Improvement of the transmission of chalcogenide photonic crystal fibres: observation of self phase modulation spectral broadening

L. Brilland (1), P. Houizot (2), J. Troles (2), F. Désévédavy (2), Q. Coulombier (2), T. N. Nguyen (3), T. Chartier(3)
1 : PERFOS, 11 rue Louis de Broglie 22 300 Lannion, France, ntraynor@perfos.com
2 : Equipe Verres et Céramiques, UMR 6226, Rennes, France, johann.troles@univ-rennes1.fr
3 : FOTON, UMR CNRS 6082, 6 rue de kerampont, 22 300 Lannion, France, thierry.chartier@enssat.fr

Abstract

We present a chalcogenide photonic crystal fibre design with a lowest attenuation of 3dB/m at 1,55 µm. We observe, for the first time, self phase modulation spectral broadening.

Introduction

Chalcogenide glasses (CG) are well known for their large infrared transmission window and for their third order non-linear coefficient that can be 2 or 3 orders of magnitude greater than that of silica glasses [1]. Fibres based on these glasses have attracted interest in a variety of applications. In particular, the large value of non-linearity is attractive for optical signal regeneration, optical demultiplexing, optical switiching, Raman and Brillouin effects [2,3,4].

In our work, we are interested in the fabrication of chalcogenide photonic crystal fibres (PCF) with a solid core [5,6,7,8,9] which present numerous advantages such as single mode guiding and a very small effective area ideal for non-linear applications. The PCF fabrication method used is the "stack-and-draw" technique. However, this technique is more problematic in the case of chalcogenide glasses than in the case of silica glasses. Compared to the intrinsic chalcogenide material losses, the fabrication process appears to induce an excess of transmission loss. In this study, we show that correct PCF design enables the improvement of final fibre losses. We also present the first experimental demonstration of self phase modulation (SPM) spectral broadening around 1,55 µm in a chalcogenide PCF.

Chalcogenide photonic crystal fibre fabrication

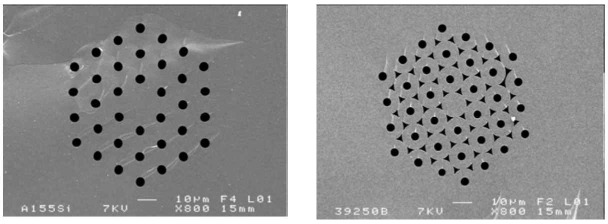
The nominal composition studied was $Ge_{15}Sb_{20}S_{65}$ (GeSbS).The transition temperature, Tg is 250 °C and the non-linear refractive index is estimated to be 120 times greater than that of silica [10]. High purity raw materials are placed in a sealed silica tube and the batch is heated to around 800 °C for 12 hours. The glass is quenched in water and then annealed at the transition temperature, Tg. The intrinsic losses of the GeSbS glass were measured to be 0.5 dB/m at 1.55 µm via cutback on a 400 µm single index fibre.

Chalcogenide tubes of 12 mm outside diameter are obtained by a rotational casting technique. One of these tubes is drawn down to obtain capillaries of around 600 µm outside diameter. These capillaries are stacked in a hexagonal lattice around a rod of identical diameter and placed in a jacket tube.

The fibre pre-form is realised by applying a depression to perfectly collapse the jacket tube around the microstructure in the furnace of the drawing tower. Parameters of depression and furnace temperature are adjusted to prevent the collapse of interstitial holes between capillaries.

During the fibre drawing process, two independent variable gas pressure systems are used. One of these systems maintains pressure inside the capillary holes to prevent their collapse. The other system is applied alternatively in a negative or positive pressure regime inside the interstitial holes. The goal is to obtain sections with open or closed interstitial holes and compare transmission properties.

Figure 1a) shows the central region of a 3-ring-PCF where interstitial holes were collapsed under depression. The distance between the hole centres is Λ=13,2 µm and the hole diameter *d* is 4,65 µm. Figure 1b) represents the same fibre, but with a positive pressure applied to open the interstitial holes. The attenuation coefficient of both the section with collapsed interstitial holes and the section with opened interstitial holes was measured at 1,55 µm using the cut back method. Results are given in table 1. When the interstitial holes are collapsed, the losses are greater than 20 dB/m. When the interstitial holes are opened, the lowest attenuation coefficient is 3 +/- 1 dB/m at 1,55 µm.



1a) *1b)*

Figure 1: Section of GeSbS PCF ; a) interstitials holes collapsed; b) interstitials holes opened

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Nominal composition: $Ge_{15}Sb_{20}S_{65}$ (Tg=250°C)	Losses at 1,55µm
Material	0,5 dB/m
interstitial holes collapsed	> 20dB/m
interstitial holes opened	3 dB/m

Table1: GeSbS material and PCF losses

Numerical simulations indicate guiding losses of less than 0,2 dB/m for the fundamental mode in both fibres (figures 1a and 1b). Compared to the intrinsic material losses, the transmission measurements show an excess loss of around 20 dB/m for the fibre with no interstitial holes. However, transmission is greatly improved when the interstitial holes are present, with excess losses reduced to a few dB/m. These results indicate that the excess losses are related to the interface between the capillaries. When a depression is applied to collapse interstitials holes, we believe that a greater number of bubbles are formed at the capillary interface causing significant scattering loss. On the other hand, when the interstitial holes are opened, the surface area of direct contact between capillaries is reduced as is the overlap between the electric field and the region of the glass interface. An additional interest of this PCF design is the reduction of the mode field diameter.

Observation of self phase modulation spectral broadening

A smaller core GeSbS-PCF with Λ=9 µm and d=2,7 µm was also fabricated. The losses at 1,55 µm are 5,5 dB/m and the effective area, measured using a far field method, is 22 µm^2. The non-linear coefficient γ is estimated to be 517 W^{-1}Km^{-1}. 7 ps pulses from a 19 MHz repetition rate mode-locked fibre laser were injected via a single mode fibre (SMF) into 2,9 m of this PCF (figure 2). The coupling losses between the SMF and the PCF are estimated to be 2,8 dB. The optical average power P_0 of the injected pulse train was monitored using a variable optical attenuator. The polarisation controller allows injection along a polarisation eigen-axis of the fibre for maximum efficiency. The output spectrum was observed on an optical spectrum analyser for different input power values. Experimental results are shown in figure 3.

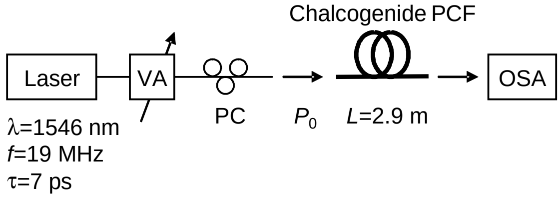

Figure 2: Experimental set up for the observation of SPM spectral broadening ; VA : variable attenuator; PC : polarisation controller

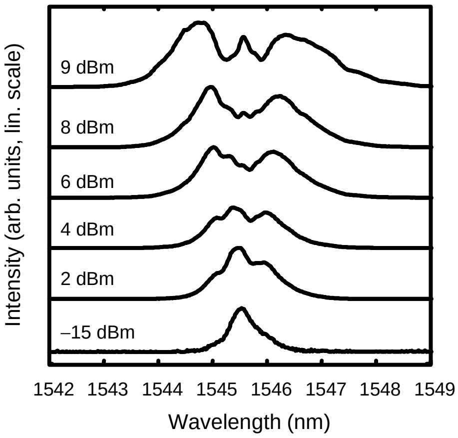

Figure 3: output spectra for different values of the average injected power P_0

It can be seen from figure 3 that for the first time in these fibres strong SPM spectral broadening is readily observed, even for low input optical powers, These results will be described in detail.

Conclusions

The presence of interstitial holes improves significantly the transmission of chalcogenide glass PCF. The best result achieved was an attenuation of 3dB/m at 1,55 µm. We have observed SPM spectral broadening for the first time in a chalcogenide PCF. Using higher non linearity chalcogenide compositions such as As_2Se_3 combined with a very small effective area (<10 µm^2), we believe that a non-linear coefficient γ of 10 000 W^{-1}Km^{-1} is within reach.

References

1. G. Boudebs et al, Opt. Com. 199 (2001), 425
2. L.B. Fu et al, Opt. Express, 19 (2005), 7367
3. J.M. Harbold et al, Opt. Lett., 27 (2002), 119
4. R.E. Slusher et al, JOSA B, 21 (2004), 1146
5. T.A. Birks et al, Opt. Lett., 22 (1997), 961
6. T.M.Monro et al, Electron. Lett, 36 (2000), 1998
7. J. Le Person et al, Mat. Res. Bull, 41 (2006), 1303
8. L. Brilland et al, Opt. Express, 14 (2006),1280
9. L.B. Shaw et al, OSA ASSP, 98(2005, 864
10. F. Smektala et al, J. Non-Cryst. Solids, 274 (2000)