Single mode planar waveguide of core-only GASIR fiber buried in chalcogenide glasses substrates

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Modal filtering in nulling interferometer is based on the capability of single-mode waveguides to transmit only one complex amplitude function to eliminate virtually any perturbation of the interfering wavefronts. In this letter, we focus on realizing single-mode waveguide of chalcogenide glasses in the thermal infrared range 6–20 μm by burying a GASIR (Ge-As-Se) fiber core in the substrates of As-Se-S glasses system. To match the single-mode operation, GASIR fiber core of about 15-μm diameter is drawn, the fiber core is buried into As-Se-S substrates by heating two kinds of glasses to a suitable temperature. The propagation mode is tested by guiding a CO_2 laser emitting at 9.3 μm into the waveguide. Single-mode out coming signal is obtained by an infrared camera.

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Chalcogenide glasses and amorphous thin films, based on S, Se, Te elements in combination with suitable element(s) from III, IV or V group of the periodical system (typically Ge, Ga, etc.), are distinguished from other materials by their large transparent domain in the infrared region of the electromagnetic spectrum, typically between 6 and 20 μm in which rare materials works. Hence, theses advantages make chalcogenides play a very important role in many applications[1,2], for example, the european space agency (ESA)s DARWIN mission[3−6] has the objective to find extra solar Earth-like planets with three major signatures which can present human-like lives: H_2O molecules absorbing in the 6-μm region, O_3 molecules around 9 μm and CO_2 molecules exhibiting a large absorption peak near 16 μm. Thereafter, a nulling interferometer will be used to scan the remote solar system in the infrared region, and a modal filter is one of the key optical elements in this interferometry system[7−9]. For shaping the light into single mode profile before destructive interference, this filter can be single mode fiber or waveguide working in the thermal infrared wavelength range and showing low optical losses. The commonly used techniques for fabricating this kind of waveguides are fiber drawing and thin film deposition[7,10,11].

The goal of this technology development is to fabricate a modal filter which has a chalcogenide fiber buried in substrates, in fact, this structure of waveguide is an innovative alternative technique in the DARWIN mission[8,12].

A waveguide was made by burying a GASIR-1[13] fiber into two As-Se-S glass bulks[14] which works in the same way than a double index fiber. The difference with a double index fibre is the size of the clad, which is much larger in the case of a waveguide. The light is conducted only if the index of the fibre is higher than the one of the bulk. Both glasses show also almost the same transmission spectra, from 2 to 16 μm. The third important physical property for the synthesis of a wave guide is the glass transition temperature (T_g). The T_g of the fiber must be much higher than the one of the bulks. Indeed, the synthesis of a waveguide involves that the bulks flows around the fiber without warping it.

The glass system used for the synthesis of waveguides is a fiber of GASIR-1 ($Ge_{22}As_{20}Se_{58}$) and two glass bulks of As-Se-S. These glasses have been chosen because they fulfil the requirements explained above. The GASIR-1 rod was ordered from UMICORE and drawn into fibre with diameter of about 15 μm, the As-Se-S glass was fabricated by classic chalcogenide glasses fabricating and purification process. The physical properties of these two glasses are presented in Table 1. The index difference is about 10^{-1}; the difference of glass transition temperatures is about 100 °C, it is enough to flow the As-Se-S bulk without warping the GASIR-1 fiber. For a single mode operation, the normalised frequency $V = \frac{2\pi}{\lambda}\sqrt[d]{n_c^2 - n_s^2}$ is required less than 2.405, which is the first root of the Bessel function J_0[15]. The calculated result of V number is also presented in Table 1, the obtained value is equal to 2.406 at 10 μm, and the propagation mode should be theoretically near single mode.

The operation consisting of digging the fiber into the bulks takes place with the following procedure: about 1 cm of a 15-μm diameter fiber is emplaced between two glass bulks and heated to a temperature higher than the T_g of the bulks, but lower than that of the fiber. This operation permits to soften the bulk while the fiber keeps

Table 1. Physical Properties of $Ge_{22}As_{20}Se_{58}$ and As-Se-S Glasses

	GASIR-1	$As_{40}Se_{16}S_{44}$
T_g (°C)	292	192
CTF* (10^{-6}/K)	17.0	20.0
n@10 μm	2.4944	2.4813
V (Φ=15 μm)	2.406	

*CTF: coefficient of thermal expansion.

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its shape. A light pressure on the top bulk increases the flow rate of the bulk around the fiber (Fig. 1). The temperature chosen is around 230 °C. After several hours in the oven, both bulks are connected and the fiber is included in between (Fig. 2). The juncture between the bulks was controlled after polishing by optical microscopy, as shown on the inset of Fig. 2

The waveguide was then tested with a set-up of CO_2 laser emitting at 9.3 μm (Fig. 3). The light is leaded into the waveguide by mirrors and lenses. The emerging signal is detected with an infrared camera and recorded in a computer. The images of the emerging signal show clearly that the light goes through the fiber. Indeed, there is a large circular light spot, and no signal around. It means that the light is conducted by the fiber included in the glass bulks. The obtained images are shown on Figs. 4 and 5 Even though the V number probably is not less than 2.405 at 9.3 μm, fortunately, the profile of the signal with its Gaussian fitting line indicates that the buried core-only fiber is typical of a single mode waveguide. This fact may be caused by following reasons. Firstly, there would be composition diffusion between fiber and substrates materials during heat pressing treatement, and the refractive indexes would also be changed; secondly, the second mode of the laser propagation possibly was lost when the light transmitted through the waveguide with relatively high optical losses.

To evaluate the optical loss of the GASIR-1 fiber, the transmissions of different lengthes of the fiber were measured and the optical loss was calculated by method of cut-off using

$$\text{Optical loss} = \frac{10}{l_1 - l_2} \times \lg\left(\frac{T_2}{T_1}\right), \tag{1}$$

where T_1 and T_2 are the transmission of the fibers with lengths of l_1 and l_2, respectively ($l_1 > l_2$). Results are presented in Fig. 6, the optical losses of the fiber at the region of 9–10 μm is typically around 4 dB/m.

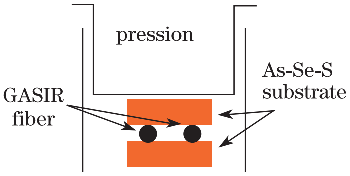

Fig. 1. Setup for fiber burying.

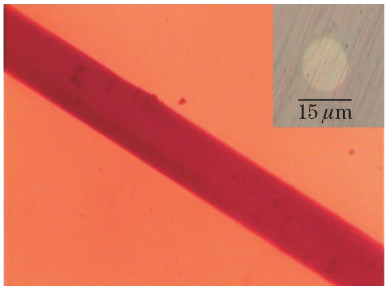

Fig. 2. Microscopic picture of a waveguide including one 15-μm diameter fiber, inset is one of the ends of the fiber.

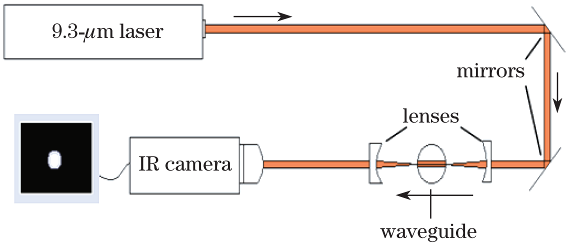

Fig. 3. Optical set-up used for the test of the waveguide.

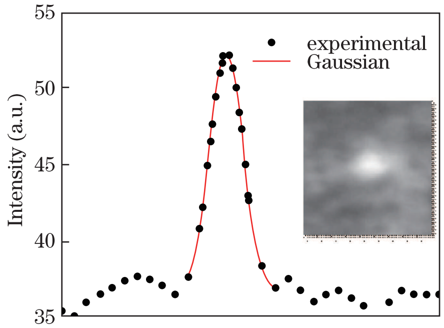

Fig. 4. Profile of the signal and Gaussian analysis, inset is the image view of the light signal out coming of the fiber.

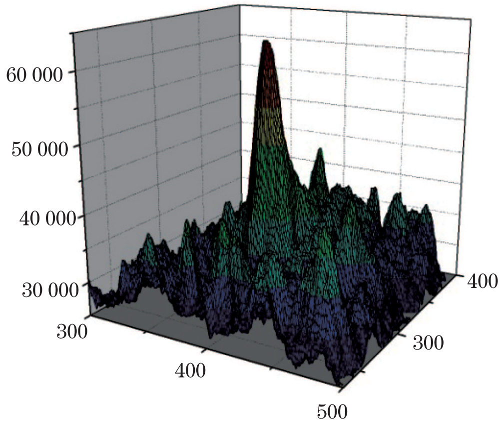

Fig. 5. Profile of the signal.

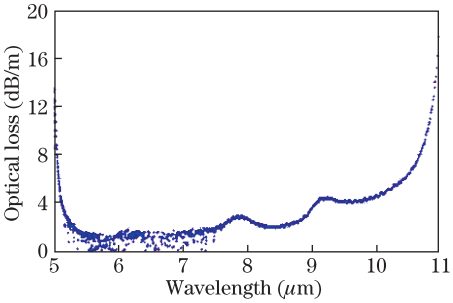

Fig. 6. Optical loss of GASIR fiber.

The first result of the buried core-only fiber planar waveguide is encouraging. A suitable temperature range is selected to bury the core-only fiber into transparent substrates and control the juncture and interface of the fiber and substrates very well. Experimental signal and Gaussian analysis demonstrate that the buried fiber shows single mode propagation when tested with a CO_2 laser. Additional purification process will be in place and operational to reduce the optical losses of the fiber materials.

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