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Design of Highly Coherence MIR Supercontinuum Generation in W-type Index Chalcogenide Fiber

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Abstract: This paper proposes the W-type index chalcogenide fiber to generate fully coherent MIR supercontinuum generation. Our fiber design has high nonlinear coefficient, flattened dispersion profile and a tight confinement of the mode within the core.
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1. Introduction

Mid-Infrared (MIR) coherence source is a key device for many applications, such as spectroscopy, metrology, few-cycle pulse compression and optical coherence tomography. One potential enabling technology for MIR coherent light source is to explore the supercontinuum generation (SC) in the optical fiber. To realize highly coherent (MIR) SC generation, there are two important factors [1]. One is a small absolute value of the chromatic dispersion in the MIR region. The other is a small effective mode diameter to increase the nonlinearity. Step-index fiber (SIF) -based supercontinuum laser systems possess the advantage of higher optical damage threshold and good mechanical robustness as well as stability against contamination from the ambient environment such as water vapor [2]. However, the tailoring of the fiber dispersion properties in standard SIF is tough. Moreover, the nonlinearity in a SIF is weaker compared to a microstructured fiber due to bigger core diameters and looser mode confinement which is based on the reduced core-cladding index contrast.

One approach to control the chromatic dispersion is by applying W-type index fiber. The investigation of tellurite W-type index structure has been already done for MIR SC (2-5 μm) [3]. However, this type of fiber has not been yet applied for chalcogenide based MIR SC. The advantages of such a double-clad fiber are a tight confinement of the mode within the core, a flattened dispersion profile with good control of the locations of the zero dispersion wavelengths (ZDWs), and a larger possible V-parameter under which single-mode operation is possible. The later property allows for larger core diameters compared to a common single-clad SIF. Furthermore, this fiber type is suitable for an all-fiber system because it can be fusion spliced to standard SIF. The benefit of a larger possible core diameter helps to lower the coupling losses while still operating under single-mode condition up to a higher V-parameter (V = 3.8) than in conventional SIF. Finite Element Method (FEM) based edge element analysis is applied to calculate the effective index and the chromatic dispersion. This approach eliminates the disadvantages of the scalar finite element approach of having undesired spurious modes or non-physical solutions and ensures an easy implementation of boundary conditions at material interfaces [4].

In this paper, the generation of fully coherent broadband MIR supercontinuum from 3.7 to 12 μm is demonstrated in W-type index chalcogenide fiber. We discuss the chromatic dispersion and nonlinear properties of W-type index chalcogenide fiber. We also numerically investigate MIR SC generation in the proposed fiber. Additionally, we analyze the statistical properties of the SC source by calculating its first order spectral coherence in the aim to investigate its sensitivity to input pump phase noise.

2. Design of a W-type index chalcogenide fiber

The fiber has core $Ge_{15}Sb_{15}Se_{70}$ (n_1), inner cladding $Ge_{20}Se_{80}$ (n_2) and outer cladding $Ge_{20}Sb_5Se_{75}$ (n_3) as shown in fig.1 (a). These materials have relatively large third-order nonlinear refractive index and relatively high laser damage threshold, as well as good transmittance in the 2–12 μm region [5]. The calculation of V-parameter (fig.1 (b)) for W-type index fiber shows that 6 μm is the optimum core diameter to keep the fiber in the single mode boundary at a large range (4.8-12μm). The simulation results show that the first zero-dispersion wavelengths (ZDWs) remain nearly fixed for different inner cladding diameters and that they are located at around 4.3μm. The second ZDWs increase with the inner cladding diameter and are located at 5.5μm, 6.5μm and 7μm with inner cladding diameter 9μm, 12μm and 18μm, respectively. Between these two ZDWs the fiber exhibits a flat anomalous dispersion. Moreover, the effective area is lower than in the case of step-index fiber with same materials and core size and therefore an enhancement on the fiber nonlinearity. The effective area increases with the larger inner cladding diameter.

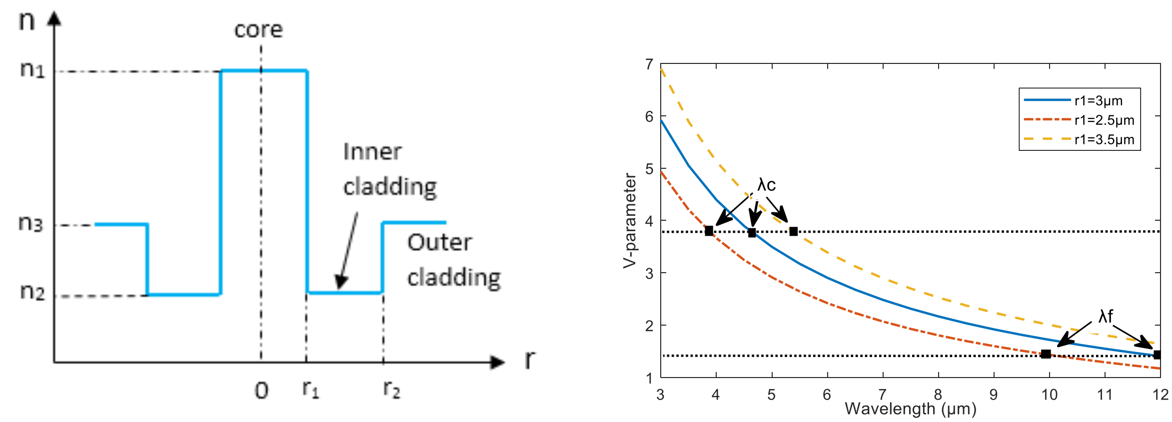

Fig.1 a) Refractive index profile of W-type index chalcogenide fiber. b) Calculated V-parameter for the W-type index chalcogenide fiber at core radiuses 2.5µm, 3µm and 3.5µm with single-mode cutoff-wavelengths at λ_c, and cutoff-wavelengths due to leakage losses at λ_f. The single-mode boundary at V = 3.8 and the leakage boundary at V = 1.4 are marked with black dotted lines.

3. Simulation of highly coherence MIR SC generation

The Split Step Fourier Method is applied to solve the Non-Linear Schrödinger Equation. The simulations are carried out with the 6.3 µm hyperbolic secant input pulse of a 1 kw peak power and a 330 fs pulse duration (FWHM) which is injected in the anomalous dispersion regime of a W-type index fiber. The noise is included by adding to the input pulse one random phase photon per mode in the frequency domain [6]. The degree of the first-order coherence was calculated with 20 simulations, which yielded 190 pairs of MIR SC obtained from input pulses with a different noise. Figure (2) shows the normalized intensity and degree of the first-order coherence in the W-type index chalcogenide fiber. In conclusion, the proposed fiber design provided the flattened chromatic dispersion to realize highly coherent MIR SC extending from 3.7 to 12 µm.

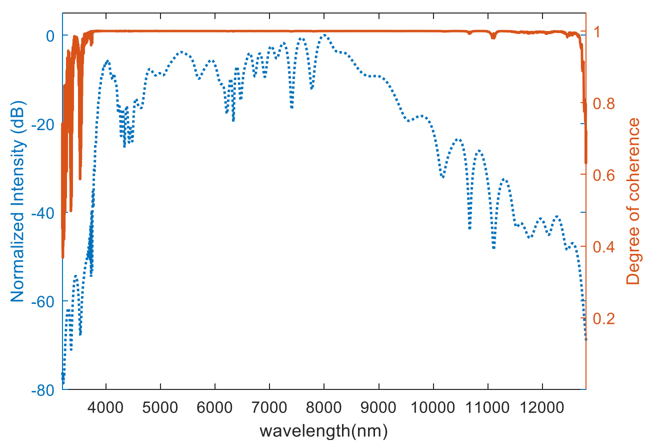

Fig.2 Normalized intensity (blue dotted curve, left axis) and degree of the first-order coherence (red curve, right axis) in the W-type index chalcogenide fiber.

4. References

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