506                              | 0.195       | 12.04483                              | 0.195         | 11.704005                             | 12.082                                |
| 0.18            | 11.49814                              | 0.18        | 12.13245                              | 0.18            | 11.9169                               | 0.18        | 12.06106                              | 0.18          | 11.70752                              | 12.096755                             |
| 0.165           | 11.50625                              | 0.165       | 12.14408                              | 0.165           | 11.94236                              | 0.165       | 12.06995                              | 0.165         | 11.724305                             | 12.107015                             |
| 0.15            | 11.51529                              | 0.15        | 12.14807                              | 0.15            | 11.97172                              | 0.15        | 12.08277                              | 0.15          | 11.743505                             | 12.11542                              |
| 0.135           | 11.51092                              | 0.135       | 12.15459                              | 0.135           | 11.97855                              | 0.135       | 12.08894                              | 0.135         | 11.744735                             | 12.121765                             |
| 0.12            | 11.51615                              | 0.12        | 12.17172                              | 0.12            | 12.00774                              | 0.12        | 12.09685                              | 0.12          | 11.761945                             | 12.134285                             |
| 0.105           | 11.51695                              | 0.105       | 12.17793                              | 0.105           | 12.0195                               | 0.105       | 12.09781                              | 0.105         | 11.768225                             | 12.13787                              |
| 0.09            | 11.52769                              | 0.09        | 12.18183                              | 0.09            | 12.01776                              | 0.09        | 12.11586                              | 0.09          | 11.772725                             | 12.148845                             |
| 0.075           | 11.52224                              | 0.075       | 12.19072                              | 0.075           | 12.03184                              | 0.075       | 12.12066                              | 0.075         | 11.77704                              | 12.15569                              |
| 0.06            | 11.53405                              | 0.06        | 12.19175                              | 0.06            | 12.05206                              | 0.06        | 12.12524                              | 0.06          | 11.793055                             | 12.158495                             |
| 0.045           | 11.52593                              | 0.045       | 12.20039                              | 0.045           | 12.06361                              | 0.045       | 12.14068                              | 0.045         | 11.79477                              | 12.170535                             |
| 0.03            | 11.53508                              | 0.03        | 12.20119                              | 0.03            | 12.06805                              | 0.03        | 12.1521                               | 0.03          | 11.801565                             | 12.176645                             |
| 0.015           | 11.53946                              | 0.015       | 12.20781                              | 0.015           | 12.09022                              | 0.015       | 12.15069                              | 0.015         | 11.81484                              | 12.17925                              |
| 0               | 11.53604                              | 0           | 12.21816                              | 0               | 12.1062                               | 0           | 12.15387                              | 0             | 11.82112                              | 12.186015                             |
| -0.015          | 11.53803                              | -0.015      | 12.23421                              | -0.015          | 12.11968                              | -0.015      | 12.16752                              | -0.015        | 11.828855                             | 12.200865                             |
| -0.03           | 11.54597                              | -0.03       | 12.25268                              | -0.03           | 12.12354                              | -0.03       | 12.17714                              | -0.03         | 11.834755                             | 12.21491                              |
| -0.045          | 11.56832                              | -0.045      | 12.25324                              | -0.045          | 12.13886                              | -0.045      | 12.18478                              | -0.045        | 11.85359                              | 12.21901                              |
| -0.06           | 11.57909                              | -0.06       | 12.25719                              | -0.06           | 12.1489                               | -0.06       | 12.20063                              | -0.06         | 11.863995                             | 12.22891                              |
| -0.075          | 11.57934                              | -0.075      | 12.26208                              | -0.075          | 12.15534                              | -0.075      | 12.19557                              | -0.075        | 11.86734                              | 12.228825                             |
| -0.09           | 11.58026                              | -0.09       | 12.26998                              | -0.09           | 12.15968                              | -0.09       | 12.19688                              | -0.09         | 11.86997                              | 12.23343                              |
| -0.1            | 11.55042                              | -0.1        | 12.23789                              | -0.1            | 12.16099                              | -0.1        | 12.19874                              | -0.1          | 11.855705                             | 12.218315                             |

Table S4.5: thermal cycling J-V data of the triple cation-based device.

| TRIPLE CATION DEVICE 1 |                                       |             |                                       | TRIPLE CATION DEVICE 2 |                                       |             |                                       | AVERAGE       |                                       |                                       |
|------------------------|---------------------------------------|-------------|---------------------------------------|------------------------|---------------------------------------|-------------|---------------------------------------|---------------|---------------------------------------|---------------------------------------|
| Initial cycle          | Initial cycle                         | 16th cycle  | 16th cycle                            | Initial cycle          | Initial cycle                         | 16th cycle  | 16th cycle                            | Initial cycle | 16th cycle                            | 16th cycle                            |
| Voltage (V)            | Current density (mA/Cm <sup>2</sup> ) | Voltage (V) | Current density (mA/Cm <sup>2</sup> ) | Voltage (V)            | Current density (mA/Cm <sup>2</sup> ) | Voltage (V) | Current density (mA/Cm <sup>2</sup> ) | Voltage (V)   | Current density (mA/Cm <sup>2</sup> ) | Current density (mA/Cm <sup>2</sup> ) |
| 1.2                    | -9.66363                              | 1.2         | -9.26662                              | 1.2                    | -9.822762                             | 1.2         | -9.424296                             | 1.2           | -9.743196                             | -9.345458                             |
| 1.185                  | -8.265697                             | 1.185       | -8.267043                             | 1.185                  | -8.024713                             | 1.185       | -8.280803                             | 1.185         | -8.145205                             | -8.273923                             |
| 1.17                   | -6.613114                             | 1.17        | -6.990912                             | 1.17                   | -6.196937                             | 1.17        | -6.876663                             | 1.17          | -6.4050255                            | -6.9337875                            |
| 1.155                  | -5.196745                             | 1.155       | -5.583659                             | 1.155                  | -4.898878                             | 1.155       | -5.426038                             | 1.155         | -5.0478115                            | -5.5048885                            |
| 1.14                   | -4.0071                               | 1.14        | -4.432581                             | 1.14                   | -3.723984                             | 1.14        | -4.219596                             | 1.14          | -3.865542                             | -4.3260885                            |
| 1.125                  | -2.88965                              | 1.125       | -3.312616                             | 1.125                  | -2.607886                             | 1.125       | -3.101314                             | 1.125         | -2.748768                             | -3.206965                             |
| 1.11                   | -1.83938                              | 1.11        | -2.259817                             | 1.11                   | -1.558491                             | 1.11        | -2.061463                             | 1.11          | -1.6989355                            | -2.16064                              |
| 1.095                  | -0.845614                             | 1.095       | -1.26551                              | 1.095                  | -0.5424362                            | 1.095       | -1.057751                             | 1.095         | -0.6940251                            | -1.1616305                            |
| 1.08                   | 0.1185403                             | 1.08        | -0.2817835                            | 1.08                   | 0.4246656                             | 1.08        | -5.24E-02                             | 1.08          | 0.27160295                            | -0.16708162                           |
| 1.065                  | 1.072152                              | 1.065       | 0.6260303                             | 1.065                  | 1.359604                              | 1.065       | 0.954492                              | 1.065         | 1.215878                              | 0.79026115                            |
| 1.05                   | 1.956833                              | 1.05        | 1.541079                              | 1.05                   | 2.70086                               | 1.05        | 1.828231                              | 1.05          | 2.3288465                             | 1.684655                              |
| 1.035                  | 2.780337                              | 1.035       | 2.373978                              | 1.035                  | 3.525703                              | 1.035       | 2.644488                              | 1.035         | 3.15302                               | 2.509233                              |
| 1.02                   | 3.561209                              | 1.02        | 3.154138                              | 1.02                   | 4.292151                              | 1.02        | 3.420533                              | 1.02          | 3.92668                               | 3.2873355                             |
| 1.005                  | 4.298406                              | 1.005       | 3.888977                              | 1.005                  | 5.013049                              | 1.005       | 4.153655                              | 1.005         | 4.6557275                             | 4.021316                              |
| 0.99                   | 4.985568                              | 0.99        | 4.590215                              | 0.99                   | 5.689609                              | 0.99        | 4.846714                              | 0.99          | 5.3375885                             | 4.7184645                             |
| 0.975                  | 5.64117                               | 0.975       | 5.249715                              | 0.975                  | 6.312873                              | 0.975       | 5.495626                              | 0.975         | 5.9770215                             | 5.3726705                             |
| 0.96                   | 6.254648                              | 0.96        | 5.86859                               | 0.96                   | 6.889574                              | 0.96        | 6.111828                              | 0.96          | 6.572111                              | 5.990209                              |
| 0.945                  | 6.820426                              | 0.945       | 6.447308                              | 0.945                  | 7.38777                               | 0.945       | 6.683251                              | 0.945         | 7.104098                              | 6.5652795                             |
| 0.93                   | 7.316707                              | 0.93        | 6.976536                              | 0.93                   | 7.893149                              | 0.93        | 7.183334                              | 0.93          | 7.604928                              | 7.079935                              |
| 0.915                  | 7.8103                                | 0.915       | 7.466803                              | 0.915                  | 8.344709                              | 0.915       | 7.69007                               | 0.915         | 8.0775045                             | 7.5784365                             |
| 0.9                    | 8.26567                               | 0.9         | 7.934126                              | 0.9                    | 8.754136                              | 0.9         | 8.143159                              | 0.9           | 8.509903                              | 8.0386425                             |
| 0.885                  | 8.668106                              | 0.885       | 8.359857                              | 0.885                  | 9.108666                              | 0.885       | 8.553276                              | 0.885         | 8.888386                              | 8.4565665                             |
| 0.87                   | 9.018853                              | 0.87        | 8.740482                              | 0.87                   | 9.428396                              | 0.87        | 8.929592                              | 0.87          | 9.2236245                             | 8.835037                              |
| 0.855                  | 9.344899                              | 0.855       | 9.085289                              | 0.855                  | 9.710499                              | 0.855       | 9.263843                              | 0.855         | 9.527699                              | 9.174566                              |
| 0.84                   | 9.63633                               | 0.84        | 9.395626                              | 0.84                   | 9.961224                              | 0.84        | 9.566086                              | 0.84          | 9.798777                              | 9.480856                              |
| 0.825                  | 9.88768                               | 0.825       | 9.639317                              | 0.825                  | 10.18662                              | 0.825       | 9.830526                              | 0.825         | 10.03715                              | 9.7472215                             |
| 0.81                   | 10.11441                              | 0.81        | 9.915736                              | 0.81                   | 10.38286                              | 0.81        | 10.06459                              | 0.81          | 10.248635                             | 9.990163                              |
| 0.795                  | 10.31331                              | 0.795       | 10.12793                              | 0.795                  | 10.5642                               | 0.795       | 10.27477                              | 0.795         | 10.438755                             | 10.20135                              |
| 0.78                   | 10.48515                              | 0.78        | 10.32165                              | 0.78                   | 10.71403                              | 0.78        | 10.44378                              | 0.78          | 10.59959                              | 10.382715                             |
| 0.765                  | 10.63712                              | 0.765       | 10.48911                              | 0.765                  | 10.85428                              | 0.765       | 10.61647                              | 0.765         | 10.7457                               | 10.55279                              |
| 0.75                   | 10.77554                              | 0.75        | 10.63531                              | 0.75                   | 10.96888                              | 0.75        | 10.76183                              | 0.75          | 10.87221                              | 10.69857                              |
| 0.735                  | 10.89775                              | 0.735       | 10.76738                              | 0.735                  | 11.0796                               | 0.735       | 10.89552                              | 0.735         | 10.988675                             | 10.83145                              |
| 0.72                   | 11.00445                              | 0.72        | 10.88954                              | 0.72                   | 11.17574                              | 0.72        | 11.00262                              | 0.72          | 11.090095                             | 10.94608                              |
| 0.705                  | 11.09853                              | 0.705       | 10.98288                              | 0.705                  | 11.26129                              | 0.705       | 11.08826                              | 0.705         | 11.17991                              | 11.03557                              |
| 0.69                   | 11.17801                              | 0.69        | 11.07221                              | 0.69                   | 11.33382                              | 0.69        | 11.18623                              | 0.69          | 11.255915                             | 11.12922                              |
| 0.675                  | 11.24289                              | 0.675       | 11.14834                              | 0.675                  | 11.40882                              | 0.675       | 11.25781                              | 0.675         | 11.325855                             | 11.203075                             |
| 0.66                   | 11.30528                              | 0.66        | 11.21774                              | 0.66                   | 11.47428                              | 0.66        | 11.32793                              | 0.66          | 11.38978                              | 11.272835                             |
| 0.645                  | 11.36493                              | 0.645       | 11.27724                              | 0.645                  | 11.52083                              | 0.645       | 11.39154                              | 0.645         | 11.44288                              | 11.33439                              |
| 0.63                   | 11.41587                              | 0.63        | 11.32548                              | 0.63                   | 11.56533                              | 0.63        | 11.45005                              | 0.63          | 11.4906                               | 11.387765                             |
| 0.615                  | 11.45109                              | 0.615       | 11.38021                              | 0.615                  | 11.61122                              | 0.615       | 11.49181                              | 0.615         | 11.531155                             | 11.43601                              |
| 0.6                    | 11.49084                              | 0.6         | 11.42286                              | 0.6                    | 11.64996                              | 0.6         | 11.52417                              | 0.6           | 11.5704                               | 11.473515                             |
| 0.585                  | 11.51716                              | 0.585       | 11.45175                              | 0.585                  | 11.68555                              | 0.585       | 11.56001                              | 0.585         | 11.601355                             | 11.50588                              |
| 0.57                   | 11.55411                              | 0.57        | 11.47566                              | 0.57                   | 11.70677                              | 0.57        | 11.59274                              | 0.57          | 11.63044                              | 11.5342                               |
| 0.555                  | 11.5781                               | 0.555       | 11.50847                              | 0.555                  | 11.73043                              | 0.555       | 11.61636                              | 0.555         | 11.654265                             | 11.562415                             |
| 0.54                   | 11.60564                              | 0.54        | 11.53202                              | 0.54                   | 11.75062                              | 0.54        | 11.64359                              | 0.54          | 11.67813                              | 11.587805                             |
| 0.525                  | 11.64736                              | 0.525       | 11.54994                              | 0.525                  | 11.76821                              | 0.525       | 11.67669                              | 0.525         | 11.707785                             | 11.613315                             |
| 0.51                   | 11.6718                               | 0.51        | 11.58559                              | 0.51                   | 11.78819                              | 0.51        | 11.70109                              | 0.51          | 11.729995                             | 11.64334                              |
| 0.495                  | 11.68722                              | 0.495       | 11.60331                              | 0.495                  | 11.80366                              | 0.495       | 11.72436                              | 0.495         | 11.74544                              | 11.663835                             |
| 0.48                   | 11.70014                              | 0.48        | 11.6223                               | 0.48                   | 11.82829                              | 0.48        | 11.73381                              | 0.48          | 11.764215                             | 11.678055                             |
| 0.465                  | 11.71553                              | 0.465       | 11.63497                              | 0.465                  | 11.84443                              | 0.465       | 11.74789                              | 0.465         | 11.77998                              | 11.69143                              |
| 0.45                   | 11.71907                              | 0.45        | 11.66079                              | 0.45                   | 11.85112                              | 0.45        | 11.75678                              | 0.45          | 11.785095                             | 11.708785                             |
| 0.435                  | 11.72794                              | 0.435       | 11.66536                              | 0.435                  | 11.86544                              | 0.435       | 11.77174                              | 0.435         | 11.79669                              | 11.71855                              |
| 0.42                   | 11.74993                              | 0.42        | 11.67979                              | 0.42                   | 11.86808                              | 0.42        | 11.79375                              | 0.42          | 11.809005                             | 11.73677                              |
| 0.405                  | 11.77272                              | 0.405       | 11.69873                              | 0.405                  | 11.87545                              | 0.405       | 11.8098                               | 0.405         | 11.824085                             | 11.754265                             |
| 0.39                   | 11.79145                              | 0.39        | 11.71424                              | 0.39                   | 11.8868                               | 0.39        | 11.81815                              | 0.39          | 11.839125                             | 11.766195                             |
| 0.375                  | 11.79212                              | 0.375       | 11.72485                              | 0.375                  | 11.90128                              | 0.375       | 11.83706                              | 0.375         | 11.8467                               | 11.780955                             |
| 0.36                   | 11.79592                              | 0.36        | 11.73164                              | 0.36                   | 11.90522                              | 0.36        | 11.84663                              | 0.36          | 11.85057                              | 11.789135                             |
| 0.345                  | 11.81781                              | 0.345       | 11.75715                              | 0.345                  | 11.91902                              | 0.345       | 11.86368                              | 0.345         | 11.868415                             | 11.810415                             |
| 0.33                   | 11.84028                              | 0.33        | 11.76114                              | 0.33                   | 11.92826                              | 0.33        | 11.87944                              | 0.33          | 11.88427                              | 11.82029                              |
| 0.315                  | 11.85264                              | 0.315       | 11.77397                              | 0.315                  | 11.92939                              | 0.315       | 11.87812                              | 0.315         | 11.891015                             | 11.826045                             |
| 0.3                    | 11.86187                              | 0.3         | 11.78357                              | 0.3                    | 11.94533                              | 0.3         | 11.88657                              | 0.3           | 11.9036                               | 11.83507                              |
| 0.285                  | 11.86653                              | 0.285       | 11.79587                              | 0.285                  | 11.94618                              | 0.285       | 11.8995                               | 0.285         | 11.906355                             | 11.847685                             |
| 0.27                   | 11.87588                              | 0.27        | 11.8085                               | 0.27                   | 11.95354                              | 0.27        | 11.91925                              | 0.27          | 11.91471                              | 11.863875                             |
| 0.255                  | 11.8866                               | 0.255       | 11.81652                              | 0.255                  | 11.97253                              | 0.255       | 11.93713                              | 0.255         | 11.929565                             | 11.876825                             |
| 0.24                   | 11.89558                              | 0.24        | 11.82082                              | 0.24                   | 11.98083                              | 0.24        | 11.94606                              | 0.24          | 11.938205                             | 11.88344                              |
| 0.225                  | 11.91455                              | 0.225       | 11.83237                              | 0.225                  | 11.9884                               | 0.225       | 11.94982                              | 0.225         | 11.951475                             | 11.891095                             |
| 0.21                   | 11.92234                              | 0.21        | 11.84202                              | 0.21                   | 12.00884                              | 0.21        | 11.95847                              | 0.21          | 11.96559                              | 11.900245                             |
| 0.195                  | 11.92752                              | 0.195       | 11.85543                              | 0.195                  | 12.02587                              | 0.195       | 11.97141                              | 0.195         | 11.976695                             | 11.91342                              |
| 0.18                   | 11.93303                              | 0.18        | 11.87071                              | 0.18                   | 12.03271                              | 0.18        | 11.97617                              | 0.18          | 11.98287                              | 11.92344                              |
| 0.165                  | 11.94624                              | 0.165       | 11.87743                              | 0.165                  | 12.02957                              | 0.165       | 11.99117                              | 0.165         | 11.987995                             | 11.9318                               |
| 0.15                   | 11.95135                              | 0.15        | 11.87954                              | 0.15                   | 12.0418                               | 0.15        | 11.99365                              | 0.15          | 11.996575                             | 11.936595                             |
| 0.135                  | 11.96094                              | 0.135       | 11.8936                               | 0.135                  | 12.03956                              | 0.135       | 12.01239                              | 0.135         | 12.00025                              | 11.952995                             |
| 0.12                   | 11.97878                              | 0.12        | 11.906                                | 0.12                   | 12.05272                              | 0.12        | 12.00949                              | 0.12          | 12.01575                              | 11.957745                             |
| 0.105                  | 11.97147                              | 0.105       | 11.90462                              | 0.105                  | 12.0613                               | 0.105       | 12.02405                              | 0.105         | 12.016385                             | 11.964335                             |
| 0.09                   | 11.99108                              | 0.09        | 11.90864                              | 0.09                   | 12.06734                              | 0.09        | 12.02041                              | 0.09          | 12.02921                              | 11.964525                             |
| 0.075                  | 11.99182                              | 0.075       | 11.91787                              | 0.075                  | 12.07425                              | 0.075       | 12.04599                              | 0.075         | 12.033035                             | 11.98193                              |
| 0.06                   | 12.00021                              | 0.06        | 11.93367                              | 0.06                   | 12.0777                               | 0.06        | 12.05597                              | 0.06          | 12.038955                             | 11.99482                              |
| 0.045                  | 12.003                                | 0.045       | 11.93847                              | 0.045                  | 12.09071                              | 0.045       | 12.05188                              | 0.045         | 12.046855                             | 11.995175                             |
| 0.03                   | 12.02956                              | 0.03        | 11.94517                              | 0.03                   | 12.10201                              | 0.03        | 12.04875                              | 0.03          | 12.065785                             | 11.99696                              |
| 0.015                  | 12.02299                              | 0.015       | 11.95438                              | 0.015                  | 12.10938                              | 0.015       | 12.05383                              | 0.015         | 12.066185                             | 12.004105                             |
| 0                      | 12.03936                              | 0           | 11.95707                              | 0                      | 12.10873                              | 0           | 12.0628                               | 0             | 12.074045                             | 12.009935                             |
| -0.015                 | 12.04797                              | -0.015      | 11.97302                              | -0.015                 | 12.12275                              | -0.015      | 12.08038                              | -0.015        | 12.08536                              | 12.0267                               |
| -0.03                  | 12.0413                               | -0.03       | 11.97939                              | -0.03                  | 12.1157                               | -0.03       | 12.0882                               | -0.03         | 12.0785                               | 12.033795                             |
| -0.045                 | 12.04798                              | -0.045      | 11.98533                              | -0.045                 | 12.12861                              | -0.045      | 12.09303                              | -0.045        | 12.088295                             | 12.03918                              |
| -0.06                  | 12.05238                              | -0.06       | 11.9847                               | -0.06                  | 12.13196                              | -0.06       | 12.09852                              | -0.06         | 12.09217                              | 12.04161                              |
| -0.075                 | 12.05859                              | -0.075      | 11.99448                              | -0.075                 | 12.14255                              | -0.075      | 12.10813                              | -0.075        | 12.10057                              | 12.051305                             |
| -0.09                  | 12.05466                              | -0.09       | 11.98735                              | -0.09                  | 12.14598                              | -0.09       | 12.11189                              | -0.09         | 12.10032                              | 12.04962                              |
| -0.1                   | 12.06547                              | -0.1        | 11.98749                              | -0.1                   | 12.13952                              | -0.1        | 12.11358                              | -0.1          | 12.102495                             | 12.050535                             |

Table S4.6: Average series resistance of MAPbI<sub>3</sub> and triple cation devices during thermal cycling.

| MAPbI3 series resistance |             |          |            | Triple cation series resistance |             |          |            |
|--------------------------|-------------|----------|------------|---------------------------------|-------------|----------|------------|
| Cycle                    | Slope (A/V) | 1/Slope  | Rs (Ω cm2) | Cycle                           | Slope (A/V) | 1/Slope  | Rs (Ω cm2) |
| Initial                  | -0.07719    | 12.95505 | 86.37      | Initial                         | -0.07225    | 13.84083 | 92.27      |
| Final                    | -0.07119    | 14.04692 | 93.65      | Final                           | -0.06748    | 14.81921 | 98.79      |

## 4.2 Jezero Crater Temperature Profile

Table S4.7: MAPbI<sub>3</sub> data from Jezero Crater temperature profile measurement.

| MAPbI <sub>3</sub> |                  |         |         |                 |                           |
|--------------------|------------------|---------|---------|-----------------|---------------------------|
| Time               | Temperature (°C) | PCE (%) | Voc (V) | Fill Factor (%) | Jsc (mA/Cm <sup>2</sup> ) |
| 0:00               | -70              | 2.66    | 0.96    | 20.32           | 7.45                      |
| 1:00               | -71.33           | 2.46    | 0.96    | 20.08           | 6.98                      |
| 2:00               | -72.67           | 2.35    | 0.96    | 20.03           | 6.7                       |
| 3:00               | -74.00           | 2.25    | 0.96    | 19.96           | 6.43                      |
| 4:00               | -75.33           | 2.09    | 0.96    | 19.87           | 6                         |
| 5:00               | -76.67           | 2       | 0.96    | 19.88           | 5.75                      |
| 6:00               | -78              | 1.91    | 0.96    | 19.91           | 5.49                      |
| 7:00               | -67.29           | 2.53    | 0.96    | 19.91           | 7.23                      |
| 8:00               | -56.57           | 3.57    | 0.96    | 21.31           | 9.51                      |
| 9:00               | -45.86           | 5.14    | 0.97    | 26.01           | 11.16                     |
| 10:00              | -35.14           | 7.16    | 0.98    | 33.96           | 11.8                      |
| 11:00              | -24.43           | 9.52    | 0.99    | 43.51           | 12.04                     |
| 12:00              | -13.71           | 11.73   | 1.02    | 52.02           | 12.12                     |
| 13:00              | -3               | 13.72   | 1.05    | 58.93           | 12.16                     |
| 14:00              | -13              | 13.35   | 1.04    | 57.77           | 12.14                     |
| 15:00              | -23              | 11.66   | 1.02    | 51.74           | 12.15                     |
| 16:00              | -33              | 9.44    | 0.99    | 43.24           | 12.05                     |
| 17:00              | -43              | 7.21    | 0.97    | 34.21           | 11.82                     |
| 18:00              | -53              | 5.16    | 0.96    | 26.2            | 11.18                     |
| 19:00              | -55.83           | 4.45    | 0.96    | 23.78           | 10.65                     |
| 20:00              | -58.67           | 3.97    | 0.96    | 22.38           | 10.1                      |
| 21:00              | -61.5            | 3.64    | 0.96    | 21.62           | 9.6                       |
| 22:00              | -64.33           | 3.26    | 0.96    | 20.86           | 8.91                      |
| 23:00              | -67.17           | 2.93    | 0.96    | 20.37           | 8.21                      |
| 0:00               | -70              | 2.63    | 0.96    | 20.04           | 7.49                      |

Table S4.8: MAPbI<sub>3</sub> J-V data from Jezero Crater temperature profile measurement.

| MAPbI3      |                          |                          |                          |                          |                          |
|-------------|--------------------------|--------------------------|--------------------------|--------------------------|--------------------------|
| Time        | 0:00                     | 6:00 AM                  | 13:00                    | 18:00                    | 24:00:00                 |
| Voltage (V) | Current density (mA/cm²) | Current density (mA/cm²) | Current density (mA/cm²) | Current density (mA/cm²) | Current density (mA/cm²) |
| 1.2         | -1.944178                | -1.437224                | -7.466253                | -3.76901                 | -2.190539                |
| 1.185       | -1.774448                | -1.299151                | -6.9198                  | -3.438457                | -1.975848                |
| 1.17        | -1.62298                 | -1.181925                | -6.214115                | -3.144802                | -1.787446                |
| 1.155       | -1.483224                | -1.075076                | -5.49078                 | -2.867318                | -1.616946                |
| 1.14        | -1.349202                | -0.9737026               | -4.728158                | -2.598588                | -1.459362                |
| 1.125       | -1.217763                | -0.8767127               | -3.963362                | -2.335647                | -1.311903                |
| 1.11        | -1.089577                | -0.7843029               | -3.189857                | -2.081416                | -1.17146                 |
| 1.095       | -0.9651543               | -0.6956513               | -2.419321                | -1.832803                | -1.036148                |
| 1.08        | -0.8435799               | -0.6088601               | -1.651573                | -1.592299                | -0.9063623               |
| 1.065       | -0.7253363               | -0.5247896               | -0.8912185               | -1.358964                | -0.781119                |
| 1.05        | -0.6102872               | -0.4439613               | -0.1111963               | -1.132932                | -0.6596625               |
| 1.035       | -0.4984282               | -0.3657908               | 0.6272775                | -0.9157923               | -0.5410612               |
| 1.02        | -0.3911601               | -0.2897315               | 1.40906                  | -0.7070596               | -0.427865                |
| 1.005       | -0.2875611               | -0.2160933               | 2.110842                 | -0.5079475               | -0.3188751               |
| 0.99        | -0.1875298               | -0.1444222               | 2.786312                 | -0.3101068               | -0.2134699               |
| 0.975       | -9.10E-02                | -0.074791                | 3.440161                 | -0.1259975               | -0.111919                |
| 0.96        | -1.26E-03                | -9.66E-03                | 4.079699                 | 4.43E-02                 | -0.0176224               |
| 0.945       | 0.0893133                | 5.94E-02                 | 4.688187                 | 0.2185258                | 7.71E-02                 |
| 0.93        | 0.1814716                | 0.1214326                | 5.275177                 | 0.3891928                | 0.175388                 |
| 0.915       | 0.2669159                | 0.1884317                | 5.835164                 | 0.5447961                | 0.2654647                |
| 0.9         | 0.3494499                | 0.251165                 | 6.360349                 | 0.6916776                | 0.352718                 |
| 0.885       | 0.4298929                | 0.3124693                | 6.859026                 | 0.835295                 | 0.4367517                |
| 0.87        | 0.509407                 | 0.3732808                | 7.338953                 | 0.9840496                | 0.51922                  |
| 0.855       | 0.5872631                | 0.4334441                | 7.766286                 | 1.125635                 | 0.5995131                |
| 0.84        | 0.6656219                | 0.4931068                | 8.188726                 | 1.264158                 | 0.6790084                |
| 0.825       | 0.7399377                | 0.5523117                | 8.554393                 | 1.403557                 | 0.7519523                |
| 0.81        | 0.820465                 | 0.6125054                | 8.911452                 | 1.544819                 | 0.8330986                |
| 0.795       | 0.9007733                | 0.6714249                | 9.222927                 | 1.687805                 | 0.9126573                |
| 0.78        | 0.9822976                | 0.7300723                | 9.511724                 | 1.832696                 | 0.9910786                |
| 0.765       | 1.063146                 | 0.7910253                | 9.77201                  | 1.982407                 | 1.069606                 |
| 0.75        | 1.146003                 | 0.8536986                | 10.0012                  | 2.13681                  | 1.149392                 |
| 0.735       | 1.229787                 | 0.9163876                | 10.20089                 | 2.297226                 | 1.228967                 |
| 0.72        | 1.31519                  | 0.979759                 | 10.38217                 | 2.462703                 | 1.311088                 |
| 0.705       | 1.402199                 | 1.043317                 | 10.54265                 | 2.635439                 | 1.394609                 |
| 0.69        | 1.492134                 | 1.109183                 | 10.68478                 | 2.810046                 | 1.480152                 |
| 0.675       | 1.58385                  | 1.174884                 | 10.81841                 | 2.993707                 | 1.566309                 |
| 0.66        | 1.675524                 | 1.241377                 | 10.92429                 | 3.181164                 | 1.655441                 |
| 0.645       | 1.771378                 | 1.309557                 | 11.03087                 | 3.373147                 | 1.745882                 |
| 0.63        | 1.867094                 | 1.379054                 | 11.12637                 | 3.572757                 | 1.839698                 |
| 0.615       | 1.967035                 | 1.448731                 | 11.19904                 | 3.779336                 | 1.936732                 |
| 0.6         | 2.069956                 | 1.521466                 | 11.25965                 | 3.989252                 | 2.035524                 |
| 0.585       | 2.173285                 | 1.595586                 | 11.31408                 | 4.201542                 | 2.135794                 |
| 0.57        | 2.279335                 | 1.670573                 | 11.38028                 | 4.420793                 | 2.239182                 |
| 0.555       | 2.387385                 | 1.747182                 | 11.43502                 | 4.643659                 | 2.346023                 |
| 0.54        | 2.498675                 | 1.823048                 | 11.48728                 | 4.866728                 | 2.456473                 |
| 0.525       | 2.60997                  | 1.901688                 | 11.52384                 | 5.092328                 | 2.567153                 |
| 0.51        | 2.72485                  | 1.982185                 | 11.56689                 | 5.319183                 | 2.681638                 |
| 0.495       | 2.840997                 | 2.06471                  | 11.61154                 | 5.551013                 | 2.798848                 |
| 0.48        | 2.960187                 | 2.14734                  | 11.6393                  | 5.78319                  | 2.91733                  |
| 0.465       | 3.081236                 | 2.23168                  | 11.66995                 | 6.012749                 | 3.03963                  |
| 0.45        | 3.204199                 | 2.317611                 | 11.69899                 | 6.244139                 | 3.162678                 |
| 0.435       | 3.329077                 | 2.405536                 | 11.73781                 | 6.47646                  | 3.290032                 |
| 0.42        | 3.456306                 | 2.493698                 | 11.75907                 | 6.7061                   | 3.418069                 |
| 0.405       | 3.585989                 | 2.582666                 | 11.79004                 | 6.935122                 | 3.549606                 |
| 0.39        | 3.716726                 | 2.675441                 | 11.82114                 | 7.225236                 | 3.680871                 |
| 0.375       | 3.848289                 | 2.768424                 | 11.84505                 | 7.402876                 | 3.816771                 |
| 0.36        | 3.9826                   | 2.863371                 | 11.86539                 | 7.621004                 | 3.953577                 |
| 0.345       | 4.11842                  | 2.959852                 | 11.87729                 | 7.832699                 | 4.093879                 |
| 0.33        | 4.255105                 | 3.0566                   | 11.89979                 | 8.044586                 | 4.233255                 |
| 0.315       | 4.393823                 | 3.156075                 | 11.90953                 | 8.256422                 | 4.377618                 |
| 0.3         | 4.534708                 | 3.256772                 | 11.92536                 | 8.457786                 | 4.52136                  |
| 0.285       | 4.67698                  | 3.359349                 | 11.95409                 | 8.65669                  | 4.667217                 |
| 0.27        | 4.819921                 | 3.462569                 | 11.95795                 | 8.850136                 | 4.811609                 |
| 0.255       | 4.963678                 | 3.566873                 | 11.97241                 | 9.036666                 | 4.958304                 |
| 0.24        | 5.107068                 | 3.672109                 | 11.9865                  | 9.214336                 | 5.10538                  |
| 0.225       | 5.251544                 | 3.779192                 | 12.00649                 | 9.390777                 | 5.252615                 |
| 0.21        | 5.39794                  | 3.886091                 | 12.01451                 | 9.55169                  | 5.40176                  |
| 0.195       | 5.54212                  | 3.995438                 | 12.02422                 | 9.711769                 | 5.551777                 |
| 0.18        | 5.68869                  | 4.105401                 | 12.02915                 | 9.86492                  | 5.701528                 |
| 0.165       | 5.837188                 | 4.216308                 | 12.04926                 | 10.01031                 | 5.850287                 |
| 0.15        | 5.984341                 | 4.329076                 | 12.07234                 | 10.14996                 | 6.000886                 |
| 0.135       | 6.133411                 | 4.440594                 | 12.07949                 | 1.03E+01                 | 6.150975                 |
| 0.12        | 6.278793                 | 4.55509                  | 1.21E+01                 | 1.04E+01                 | 6.300761                 |
| 0.105       | 6.427108                 | 4.669001                 | 1.21E+01                 | 10.52273                 | 6.450805                 |
| 0.09        | 6.573357                 | 4.784606                 | 12.12297                 | 10.62934                 | 6.602041                 |
| 0.075       | 6.719679                 | 4.900756                 | 12.12525                 | 10.74059                 | 6.752559                 |
| 0.06        | 6.865336                 | 5.017277                 | 12.12938                 | 10.84614                 | 6.89994                  |
| 0.045       | 7.050513                 | 5.133805                 | 12.1336                  | 10.94211                 | 7.086579                 |
| 0.03        | 7.160949                 | 5.251603                 | 12.13755                 | 11.02567                 | 7.206163                 |
| 0.015       | 7.305533                 | 5.369265                 | 12.15966                 | 11.10938                 | 7.349316                 |
| 0           | 7.448167                 | 5.489392                 | 12.16144                 | 11.18379                 | 7.49286                  |
| -0.015      | 7.590096                 | 5.609282                 | 12.17455                 | 11.25014                 | 7.638732                 |
| -0.03       | 7.730786                 | 5.727621                 | 12.17503                 | 11.32176                 | 7.780687                 |
| -0.045      | 7.872242                 | 5.848402                 | 12.19704                 | 11.3752                  | 7.922746                 |
| -0.06       | 8.013869                 | 5.966001                 | 12.20008                 | 11.44421                 | 8.065493                 |
| -0.075      | 8.150303                 | 6.085514                 | 12.20237                 | 11.50516                 | 8.202129                 |
| -0.09       | 8.281423                 | 6.206893                 | 12.20417                 | 11.54931                 | 8.338313                 |
| -0.1        | 8.364456                 | 6.282522                 | 12.20258                 | 11.57204                 | 8.41928                  |

Table S4.9: triple Cation data from Jezero Crater temperature profile measurement.

| Triple Cation |                  |         |         |                 |                           |
|---------------|------------------|---------|---------|-----------------|---------------------------|
| Time          | Temperature (°C) | PCE (%) | Voc (V) | Fill Factor (%) | Jsc (mA/Cm <sup>2</sup> ) |
| 0:00          | -70              | 3.64    | 0.95    | 24.29           | 8.61                      |
| 1:00          | -71.33           | 3.51    | 0.95    | 24.15           | 8.35                      |
| 2:00          | -72.67           | 3.34    | 0.95    | 23.93           | 8.02                      |
| 3:00          | -74.00           | 3.19    | 0.95    | 23.71           | 7.73                      |
| 4:00          | -75.33           | 3.04    | 0.95    | 23.55           | 7.43                      |
| 5:00          | -76.67           | 2.95    | 0.95    | 23.42           | 7.23                      |
| 6:00          | -78              | 2.81    | 0.95    | 23.27           | 6.94                      |
| 7:00          | -67.29           | 3.44    | 0.96    | 24.06           | 8.19                      |
| 8:00          | -56.57           | 4.42    | 0.96    | 25.69           | 9.82                      |
| 9:00          | -45.86           | 5.74    | 0.97    | 28.72           | 11.31                     |
| 10:00         | -35.14           | 7.46    | 0.98    | 34.25           | 12.15                     |
| 11:00         | -24.43           | 9.73    | 1       | 42.72           | 12.42                     |
| 12:00         | -13.71           | 11.82   | 1.03    | 50.72           | 12.42                     |
| 13:00         | -3               | 14.1    | 1.06    | 58.58           | 12.41                     |
| 14:00         | -13              | 13.72   | 1.05    | 57.35           | 12.42                     |
| 15:00         | -23              | 11.95   | 1.03    | 51.24           | 12.43                     |
| 16:00         | -33              | 9.73    | 1       | 42.81           | 12.43                     |
| 17:00         | -43              | 7.58    | 0.98    | 34.56           | 12.25                     |
| 18:00         | -53              | 5.66    | 0.96    | 28.5            | 11.26                     |
| 19:00         | -55.83           | 4.99    | 0.96    | 26.85           | 10.58                     |
| 20:00         | -58.67           | 4.62    | 0.96    | 26.09           | 10.09                     |
| 21:00         | -61.5            | 4.27    | 0.96    | 25.47           | 9.58                      |
| 22:00         | -64.33           | 3.94    | 0.96    | 24.94           | 9.03                      |
| 23:00         | -67.17           | 3.66    | 0.96    | 24.52           | 8.53                      |
| 0:00          | -70              | 3.39    | 0.96    | 24.15           | 8.03                      |

Table S4.10: triple Cation J-V data from Jezero Crater temperature profile measurement.

| Triple Cation |                                       |                                       |                                       |                                       |                                       |
|---------------|---------------------------------------|---------------------------------------|---------------------------------------|---------------------------------------|---------------------------------------|
| Time          | 0:00:00                               | 6:00:00                               | 13:00:00                              | 18:00:00                              | 24:00:00                              |
| Voltage (V)   | Current density (mA/cm <sup>2</sup> ) | Current density (mA/cm <sup>2</sup> ) | Current density (mA/cm <sup>2</sup> ) | Current density (mA/cm <sup>2</sup> ) | Current density (mA/cm <sup>2</sup> ) |
| 1.2           | -2.286973                             | -1.61624                              | -7.06381                              | -3.766836                             | -2.080329                             |
| 1.185         | -2.083064                             | -1.466889                             | -6.039783                             | -3.424199                             | -1.88238                              |
| 1.17          | -1.897828                             | -1.335042                             | -5.247478                             | -3.111694                             | -1.707514                             |
| 1.155         | -1.724734                             | -1.213041                             | -4.503276                             | -2.822285                             | -1.548163                             |
| 1.14          | -1.561842                             | -1.098522                             | -3.763804                             | -2.546466                             | -1.397616                             |
| 1.125         | -1.40607                              | -0.989633                             | -3.046636                             | -2.28087                              | -1.2552                               |
| 1.11          | -1.25782                              | -0.8862134                            | -2.340223                             | -2.02986                              | -1.120764                             |
| 1.095         | -1.116183                             | -0.78777                              | -1.645967                             | -1.789355                             | -0.9930136                            |
| 1.08          | -0.979899                             | -0.6934983                            | -0.956999                             | -1.55797                              | -0.8708379                            |
| 1.065         | -0.8501153                            | -0.6037438                            | -0.1816697                            | -1.33399                              | -0.7531793                            |
| 1.05          | -0.7250593                            | -0.5148789                            | 0.5299473                             | -1.118597                             | -0.6407177                            |
| 1.035         | -0.6035777                            | -0.4309535                            | 1.337211                              | -0.9116566                            | -0.5298553                            |
| 1.02          | -0.4861857                            | -0.3495267                            | 2.038296                              | -0.7112453                            | -0.4242727                            |
| 1.005         | -0.3744057                            | -0.2706302                            | 2.708504                              | -0.5136526                            | -0.3217011                            |
| 0.99          | -0.2650673                            | -0.1931236                            | 3.366565                              | -0.3190704                            | -0.2207805                            |
| 0.975         | -0.1594324                            | -0.1171807                            | 3.996973                              | -0.1332064                            | -0.1219438                            |
| 0.96          | -5.55E-02                             | -0.0448551                            | 4.613751                              | 5.03E-02                              | -0.0270812                            |
| 0.945         | 5.12E-02                              | 3.33E-02                              | 5.198852                              | 0.2431981                             | 7.18E-02                              |
| 0.93          | 0.1545973                             | 0.105673                              | 5.754879                              | 0.430492                              | 0.1756929                             |
| 0.915         | 0.2624527                             | 0.1854946                             | 6.284029                              | 0.6100863                             | 0.2749301                             |
| 0.9           | 0.3664449                             | 0.2627901                             | 6.778693                              | 0.791147                              | 0.3745364                             |
| 0.885         | 0.4709872                             | 0.3411595                             | 7.256253                              | 0.9775186                             | 0.4746516                             |
| 0.87          | 0.5773557                             | 0.4204282                             | 7.704456                              | 1.157809                              | 0.5767421                             |
| 0.855         | 0.6856856                             | 0.5011218                             | 8.12334                               | 1.338125                              | 0.6792477                             |
| 0.84          | 0.7962686                             | 0.5835535                             | 8.511826                              | 1.518922                              | 0.7822653                             |
| 0.825         | 0.911138                              | 0.668406                              | 8.867066                              | 1.701892                              | 0.8905063                             |
| 0.81          | 1.028074                              | 0.7545509                             | 9.202693                              | 1.885524                              | 1.000324                              |
| 0.795         | 1.146124                              | 0.8443939                             | 9.51003                               | 2.070488                              | 1.110764                              |
| 0.78          | 1.266159                              | 0.9358259                             | 9.79151                               | 2.257854                              | 1.223189                              |
| 0.765         | 1.389774                              | 1.030078                              | 10.0523                               | 2.444446                              | 1.337686                              |
| 0.75          | 1.514533                              | 1.125333                              | 10.28142                              | 2.636492                              | 1.452442                              |
| 0.735         | 1.641787                              | 1.222969                              | 10.49285                              | 2.829209                              | 1.569633                              |
| 0.72          | 1.771683                              | 1.323205                              | 10.67806                              | 3.022564                              | 1.688582                              |
| 0.705         | 1.902982                              | 1.424686                              | 10.85476                              | 3.213249                              | 1.808921                              |
| 0.69          | 2.036698                              | 1.527507                              | 11.00669                              | 3.41613                               | 1.931684                              |
| 0.675         | 2.174155                              | 1.632809                              | 11.13445                              | 3.619302                              | 2.05618                               |
| 0.66          | 2.311521                              | 1.74026                               | 11.25677                              | 3.823027                              | 2.181841                              |
| 0.645         | 2.450247                              | 1.849082                              | 11.36724                              | 4.029148                              | 2.309498                              |
| 0.63          | 2.592676                              | 1.959335                              | 11.46688                              | 4.235801                              | 2.439671                              |
| 0.615         | 2.736034                              | 2.072181                              | 11.55293                              | 4.446007                              | 2.571074                              |
| 0.6           | 2.882986                              | 2.187962                              | 11.62666                              | 4.660154                              | 2.70386                               |
| 0.585         | 3.027813                              | 2.3032                                | 11.70105                              | 4.87274                               | 2.838788                              |
| 0.57          | 3.176691                              | 2.419624                              | 11.75844                              | 5.091334                              | 2.975966                              |
| 0.555         | 3.328419                              | 2.537854                              | 11.81603                              | 5.312397                              | 3.114441                              |
| 0.54          | 3.481824                              | 2.658051                              | 11.86842                              | 5.529989                              | 3.253114                              |
| 0.525         | 3.634664                              | 2.77983                               | 11.90591                              | 5.749576                              | 3.396027                              |
| 0.51          | 3.79                                  | 2.901983                              | 11.94477                              | 5.974145                              | 3.535902                              |
| 0.495         | 3.945521                              | 3.026657                              | 11.98448                              | 6.195849                              | 3.680236                              |
| 0.48          | 4.101861                              | 3.151211                              | 12.02092                              | 6.413208                              | 3.823174                              |
| 0.465         | 4.261159                              | 3.277331                              | 12.03927                              | 6.634488                              | 3.965606                              |
| 0.45          | 4.419824                              | 3.403717                              | 12.07133                              | 6.849203                              | 4.113805                              |
| 0.435         | 4.58178                               | 3.532905                              | 12.09478                              | 7.162957                              | 4.26219                               |
| 0.42          | 4.741411                              | 3.659479                              | 12.11705                              | 7.304117                              | 4.410091                              |
| 0.405         | 4.900556                              | 3.787926                              | 12.13305                              | 7.504096                              | 4.557079                              |
| 0.39          | 5.061125                              | 3.917253                              | 12.17082                              | 7.705707                              | 4.704412                              |
| 0.375         | 5.220308                              | 4.046836                              | 12.1904                               | 7.905386                              | 4.853086                              |
| 0.36          | 5.377598                              | 4.173169                              | 12.19914                              | 8.104916                              | 4.997776                              |
| 0.345         | 5.538998                              | 4.30131                               | 12.21001                              | 8.293519                              | 5.143672                              |
| 0.33          | 5.698048                              | 4.430899                              | 12.22025                              | 8.479877                              | 5.290433                              |
| 0.315         | 5.856861                              | 4.560543                              | 12.23074                              | 8.662666                              | 5.434229                              |
| 0.3           | 6.011846                              | 4.686664                              | 12.24474                              | 8.831943                              | 5.576666                              |
| 0.285         | 6.165538                              | 4.813426                              | 12.25662                              | 9.00079                               | 5.719521                              |
| 0.27          | 6.317015                              | 4.938507                              | 12.27617                              | 9.161503                              | 5.857682                              |
| 0.255         | 6.468417                              | 5.063417                              | 12.27911                              | 9.32301                               | 5.997722                              |
| 0.24          | 6.61266                               | 5.18605                               | 12.30008                              | 9.469833                              | 6.136549                              |
| 0.225         | 6.75949                               | 5.308334                              | 12.30246                              | 9.61438                               | 6.268704                              |
| 0.21          | 6.896039                              | 5.428123                              | 12.30366                              | 9.758993                              | 6.401002                              |
| 0.195         | 7.103833                              | 5.550187                              | 12.32431                              | 9.895793                              | 6.53252                               |
| 0.18          | 7.189754                              | 5.66686                               | 12.33506                              | 10.02646                              | 6.661313                              |
| 0.165         | 7.319533                              | 5.781751                              | 12.34293                              | 10.1488                               | 6.786789                              |
| 0.15          | 7.447716                              | 5.896801                              | 12.35019                              | 10.27238                              | 6.911733                              |
| 0.135         | 7.575373                              | 6.009648                              | 12.35746                              | 10.39409                              | 7.087223                              |
| 0.12          | 7.696612                              | 6.123879                              | 12.37055                              | 1.05E+01                              | 7.16237                               |
| 0.105         | 7.820643                              | 6.231639                              | 12.37097                              | 1.06E+01                              | 7.270783                              |
| 0.09          | 7.939773                              | 6.337584                              | 12.38626                              | 1.07E+01                              | 7.382076                              |
| 0.075         | 8.055633                              | 6.441857                              | 1.24E+01                              | 10.81775                              | 7.495114                              |
| 0.06          | 8.171399                              | 6.544094                              | 12.38542                              | 10.91256                              | 7.604846                              |
| 0.045         | 8.287443                              | 6.648773                              | 12.4013                               | 11.01013                              | 7.711195                              |
| 0.03          | 8.39917                               | 6.750206                              | 12.38972                              | 11.09124                              | 7.818066                              |
| 0.015         | 8.504666                              | 6.848973                              | 12.40213                              | 11.18107                              | 7.926446                              |
| 0             | 8.613736                              | 6.945209                              | 12.42293                              | 11.26431                              | 8.02891                               |
| -0.015        | 8.721393                              | 7.0366                                | 12.41172                              | 11.34312                              | 8.127253                              |
| -0.03         | 8.826726                              | 7.13307                               | 12.41576                              | 11.42322                              | 8.23E+00                              |
| -0.045        | 8.927727                              | 7.228373                              | 12.42644                              | 11.50108                              | 8.32249                               |
| -0.06         | 9.028656                              | 7.321533                              | 12.43244                              | 11.56492                              | 8.422013                              |
| -0.075        | 9.130553                              | 7.412054                              | 12.4398                               | 11.6306                               | 8.518057                              |
| -0.09         | 9.223332                              | 7.502966                              | 12.44304                              | 11.69789                              | 8.60872                               |
| -0.1          | 9.277749                              | 7.559929                              | 12.44581                              | 11.73                                 | 8.667233                              |

## A1 Short-Circuit Photoluminescence

Table SA.1: PL<sub>SC</sub> cooling parameters of the MAPI-based device.

| Temperature (°C) | Peak Position (nm) | Peak Shift (nm) | Optical Band Gap (eV) | FWHM (nm) |
|------------------|--------------------|-----------------|-----------------------|-----------|
| 20               | 765.46356          | 0               | 1.62                  | 42        |
| 10               | 768.17676          | 2.7132          | 1.61                  | 35        |
| 0                | 768.17676          | 2.7132          | 1.61                  | 34        |
| -10              | 776.31708          | 10.85352        | 1.60                  | 43        |
| -20              | 768.51593          | 3.05237         | 1.61                  | 32        |
| -30              | 770.21173          | 4.74817         | 1.61                  | 31        |
| -40              | 770.89008          | 5.42652         | 1.61                  | 30        |
| -50              | 771.22931          | 5.76575         | 1.61                  | 29        |
| -60              | 769.53345          | 4.06989         | 1.61                  | 29        |
| -70              | 771.22931          | 5.76575         | 1.61                  | 28        |
| -80              | 771.22931          | 5.76575         | 1.61                  | 30        |
| -90              | 770.89008          | 5.42652         | 1.61                  | 30        |
| -100             | 770.21173          | 4.74817         | 1.61                  | 31        |
| -110             | 768.17676          | 2.7132          | 1.61                  | 32        |
| -120             | 768.51593          | 3.05237         | 1.61                  | 34        |
| -125             | 767.1593           | 1.69574         | 1.62                  | 35        |

Table SA.2: PL<sub>SC</sub> cooling parameters of the triple cation-based device.

| Temperature (°C) | Peak Position (nm) | Peak Shift (nm) | Optical Band Gap (eV) | FWHM (nm) |
|------------------|--------------------|-----------------|-----------------------|-----------|
| 20               | 765.46356          | 0               | 1.62                  | 38        |
| 10               | 765.46356          | 0               | 1.62                  | 42        |
| 0                | 765.80273          | 0.33917         | 1.62                  | 41        |
| -10              | 763.42871          | -2.03485        | 1.62                  | 34        |
| -20              | 763.0896           | -2.37396        | 1.62                  | 35        |
| -30              | 765.46356          | 0               | 1.62                  | 38        |
| -40              | 765.12445          | -0.33911        | 1.62                  | 37        |
| -50              | 765.46356          | 0               | 1.62                  | 35        |
| -60              | 767.1593           | 1.69574         | 1.62                  | 35        |
| -70              | 768.17676          | 2.7132          | 1.61                  | 35        |
| -80              | 768.17676          | 2.7132          | 1.61                  | 34        |
| -90              | 768.51593          | 3.05237         | 1.61                  | 32        |
| -100             | 770.21173          | 4.74817         | 1.61                  | 31        |
| -110             | 770.89008          | 5.42651         | 1.61                  | 30        |
| -120             | 771.22931          | 5.76575         | 1.61                  | 29        |
| -125             | 769.53345          | 4.06989         | 1.61                  | 29        |

## B1 Humidity Stepping

Table SB.1: Relative humidity stepping data of the MAPI-based device.

| RH (%) | PCE (%) | Voc (V) | FF (%) | Jsc (mA/Cm <sup>2</sup> ) |
|--------|---------|---------|--------|---------------------------|
| 10     | 11.89   | 0.98    | 53.64  | 12.39                     |
| 20     | 10.9    | 0.97    | 50.12  | 12.27                     |
| 30     | 10.85   | 0.97    | 49.99  | 12.26                     |
| 40     | 11.03   | 0.97    | 50.6   | 12.3                      |
| 50     | 11.57   | 0.97    | 52.89  | 12.33                     |
| 60     | 11.55   | 0.97    | 52.74  | 12.35                     |
| 70     | 10.92   | 0.96    | 50.51  | 12.26                     |
| 80     | 11.35   | 0.97    | 52.05  | 12.32                     |
| 90     | 11.22   | 0.97    | 51.55  | 12.31                     |
| 80     | 11.3    | 0.97    | 51.95  | 12.3                      |
| 70     | 12.03   | 0.97    | 55.13  | 12.25                     |
| 60     | 12.08   | 0.97    | 55.1   | 12.32                     |
| 50     | 12.13   | 0.97    | 55.07  | 12.39                     |
| 40     | 11.46   | 0.97    | 52.59  | 12.33                     |
| 30     | 11.82   | 0.97    | 54.04  | 12.35                     |
| 20     | 11.83   | 0.97    | 53.92  | 12.37                     |
| 10     | 11.64   | 0.97    | 53.26  | 12.34                     |

Table SB.2: Relative humidity stepping data of the triple cation-based device.

| Relative Humidity (%) | PCE (%) | Voc (V) | FF (%) | Jsc (mA/Cm <sup>2</sup> ) |
|-----------------------|---------|---------|--------|---------------------------|
| 10%                   | 14.31   | 1.1     | 60.5   | 11.71                     |
| 20%                   | 13.68   | 1.09    | 58.85  | 11.66                     |
| 30%                   | 13.7    | 1.09    | 58.99  | 11.68                     |
| 40%                   | 13.62   | 1.09    | 58.83  | 11.67                     |
| 50%                   | 13.66   | 1.08    | 58.99  | 11.68                     |
| 60%                   | 13.51   | 1.08    | 58.5   | 11.68                     |
| 70%                   | 13.67   | 1.08    | 57.84  | 11.98                     |
| 80%                   | 13.87   | 1.08    | 58.61  | 11.98                     |
| 90%                   | 13.64   | 1.08    | 58.49  | 11.84                     |

## B2 Humidity Cycling

Table SB.3: Relative humidity cycling data of the MAPI-based device.

| Cycle | RH (%) | PCE (%) | Voc (V) | FF (%) | Jsc (mA/Cm <sup>2</sup> ) |
|-------|--------|---------|---------|--------|---------------------------|
| 0     | 10     | 13.02   | 1.01    | 58.57  | 11.99                     |
| 0     | 90     | 12.65   | 1.01    | 57.36  | 11.95                     |
| 1     | 10     | 12.51   | 1.01    | 56.85  | 11.93                     |
| 1     | 90     | 12.33   | 1.01    | 56.21  | 11.92                     |
| 2     | 10     | 12.3    | 1.01    | 56.03  | 11.93                     |
| 2     | 90     | 12.17   | 1.01    | 55.51  | 11.91                     |
| 3     | 10     | 12.1    | 1.01    | 55.35  | 11.89                     |
| 3     | 90     | 12.03   | 1.01    | 55.02  | 11.89                     |
| 4     | 10     | 12.05   | 1.01    | 55.08  | 11.89                     |
| 4     | 90     | 11.99   | 1.01    | 54.83  | 11.89                     |
| 5     | 10     | 11.95   | 1.01    | 54.69  | 11.88                     |
| 5     | 90     | 11.96   | 1.01    | 54.68  | 11.89                     |
| 6     | 10     | 11.93   | 1.01    | 54.61  | 11.89                     |
| 6     | 90     | 11.92   | 1.01    | 54.56  | 11.89                     |

Table SB.4: Relative humidity cycling data of the triple cation-based device.

| Cycle | RH (%) | PCE (%) | Voc (V) | FF (%) | Jsc (mA/Cm <sup>2</sup> ) |
|-------|--------|---------|---------|--------|---------------------------|
| 0     | 10     | 13.28   | 1.01    | 60.01  | 12.01                     |
| 0     | 90     | 13.3    | 1.01    | 60.14  | 12.01                     |
| 1     | 10     | 13.34   | 1.01    | 60.23  | 12.02                     |
| 1     | 90     | 13.31   | 1.01    | 60.04  | 12.04                     |
| 2     | 10     | 13.29   | 1.01    | 60.03  | 12.03                     |
| 2     | 90     | 13.29   | 1.01    | 59.95  | 12.03                     |
| 3     | 10     | 13.4    | 1.01    | 60.44  | 12.04                     |
| 3     | 90     | 13.39   | 1.01    | 60.27  | 12.07                     |
| 4     | 10     | 13.43   | 1.01    | 60.45  | 12.06                     |
| 4     | 90     | 13.45   | 1.01    | 60.52  | 12.06                     |
| 5     | 10     | 13.53   | 1.01    | 60.81  | 12.08                     |
| 5     | 90     | 13.48   | 1.01    | 60.87  | 12.08                     |
| 6     | 10     | 13.57   | 1.01    | 60.93  | 12.08                     |
| 6     | 90     | 13.51   | 1.01    | 60.67  | 12.09                     |

## B3 Jezero Crater Humidity Profile

Table SB.5: Jezero Crater relative humidity profile data of the MAPI-based device.

| Local Mars Time | RH (%) | PCE (%) | Voc (V) | FF (%) | Jsc (mA/Cm <sup>2</sup> ) |
|-----------------|--------|---------|---------|--------|---------------------------|
| 0:00            | 10     | 12.74   | 1.01    | 58.12  | 11.9                      |
| 1:00            | 13.33  | 12.6    | 1.01    | 57.6   | 11.89                     |
| 2:00            | 16.67  | 12.51   | 1.01    | 57.33  | 11.86                     |
| 3:00            | 20     | 12.47   | 1.01    | 57.08  | 11.88                     |
| 4:00            | 23.33  | 12.37   | 1.01    | 56.79  | 11.86                     |
| 5:00            | 26.67  | 12.35   | 1.01    | 56.7   | 11.84                     |
| 6:00            | 30     | 12.26   | 1       | 56.39  | 11.84                     |
| 7:00            | 20     | 12.26   | 1       | 56.42  | 11.83                     |
| 8:00            | 10     | 12.39   | 1.01    | 56.82  | 11.85                     |
| 9:00            | 10     | 12.48   | 1.01    | 57.18  | 11.86                     |
| 10:00           | 10     | 12.61   | 1.01    | 57.58  | 11.88                     |
| 11:00           | 10     | 12.58   | 1.01    | 57.47  | 11.88                     |
| 12:00           | 10     | 12.44   | 1.01    | 56.93  | 11.87                     |
| 13:00           | 10     | 12.64   | 1.01    | 57.72  | 11.88                     |
| 14:00           | 10     | 12.78   | 1.01    | 58.1   | 11.91                     |
| 15:00           | 10     | 12.57   | 1.01    | 57.37  | 11.89                     |
| 16:00           | 10     | 12.43   | 1.01    | 56.95  | 11.86                     |
| 17:00           | 10     | 12.69   | 1.01    | 57.91  | 11.89                     |
| 18:00           | 10     | 12.74   | 1.01    | 57.97  | 11.91                     |
| 19:00           | 10     | 12.45   | 1.01    | 56.92  | 11.89                     |
| 20:00           | 10     | 12.46   | 1.01    | 57     | 11.87                     |
| 21:00           | 10     | 12.58   | 1.01    | 57.48  | 11.88                     |
| 22:00           | 10     | 12.5    | 1.01    | 57.21  | 11.86                     |
| 23:00           | 10     | 12.64   | 1.01    | 57.62  | 11.9                      |
| 24:00           | 10     | 12.44   | 1.01    | 56.95  | 11.87                     |

Table SB.6: JV curves of MAPbI<sub>3</sub>.

|             | 0:00                                  | 6:00                                  | 24:00                                 |
|-------------|---------------------------------------|---------------------------------------|---------------------------------------|
| Voltage (V) | Current Density (mA/cm <sup>2</sup> ) | Current Density (mA/cm <sup>2</sup> ) | Current Density (mA/cm <sup>2</sup> ) |
| 1.2         | -12.0917                              | -12.1392                              | -12.69029                             |
| 1.185       | -12.48415                             | -12.83905                             | -13.968                               |
| 1.17        | -12.15774                             | -12.49558                             | -13.47087                             |
| 1.155       | -11.25904                             | -11.55895                             | -12.3072                              |
| 1.14        | -10.12265                             | -10.39549                             | -10.96313                             |
| 1.125       | -8.88766                              | -9.14493                              | -9.56857                              |
| 1.11        | -7.62762                              | -7.88013                              | -8.18981                              |
| 1.095       | -6.406                                | -6.66611                              | -6.84606                              |
| 1.08        | -5.13476                              | -5.37751                              | -5.60071                              |
| 1.065       | -3.94898                              | -4.17995                              | -4.2731                               |
| 1.05        | -2.81352                              | -3.03108                              | -3.05003                              |
| 1.035       | -1.73313                              | -1.93606                              | -1.89916                              |
| 1.02        | -0.8686                               | -0.89592                              | -0.8069                               |
| 1.005       | 0.1775                                | -0.12735                              | 0.11404                               |
| 0.99        | 1.10898                               | 0.87595                               | 1.03568                               |
| 0.975       | 2.11517                               | 1.90853                               | 2.07103                               |
| 0.96        | 2.97364                               | 2.78238                               | 2.94955                               |
| 0.945       | 3.7532                                | 3.56789                               | 3.75057                               |
| 0.93        | 4.47126                               | 4.28351                               | 4.47623                               |
| 0.915       | 5.13003                               | 4.94372                               | 5.13507                               |
| 0.9         | 5.73212                               | 5.54141                               | 5.72728                               |
| 0.885       | 6.28159                               | 6.07797                               | 6.27535                               |
| 0.87        | 6.7772                                | 6.56554                               | 6.74575                               |
| 0.855       | 7.07879                               | 6.95218                               | 7.04014                               |
| 0.84        | 7.57538                               | 7.2568                                | 7.51488                               |
| 0.825       | 7.97521                               | 7.68073                               | 7.87347                               |
| 0.81        | 8.31952                               | 8.01376                               | 8.17601                               |
| 0.795       | 8.60888                               | 8.29072                               | 8.44176                               |
| 0.78        | 8.87494                               | 8.53095                               | 8.68704                               |
| 0.765       | 9.09633                               | 8.74315                               | 8.88935                               |
| 0.75        | 9.28485                               | 8.93541                               | 9.02932                               |
| 0.735       | 9.48169                               | 9.10337                               | 9.21263                               |
| 0.72        | 9.64447                               | 9.25268                               | 9.36563                               |
| 0.705       | 9.78905                               | 9.39852                               | 9.47643                               |
| 0.69        | 9.91128                               | 9.52721                               | 9.6199                                |
| 0.675       | 10.0293                               | 9.64341                               | 9.73335                               |
| 0.66        | 10.13119                              | 9.762                                 | 9.84193                               |
| 0.645       | 10.21983                              | 9.83823                               | 9.94762                               |
| 0.63        | 10.30868                              | 9.95232                               | 10.03703                              |
| 0.615       | 10.3944                               | 10.05305                              | 10.13501                              |
| 0.6         | 10.4482                               | 10.13929                              | 10.23538                              |
| 0.585       | 10.53508                              | 10.21981                              | 10.32057                              |
| 0.57        | 10.61364                              | 10.30762                              | 10.39757                              |
| 0.555       | 10.68083                              | 10.38585                              | 10.47116                              |
| 0.54        | 10.74448                              | 10.46249                              | 10.5513                               |
| 0.525       | 10.80251                              | 10.53537                              | 10.61579                              |
| 0.51        | 10.87467                              | 10.60334                              | 10.68131                              |
| 0.495       | 10.92679                              | 10.65722                              | 10.74231                              |
| 0.48        | 10.97811                              | 10.72752                              | 10.8034                               |
| 0.465       | 11.03803                              | 10.79451                              | 10.86217                              |
| 0.45        | 11.07981                              | 10.84686                              | 10.9203                               |
| 0.435       | 11.12412                              | 10.91314                              | 10.97551                              |
| 0.42        | 11.17298                              | 10.97072                              | 11.01314                              |
| 0.405       | 11.21554                              | 11.0142                               | 11.08613                              |
| 0.39        | 11.25486                              | 11.07038                              | 11.12853                              |
| 0.375       | 11.29266                              | 11.11405                              | 11.19523                              |
| 0.36        | 11.33898                              | 11.16468                              | 11.23482                              |
| 0.345       | 11.36264                              | 11.20574                              | 11.27613                              |
| 0.33        | 11.40373                              | 11.25545                              | 11.30567                              |
| 0.315       | 11.45201                              | 11.29154                              | 11.35555                              |
| 0.3         | 11.48329                              | 11.31388                              | 11.38401                              |
| 0.285       | 11.51638                              | 11.37556                              | 11.41883                              |
| 0.27        | 11.5305                               | 11.3977                               | 11.45434                              |
| 0.255       | 11.56521                              | 11.43294                              | 11.49143                              |
| 0.24        | 11.60241                              | 11.4673                               | 11.52092                              |
| 0.225       | 11.62003                              | 11.50633                              | 11.53074                              |
| 0.21        | 11.63959                              | 11.53011                              | 11.56042                              |
| 0.195       | 11.67113                              | 11.55875                              | 11.59196                              |
| 0.18        | 11.69757                              | 11.59037                              | 11.62705                              |
| 0.165       | 11.71763                              | 11.61241                              | 11.65074                              |
| 0.15        | 11.73939                              | 11.62362                              | 11.67133                              |
| 0.135       | 11.76017                              | 11.65044                              | 11.6966                               |
| 0.12        | 11.7745                               | 11.68427                              | 11.72078                              |
| 0.105       | 11.77661                              | 11.70754                              | 11.74337                              |
| 0.09        | 11.81596                              | 11.71941                              | 11.76305                              |
| 0.075       | 11.83052                              | 11.74908                              | 11.77867                              |
| 0.06        | 11.84749                              | 11.77075                              | 11.81185                              |
| 0.045       | 11.8628                               | 11.79533                              | 11.82933                              |
| 0.03        | 11.87125                              | 11.81465                              | 11.84948                              |
| 0.015       | 11.90309                              | 11.82763                              | 11.8511                               |
| 0           | 11.90468                              | 11.84156                              | 11.86048                              |
| -0.015      | 11.91552                              | 11.84827                              | 11.89001                              |
| -0.03       | 11.93026                              | 11.87129                              | 11.90599                              |
| -0.045      | 11.9327                               | 11.89244                              | 11.90603                              |
| -0.06       | 11.95485                              | 11.91268                              | 11.91881                              |
| -0.075      | 11.95447                              | 11.91974                              | 11.93592                              |
| -0.09       | 11.98128                              | 11.92911                              | 11.9576                               |
| -0.1        | 11.97063                              | 11.93028                              | 11.95073                              |

Table SB.7: Jezero Crater relative humidity profile data of the triple cation-based device.

| Local Mars Time | RH (%) | PCE (%) | Voc (V) | FF (%) | Jsc (mA/Cm <sup>2</sup> ) |
|-----------------|--------|---------|---------|--------|---------------------------|
| 0:00            | 10     | 13.6    | 1.01    | 60.86  | 12.07                     |
| 1:00            | 13.33  | 13.57   | 1.01    | 60.86  | 12.05                     |
| 2:00            | 16.67  | 13.85   | 1.01    | 61.82  | 12.07                     |
| 3:00            | 20     | 13.81   | 1.01    | 61.59  | 12.09                     |
| 4:00            | 23.33  | 13.72   | 1.01    | 61.31  | 12.08                     |
| 5:00            | 26.67  | 13.71   | 1.01    | 61.31  | 12.07                     |
| 6:00            | 30     | 13.77   | 1.01    | 61.52  | 12.09                     |
| 7:00            | 20     | 13.75   | 1.01    | 61.45  | 12.08                     |
| 8:00            | 10     | 13.64   | 1.01    | 60.98  | 12.08                     |
| 9:00            | 10     | 13.89   | 1.01    | 62.02  | 12.07                     |
| 10:00           | 10     | 13.96   | 1.02    | 62.15  | 12.1                      |
| 11:00           | 10     | 14.05   | 1.02    | 62.29  | 12.14                     |
| 12:00           | 10     | 13.95   | 1.01    | 62.14  | 12.09                     |
| 13:00           | 10     | 14.01   | 1.02    | 62.32  | 12.1                      |
| 14:00           | 10     | 14.04   | 1.02    | 62.4   | 12.1                      |
| 15:00           | 10     | 14.02   | 1.02    | 62.37  | 12.11                     |
| 16:00           | 10     | 14.18   | 1.02    | 62.8   | 12.13                     |
| 17:00           | 10     | 14.04   | 1.02    | 62.39  | 12.11                     |
| 18:00           | 10     | 14.28   | 1.02    | 63.09  | 12.14                     |
| 19:00           | 10     | 14.12   | 1.02    | 62.6   | 12.12                     |
| 20:00           | 10     | 14.16   | 1.02    | 62.77  | 12.12                     |
| 21:00           | 10     | 14.06   | 1.02    | 62.57  | 12.1                      |
| 22:00           | 10     | 14.12   | 1.02    | 62.72  | 12.11                     |
| 23:00           | 10     | 14.19   | 1.02    | 62.9   | 12.12                     |
| 24:00           | 10     | 14.29   | 1.02    | 63.16  | 12.13                     |

Table SB.8: J-V curves of triple cation.

|             | 0:00                                  | 6:00                                  | 24:00                                 |
|-------------|---------------------------------------|---------------------------------------|---------------------------------------|
| Voltage (V) | Current Density (mA/cm <sup>2</sup> ) | Current Density (mA/cm <sup>2</sup> ) | Current Density (mA/cm <sup>2</sup> ) |
| 1.2         | -13.20022                             | -13.21611                             | -13.76951                             |
| 1.185       | -13.46797                             | -13.58345                             | -14.14144                             |
| 1.17        | -12.21877                             | -12.40348                             | -12.76389                             |
| 1.155       | -10.87605                             | -11.06674                             | -11.28923                             |
| 1.14        | -9.565116                             | -9.74418                              | -9.8466                               |
| 1.125       | -8.28289                              | -8.445323                             | -8.425447                             |
| 1.11        | -7.030536                             | -7.179186                             | -7.06896                              |
| 1.095       | -5.851442                             | -5.975862                             | -5.783892                             |
| 1.08        | -4.643251                             | -4.74597                              | -4.485356                             |
| 1.065       | -3.504778                             | -3.588156                             | -3.260183                             |
| 1.05        | -2.412198                             | -2.47492                              | -2.094795                             |
| 1.035       | -1.379478                             | -1.403526                             | -0.9666363                            |
| 1.02        | -0.4397173                            | -0.4621231                            | -2.38E-02                             |
| 1.005       | 0.5849248                             | 0.5722812                             | 1.010713                              |
| 0.99        | 1.415853                              | 1.4347                                | 2.070202                              |
| 0.975       | 2.369132                              | 2.406464                              | 3.005347                              |
| 0.96        | 3.211442                              | 3.275918                              | 3.873605                              |
| 0.945       | 3.99357                               | 4.080658                              | 4.684385                              |
| 0.93        | 4.743017                              | 4.833347                              | 5.428923                              |
| 0.915       | 5.428025                              | 5.527716                              | 6.128033                              |
| 0.9         | 6.065948                              | 6.172586                              | 6.752308                              |
| 0.885       | 6.661508                              | 6.77285                               | 7.19542                               |
| 0.87        | 7.045049                              | 7.172926                              | 7.795207                              |
| 0.855       | 7.612486                              | 7.748003                              | 8.29299                               |
| 0.84        | 8.098307                              | 8.220799                              | 8.724032                              |
| 0.825       | 8.498316                              | 8.62552                               | 9.111997                              |
| 0.81        | 8.851572                              | 8.985844                              | 9.416623                              |
| 0.795       | 9.169326                              | 9.304426                              | 9.723326                              |
| 0.78        | 9.45724                               | 9.581573                              | 9.996936                              |
| 0.765       | 9.718364                              | 9.830796                              | 10.21929                              |
| 0.75        | 9.929852                              | 10.02941                              | 10.40691                              |
| 0.735       | 10.08067                              | 10.22988                              | 10.5625                               |
| 0.72        | 10.23754                              | 10.39195                              | 10.724                                |
| 0.705       | 10.42687                              | 10.53943                              | 10.85883                              |
| 0.69        | 10.54728                              | 10.65929                              | 10.9561                               |
| 0.675       | 10.65395                              | 10.74943                              | 11.06006                              |
| 0.66        | 10.73678                              | 10.8595                               | 11.1359                               |
| 0.645       | 10.83651                              | 10.94678                              | 11.21179                              |
| 0.63        | 10.90589                              | 11.00598                              | 11.28299                              |
| 0.615       | 10.9764                               | 11.06584                              | 11.34043                              |
| 0.6         | 11.04015                              | 11.11417                              | 11.38883                              |
| 0.585       | 11.08463                              | 11.18347                              | 11.41836                              |
| 0.57        | 11.13283                              | 11.2139                               | 11.46892                              |
| 0.555       | 11.18069                              | 11.27472                              | 11.49924                              |
| 0.54        | 11.22687                              | 11.32288                              | 11.53105                              |
| 0.525       | 11.27047                              | 11.37118                              | 11.56198                              |
| 0.51        | 11.31096                              | 11.4117                               | 11.59083                              |
| 0.495       | 11.36199                              | 11.43381                              | 11.62526                              |
| 0.48        | 11.38726                              | 11.47538                              | 11.6463                               |
| 0.465       | 11.4175                               | 11.5107                               | 11.66892                              |
| 0.45        | 11.46631                              | 11.5419                               | 11.70561                              |
| 0.435       | 11.50115                              | 11.56972                              | 11.72947                              |
| 0.42        | 11.5355                               | 11.60097                              | 11.73843                              |
| 0.405       | 11.5684                               | 11.62892                              | 11.76999                              |
| 0.39        | 11.58506                              | 11.66281                              | 11.79585                              |
| 0.375       | 11.62161                              | 11.68692                              | 11.7903                               |
| 0.36        | 11.64039                              | 11.70846                              | 11.82422                              |
| 0.345       | 11.67831                              | 11.73338                              | 11.84078                              |
| 0.33        | 11.70364                              | 11.74654                              | 11.85859                              |
| 0.315       | 11.71777                              | 11.78562                              | 11.88139                              |
| 0.3         | 11.74269                              | 11.80784                              | 11.90568                              |
| 0.285       | 11.76177                              | 11.81929                              | 11.90925                              |
| 0.27        | 11.78173                              | 11.8467                               | 11.9409                               |
| 0.255       | 11.79857                              | 11.86893                              | 11.9656                               |
| 0.24        | 11.81943                              | 11.88444                              | 11.96252                              |
| 0.225       | 11.84581                              | 11.89966                              | 11.98518                              |
| 0.21        | 11.864                                | 11.91767                              | 11.99091                              |
| 0.195       | 11.88037                              | 11.93799                              | 12.00848                              |
| 0.18        | 11.90857                              | 11.95259                              | 12.02213                              |
| 0.165       | 11.93176                              | 11.97263                              | 12.02221                              |
| 0.15        | 11.93765                              | 11.97701                              | 12.03903                              |
| 0.135       | 11.94775                              | 11.98466                              | 12.03842                              |
| 0.12        | 11.96947                              | 12.00121                              | 12.05839                              |
| 0.105       | 11.98189                              | 12.01175                              | 12.06867                              |
| 0.09        | 12.00128                              | 12.02836                              | 12.07063                              |
| 0.075       | 12.00286                              | 12.04424                              | 12.09526                              |
| 0.06        | 12.01706                              | 12.05678                              | 12.09873                              |
| 0.045       | 12.02834                              | 12.06601                              | 12.10732                              |
| 0.03        | 12.04679                              | 12.06495                              | 12.11103                              |
| 0.015       | 12.0576                               | 12.07793                              | 12.12745                              |
| 0           | 12.06496                              | 12.09569                              | 12.14458                              |
| -0.015      | 12.07116                              | 12.0982                               | 12.13639                              |
| -0.03       | 12.08826                              | 12.1147                               | 12.13998                              |
| -0.045      | 12.08761                              | 12.11938                              | 12.15661                              |
| -0.06       | 12.10079                              | 12.12973                              | 12.15127                              |
| -0.075      | 12.1087                               | 12.13901                              | 12.16401                              |
| -0.09       | 12.11885                              | 12.13892                              | 12.16338                              |
| -0.1        | 12.12287                              | 12.14736                              | 12.16624                              |

## B4 90% Relative Humidity Endurance

Table SB.9: MAPI 90% RH endurance data.

| Time (min) | PCE (%) | Voc (V) | FF (%) | Jsc (mA/Cm <sup>2</sup> ) |
|------------|---------|---------|--------|---------------------------|
| 0          | 12.75   | 0.99    | 58.32  | 12.03                     |
| 1          | 12.77   | 0.99    | 58.49  | 12.04                     |
| 2          | 12.98   | 0.99    | 59.35  | 12.04                     |
| 4          | 12.9    | 0.99    | 59.02  | 12.05                     |
| 8          | 12.2    | 0.99    | 56.58  | 11.97                     |
| 16         | 11.98   | 0.98    | 55.75  | 11.95                     |
| 32         | 11.47   | 0.98    | 53.83  | 11.89                     |
| 64         | 11.23   | 0.98    | 52.87  | 11.88                     |
| 128        | 10.66   | 0.98    | 50.58  | 11.82                     |
| 256        | 10.45   | 0.97    | 49.71  | 11.81                     |
| 1440       | 0.01    | 0.05    | 78.19  | 0.15                      |

Table SB.10: triple cation 90% RH endurance data.

| Time (min) | PCE (%) | Voc (V) | FF (%) | Jsc (mA/Cm <sup>2</sup> ) |
|------------|---------|---------|--------|---------------------------|
| 0          | 12.04   | 1.09    | 53.54  | 11.39                     |
| 1          | 12.04   | 1.09    | 54.19  | 11.39                     |
| 2          | 12.05   | 1.1     | 55.86  | 11.45                     |
| 4          | 11.97   | 1.09    | 55.33  | 11.38                     |
| 8          | 11.95   | 1.08    | 54.66  | 11.37                     |
| 16         | 11.89   | 1.09    | 54.48  | 11.41                     |
| 32         | 11.88   | 1.08    | 53.49  | 11.38                     |
| 64         | 11.82   | 1.08    | 55.01  | 11.14                     |
| 128        | 11.81   | 1.06    | 53.6   | 11.35                     |
| 256        | 11.66   | 1.04    | 55.68  | 11.05                     |
| 1440       | 1.12    | 0.36    | 33.87  | 5.03                      |