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Soft glass based specialty optical fibers and their applications - INVITED

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Abstract. This paper describes a prospect for broadband mid-infrared (mid-IR) highly coherent supercontinuum generation. Tellurite and chalcogenide glass with high transparency up to the mid-IR range are used as fiber materials. We successfully develop all-solid hybrid microstructured optical fibers made of tellurite and chalcogenide glass to control chromatic dispersion and demonstrate that highly nonlinear soft glass microstructured optical fibers are promising media for broadband mid-IR highly coherent supercontinuum generation.

1 Introduction

The mid-IR region from 2.5 to 25 μm has a large amount of absorption bands specific to molecular bonding, making it suitable for identifying and detecting substances. For this reason, there are high expectations for the development of technology applied to medical, industrial, and advanced measurement fields using spectroscopy in the mid-IR region. Research into mid-IR broadband light generation is underway to realize spectroscopy in the mid-IR region. One type of light source that is currently attracting attention is supercontinuum (SC). Tellurite and chalcogenide glasses are excellent materials with much higher nonlinearity (several hundred times higher) and wider transmission characteristics than silica glass. By using optical fibers, SC with high spatial and temporal coherence can be generated simultaneously. However, these glasses have a problem that it is difficult to reduce chromatic dispersion, which is advantageous for SC generation, due to the extremely large material dispersion.

The wavelength range of SC generation using optical fibers has been expanding to longer wavelengths every year, and SC generation extending beyond 10 μm has been reported since 2014 [1, 2, 3]. However, highly coherent mid-infrared SC generation has not been reported so far. As mentioned above, tellurite and chalcogenide glasses have large material dispersion, and the key to generate highly coherent SC is to realize an optical fiber structure that can reduce chromatic dispersion. We have developed all-solid hybrid microstructured optical fiber (ASHMOF) made of tellurite and chalcogenide glass. And we have succeeded in chromatic dispersion reduction of tellurite and chalcogenide glass optical fibers. Here, we describe the generation of highly coherent mid-IR broadband SC using tellurite and chalcogenide glass optical fibers, which have high transmission in the mid-IR region.

2 Chromatic dispersion control by ASHMOF

ASHMOF was devised to control the wavelength dispersion of tellurite and chalcogenide optical fibers. The structure is shown in Fig. 1. By arranging glass rods around the core, the material dispersion property of the glass rods is utilized to improve the controllability of chromatic dispersion.

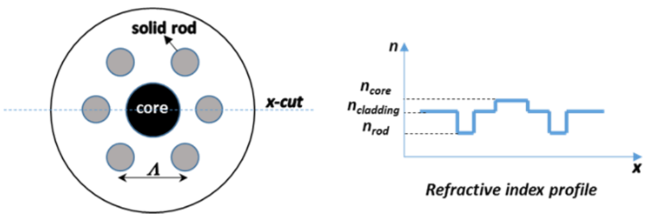

Fig. 1. Structural diagram of ASHMOF.

3 Chromatic dispersion and SC generation property of tellurite ASHMOF

Three types of tellurite glass, TLWMN (TeO_2-Li_2O-WO_3-MO_3-Nb_2O_5), TZNL (TeO_2-ZnO-Na_2O-La_2O_3), and TZLKAP (TeO_2-ZnO-Li_2O-K_2O-Al_2O_3-P_2O_5) glass were used as optical fiber materials. TLWMN glass was used as the core glass because it has the highest refractive index, TZLKAP glass was used for the glass rods surrounding the core, and TZNL glass was used as the cladding glass. The expansion coefficients of these glasses are very close, and their glass softening points are almost the same.

Figure 2 shows a cross-sectional photograph of the fabricated tellurite ASHMOF. It can be seen that the central core is surrounded by six TZLKAP glass rods with low refractive index.

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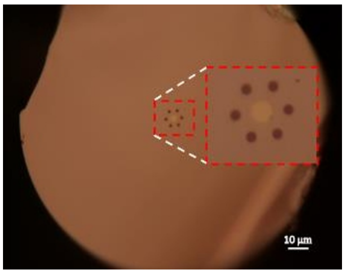

Fig. 2. Cross section of tellurite ASHMOF.

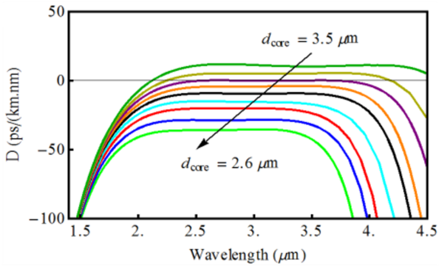

Fig. 3. Dependence of chromatic dispersion of tellurite ASHMOF on structural parameters.

Figure 3 shows the change in chromatic dispersion spectrum when the core diameter (d_{core}) is varied from 2.6 to 3.5 μm. Then the rod-to-rod distance (Λ) and the ratio of Λ to the rod diameter (d_{rod}) (Λ/d_{rod}) are 2.7, and Λ and d_{rod} are 1.55 μm. The chromatic dispersion spectrum changes from normal to anomalous dispersion with maintaining spectral flatness when d_{core} is varied from 2.6 to 3.5 μm. It is found that flatness as low as ± 0.2 ps/km/nm can be achieved in the wavelength range from 2.5 to 3.7 μm.

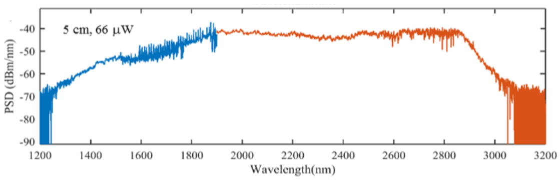

Fig. 4. SC spectrum by tellurite ASHMOF.

Figure 4 shows the SC spectrum of a 5 cm long ASHMOF generated by the excitation at 2 μm. The spectrum extends from 1.4 to 3.0 μm at an intensity of 20 dB down. At a 3 dB down in intensity, SC with good flatness covering a range from 1.9 to 2.85 μm was generated. It was also found that high coherence was maintained [4].

4 Chromatic dispersion and SC generation property of chalcogenide ASHMOF

Chalcogenide ASHMOFs were fabricated with As_2Se_3, $AsSe_2$, and As_2S_5 glass as the core, cladding, and rod around the core, respectively. A cross-sectional view of the fabricated ASHMOF is shown in Fig. 5.

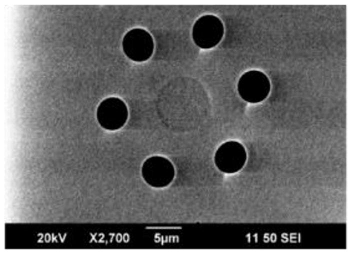

Fig. 5. Cross section of chalcogenide ASHMOF.

As shown in Fig. 6, the normal dispersion characteristics in the whole spectral range can be realized by ASHMOF structure while maintaining the flatness of the chromatic dispersion. Especially when d_{core} is 9.74 μm, Λ is 13.2 μm, and Λ/d_{rod} is 3.3, extremely flat chromatic dispersion characteristics with a dispersion variation of ± 0.4 ps/km/nm can be achieved in the wavelength range from 6 to 13.2 μm.

The chromatic dispersion of the fabricated chalcogenide ASHMOF is also shown in Fig. 6. It can be seen that it has normal dispersion. The SC spectrum obtained by the excitation at 5 μm is shown in Fig. 7. We can see that the SC broadens from 2.2 to 10.5 μm. Since the wavelength of 5 μm is in the normal dispersion region, the SC broadens mainly due to self-phase modulation, and coherence is maintained [5].

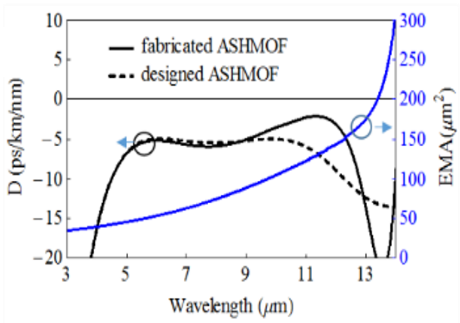

Fig. 6. Chromatic dispersion of chalcogenide ASHMOF.

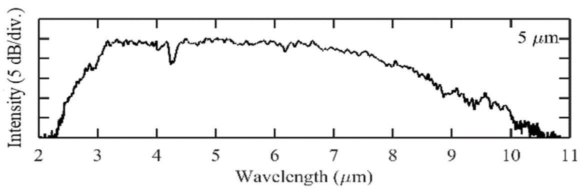

Fig. 7. SC spectrum by chalcogenide ASHMOF.

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