Ultra Highly Nonlinear AsSe Chalcogenide Holey Fiber for Nonlinear Applications

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Abstract *We report the characterizations of an AsSe chalcogenide holey fiber including loss, dispersion, effective area and nonlinear coefficient. The fiber exhibits a record Kerr nonlinearity of 15000 $W^{-1}km^{-1}$, which allows great potential for nonlinear applications.*

Introduction

Recently, highly nonlinear optical fibers have been of a great interest in many applications such as regeneration, wavelength conversion or supercontiniuum generation[1]… Since many of them exploit the large Kerr nonlinearity of these kinds of fibers, the efficiency of these devices could be improved by increasing their Kerr coefficient. To achieve this aim, one can fabricate fiber with reduced effective area and/or the use of highly nonlinear glasses[2]. Chalcogenide glasses have demonstrated very high Kerr nonlinearities (up to 500x greater than fused silica) which make them good candidates to reach nonlinearities from three to four orders of magnitude higher than standard silica fibers. In this work, we report the characterization of a chalcogenide holey fiber having a nonlinear Kerr coefficient of 15000 $W^{-1}km^{-1}$. Moreover, we experimentally demonstrate a nonlinear optical gate working at low power with only 60 cm of fiber.

Chalcogenide holey fiber

The chalcogenide holey fiber has a structure of 3-hexagonal-rings. The average hole diameter *d* is 0.7 µm and the distance Λ between the hole centres is about 1.4 µm. Figure 1 presents the cross section of the fiber.

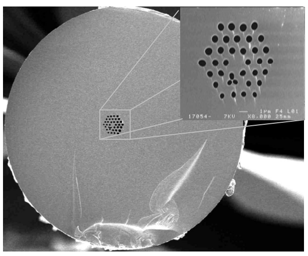

Fig 1. Cross section of the AsSe chalcogenide holey fiber.

The nominal composition of the chalcogenide glass is $As_{38}Se_{62}$. The transition temperature is 170℃ and the non-linear refractive index is estimated to be 500 times greater than one of pure silica[3]. High purity raw materials are placed in a sealed silica tube and the batch is heated to around 800℃ for 12 hours. The glass is quenched in water and then annealed at the transition temperature.

Fiber characterization

(a) Loss measurement

The attenuation losses were measured at 1550 nm using a cut-back method. Based on the linear fit of the data represented in figure 2, we found fiber losses around 15 dB/m. The coupling loss is estimated around 4 dB. Although the material losses are around 1 dB/m for this glass, we think that the excess of losses is principally due to the fabrication process[4]. We can note that three holes, between the central and the second ring of holes, are unfortunately closed together, increasing subsequently the guiding losses.

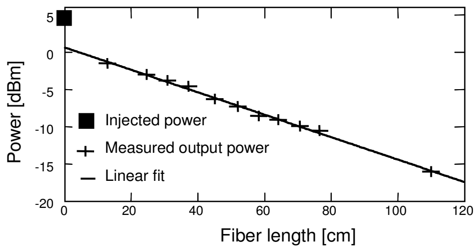

Fig 2. Loss measurement using cutback method.

(b) Dispersion measurement

The chromatic dispersion of the fiber around 1550 nm was measured on a 17-cm long sample thanks to a classical white light interferometric method[5]. Figure 3(a) represents the position of the central fringe of the interferometer output pattern as a function of the temporal delay provided by its reference arm. The dispersion curve of our sample, presented in figure 3(b), is then simply deduced by means of the derivative of the delay variations[5]. The dispersion *D* and dispersion slope *S* at 1550 nm were found to be $D = -2117$ ps/nm/km and $S = dD/d\lambda = 1.4$ ps/nm²/km.

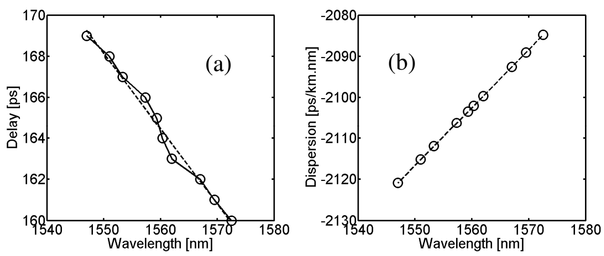

Fig 3. (a) Experimental values (circles) and polynomial fit (dashed line) of optical delay as a function of wavelength. (b) Experimental values (circles) and linear fit (dashed line) of dispersion as a function of wavelength.

(c) Effective area measurement

The effective area of the fiber has been measured using both near field and far field methods. With the near field method, the intensity at the output of the fiber is recorded on a camera using a large numerical aperture microscope objective. The camera is calibrated using the near field of a well-known fiber, i.e. a standard single-mode fiber. Figure 4(a) shows the image of the near field and the measured intensity distributions along the x, y axis. The output profiles are accurately fitted by a Gaussian function proving the single mode behaviour and giving a mode field diameter $2\omega_0$ (at $1/e^2$ intensity point) of 1.95 ± 0.1 µm which leads to an effective area A_{eff} of 3.0 ± 0.3 µm^2. Regarding the far field method, the output intensity is recorded as a function of rotation angle thanks to a photodetector moving circularly at a fixed long distance from the fiber output (around 1 cm). Angles are swept from –65° to +65° to ensure capturing the entire light beam. Figure 4(b) presents the normalised distribution of the far field. To calculate the effective area, the far field data is transformed to the near field using the inverse Hankel transform[6] and then calculated as if the data were obtained by the near field method. From this far field measurement, we found an effective area A_{eff} of 2.9 ± 0.2 µm^2, in good agreement with the previous result. To our best knowledge, this value is the smallest value reported in a chalcogenide fiber. With a nonlinear refractive index 500x greater than fused silica, this fiber potentially reaches a nonlinear coefficient γ of 15 000 W^{-1}km^{-1}.

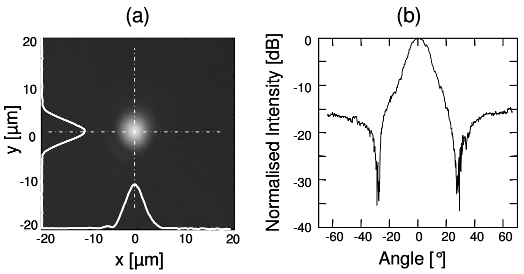

Fig 4. (a) Near filed of the fiber recorded on the camera. (b) Far field distribution as a function of the rotation angle.

(d) Nonlinear coefficient measurement

The nonlinear coefficient γ has been measured using the fit between the simulation and the experimental observation of spectral broadening due to self-phase modulation (SPM) in the fiber. The setup of the experiment is shown in figure 5(a).

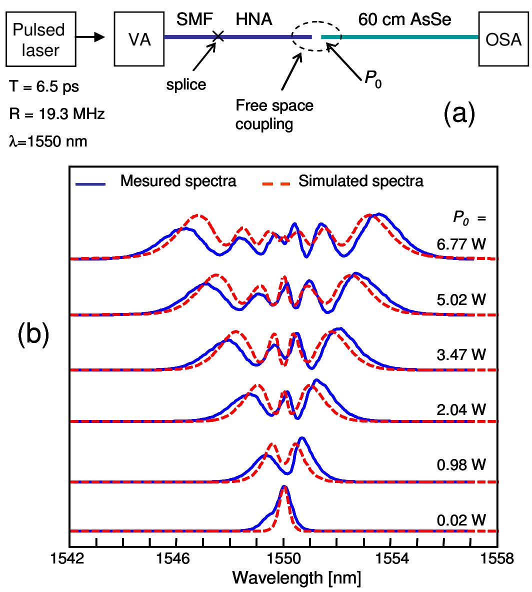

Fig 5. (a) Experimental setup for nonlinear coefficient measurement. (b) Broadening spectra due to SPM.

We used a mode-locked fiber laser operating at 1550 nm with a repetition rate of 19.3 MHz and pulse duration of 6.5 ps. Pulsed are injected in a 60-cm long sample of the AsSe fiber thanks to a highly-numerical-aperture fiber (HNA) to ensure mode matching. The coupling loss is estimated to be 4 dB. The input optical power P_0 is monitored using a variable optical attenuator (VA) while the output spectrum is recorded thanks to an optical spectrum analyzer (OSA). Figure 5(b) shows the experimental spectra (continuous lines) compared with the simulation results (dashed lines) obtained by resolving the nonlinear Schrödinger equation. We note a very good agreement between experimental and simulated spectra confirming the value γ of 15000 W^{-1}km^{-1}.

Nonlinear optical gate demonstration

In order to demonstrate the potential for nonlinear applications of the fiber, we have measured the transmission function of an all-optical SPM-based Mamyshev regenerator[7]. The experimental setup is similar to figure 5(a) except that a 0.5-nm width Gaussian filter, centred around 1551.5 nm, was placed at the output of the fiber. Figure 6 shows the transmission function describing the relation between input peak power and output average power. We note that the working power is found to be close to a peak-power of 2.5 W corresponding to an average power of 25 dBm in a 40-Gbit/s telecommunication return-to-zero signal (25% duty cycle). With this working power, the output pulse duration was estimated to be 7 ps.

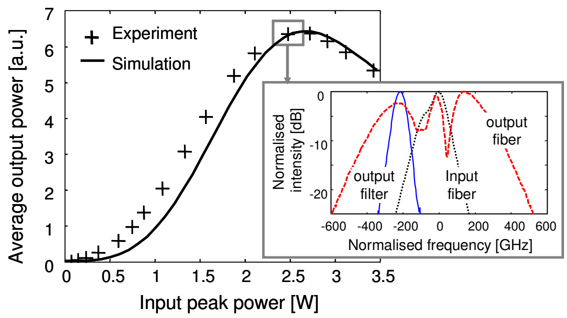

Fig 6. Nonlinear optical transmission function for 6.5 ps input signal. Inset: spectra of the signal at working point power.

Conclusions

We have reported the characterization of a single mode AsSe chalcogenide holey fiber. The measured nonlinear coefficient of 15 000 W^{-1}km^{-1} is, for the best of our knowledge, the highest value yet reported for a fiber. With its nonlinearity, this fiber has a strong potential for many nonlinear applications.

References

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