
Volume 357, Issues 11–13, June 2011
ISSN 0022-3093
ELSEVIER
JOURNAL OF
NON-CRYSTALLINE SOLIDS
Editors: B.G. Potter, Tucson, AZ, USA
E.D. Zanotto, São Carlos, SP, Brazil
J.W. Zwanziger, Halifax, Nova Scotia, Canada
17th International Symposium on Non-Oxide and
New Optical Glasses (XVII ISNOG)
June 13–18, 2010, Ningbo, China
Guest Editors:
Long Zhang and Jianrong Qiu
Available online at www.sciencedirect.com
ScienceDirect

Journal of Non-Crystalline Solids 357 (2011) 2480–2483

Contents lists available at ScienceDirect

Journal of Non-Crystalline Solids

journal homepage: www.elsevier.com/ locate/ jnoncrysol

Chalcogenide step index and microstructured single mode fibers

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ARTICLE INFO

Article history:
Received 9 July 2010
Received in revised form 1 October 2010
Available online 18 December 2010

Keywords:
Chalcogenide glasses;
Microstructured optical fiber;
Infrared single mode fiber

ABSTRACT

Chalcogenide glasses are known for their large transparency in the mid infrared, which includes the two atmospheric windows lying from 3–5 μm and 8–12 μm. Chalcogenide single mode fibers present numerous potential applications in the IR field, such as military countermeasures, LIDAR spectroscopy and spatial interferometry. Two routes can be considered for the elaboration of a single mode fiber. The first method consists in preparing a classical step index fiber (SIF) with a core-clad configuration. This procedure is based on two glass compositions (core and clad) with compatible thermal and optical properties and having a refractive index difference allowing the single mode propagation. The second route is based on the design of a microstructured optical fiber (MOF) in which the guiding function is ensured by the refractive index contrast between the core glass and the air contained in the capillaries surrounding the core. Two kinds of fibers exhibiting single mode propagation were fabricated; the first one is a SIF with a 22 μm core diameter and the second one is a three rings of holes MOF. The geometry of the MOF shows a d/Λ around 0.35 and a 40 μm core diameter. In both cases the optical losses in the 2 to 12 μm region were measured and compared.

1. Introduction

Chalcogenide glasses are known for their large transparency window and their high non linear optical properties. Indeed, they can be transparent from the visible region up to the mid infrared with an ultimate limit close to 25 μm, which depends on the glass composition [1–3]. Due to their capability of transmitting the IR light, the chalcogenide glasses present a wide interest for power transmission, remote thermal imaging as well as spatial interferometry [4]. For most of these applications, single mode waveguiding is needed. A first way consists in the preparation of classical step index fiber (SIF) with a core-clad structure [5,6]. To achieve this goal, two compositions (core and clad) exhibiting compatible thermal and optical properties and having a refractive index difference allowing the single mode propagation have to be considered [7].

The second route resides in the design of a microstructured optical fiber (MOF) in which the guiding properties are mainly defined by the d/Λ ratio (d: size of the holes, Λ: distance between the holes). Since the first manufacturing attempt in 2000 of an holey chalcogenide fiber which was not exhibiting light guidance [8], chalcogenide MOF with light propagation [9,10] and small mode area [11] have been obtained.

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doi:10.1016/j.jnoncrysol.2010.11.090

The common method to realize MOF is the stack and draw technique. This method is widely used for the silica MOF [12]. In 2008, we showed that most of the optical losses in chalcogenide fibers are due to the presence of scattering defects at the interface between capillaries [13]. So, to avoid interface defects, the MOF has been prepared by a casting method [14].

In this paper, single mode SIF and MOF at 9.3 μm were prepared. The SIF was prepared with two glass compositions having a refractive index difference allowing the single mode propagation. The MOF presents 3 rings of holes with a d/Λ ratio around 0.35 to ensure a broadband single mode behaviour. The losses of the fibers have been measured and compared between 2 and 12 μm.

2. Experimental

For the SIF, two glass compositions are needed. The glass compositions $Te_{20}As_{30}Se_{50}$ and $Te_{20.5}As_{30}Se_{49.5}$ have been chosen for the clad and the core respectively, according to the results of the refractive index measurements obtained by the minimum of the deviation method on three glass prisms having the compositions $Te_{20}As_{30}Se_{50,}$ $Te_{23}As_{30}Se_{47}$ $Te_{25}As_{30}Se_{45}$ (Fig. 1). The experimental set-up for measuring the refractive index in IR is composed of a black body source, a mono-chromator, a goniometer on which is placed the prism, and a cooled MCT detector. The accuracy on the refractive is around 1.10^{-4}.

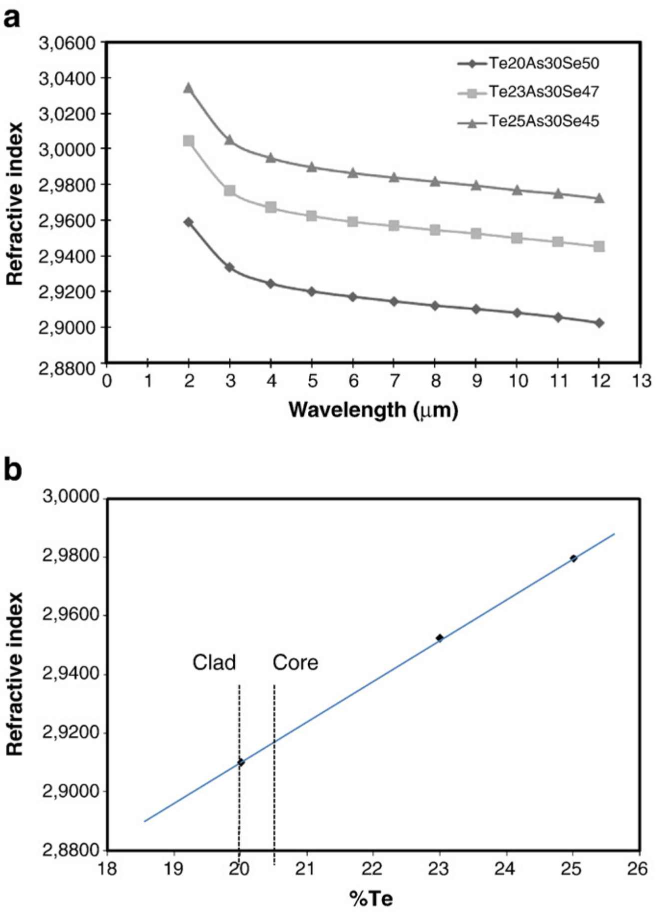

Fig. 1. Evolution of the refractive index versus wavelength for the $Te_{20}As_{30}Se_{50}$, $Te_{23}As_{30}Se_{47}$ and $Te_{25}As_{30}Se_{45}$ glass compositions (a). Evolution of the refractive index versus composition at 9 µm (b).

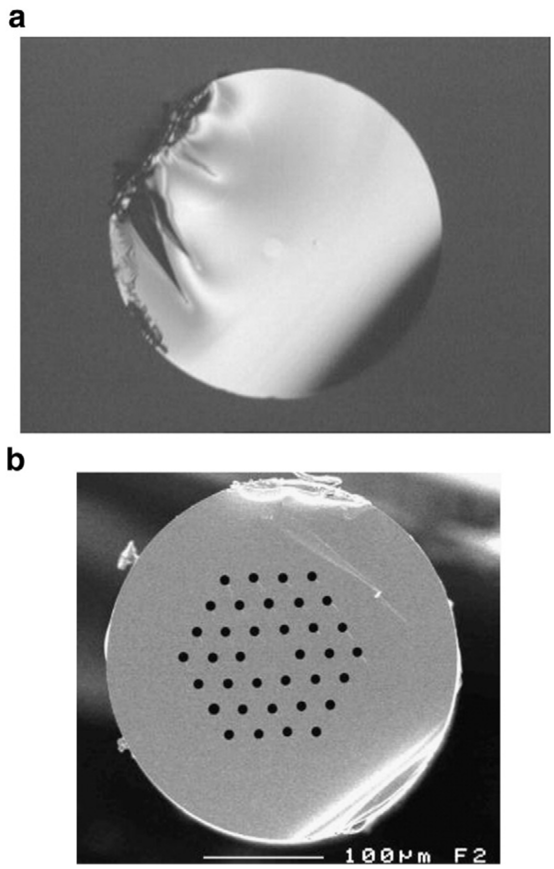

Fig. 2. Fiber cross section. (a) Step index, and (b) MOF.

The elaboration of the starting glasses includes several steps of purification by addition of oxygen getters, such as aluminium, and distillation. The classical rod in tube method was used. Cladding tubes having an external diameter of 9.9 mm and an internal diameter of 2.9 mm are fabricated by the rotational casting method. The first step consists in the elaboration of a core stick having a diameter of 2 mm. This stick is inserted in the tube and drawn on the fibering tower in order to obtain a core/clad stick with a reduced diameter. This new stick is inserted in a second tube and drawn to elaborate the core/clad fiber having a suitable diameter for single mode propagation. All the rod in tube fibering steps are run with an under-pressure between the rod and the tube in order to ensure a good quality of the interfaces and with a controlled atmosphere of He around the preforms. The final diameter of the fiber is 525 µm with a core diameter of 22 µm (Fig. 2a).

For the MOF fibers, glass samples with the composition $Te_{20}As_{30}Se_{50}$ are fabricated and purified in using the usual sealed silica tube method as described above. The methodology for elaborating the fiber is in molding a rather fluid liquid glass into a silica vessel which contains aligned silica capillaries [14]. After controlling that the liquid is feeling the empty space, the silica vessel is quenched. This operation is followed by the dissolution of the silica capillaries by an HF treatment. [14]. The mold is entirely made of silica capillaries thread into silica hexagonal guides. The silica guides are prepared by slicing a silica microstructured preform [14]. After the silica dissolution the resulting microstructured chalcogenide preform is drawn into fiber under a He controlled atmosphere. Typically the diameter of the fibers can vary from 100 to 300 µm. During the drawing step, the hole diameters are adjusted by applying a pressure into the preform holes.

This method permits to obtain various geometries. For example, the fibers can have 3 rings of holes (Fig. 2b). The core size can also be controlled, and it is possible to obtain a very small core, to exacerbate the non linear properties of the chalcogenide glass. Power delivery can also be considered with large core fibers (up to 20 µm diameter). In this study we fabricated a 200 µm-diameter fiber having a large core (40 µm). The hole diameter (d) is around 8.5 µm, the distance between the holes (Λ) is around 24 µm and therefore the d/Λ ratio is near 0.35 (Fig. 2b).

3. Results and discussion

3.1. Near field profiles

Various applications, as signal regeneration in telecommunication, interferometry, generation of supercontinuum or other non linear phenomena, require a Gaussian light propagation. In our glassy system, different designs of fibers have been studied to obtain single mode guiding.

The near field profiles are shown on Fig. 3. The set-up to obtain the near field profiles is composed of a He–Ne laser emitting at 3.39 µm or a CO_2 laser emitting at 9.3 µm and of two infrared cameras operating in the 3–5 µm and 7–13 µm range respectively. The laser beam is injected in the fiber core, and a germanium lens is placed near the output of the fiber in order to ensure a focalization on the camera sensor. The cladding modes are removed using a Ga–Sn alloy applied on the external surface of the MOF.

For the SIF, according to the core and clad refractive index values, the λ cut off is calculated at 5.8 µm. The near field capture at 9.3 µm confirms a single mode behaviour above this λ cut off.

In the MOF, the fiber is considered as a single mode fiber when the 2nd mode is not confined in the core of the fiber or if the losses of the

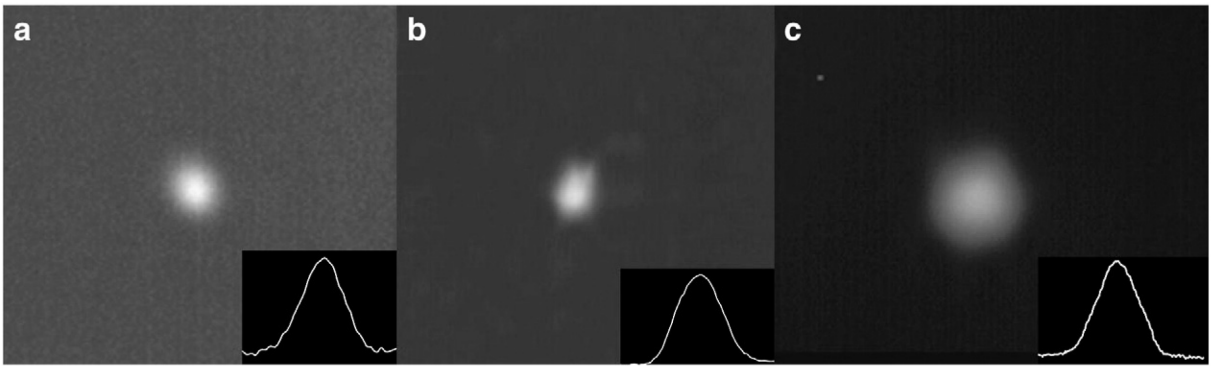

Fig. 3. Near field imaging: (a) Step index fiber at 9.3 μm, (b) and (c) MOF at 3.39 μm and 9.3 μm respectively.

second mode are much greater than the losses of the fundamental mode [15].

In this work, the MOF presents a d/Λ value equal to 0.35 corresponding to an endlessly single mode fiber. Near field images at 3.39 μm and 9.3 μm (Fig. 3b, c) confirm the Gaussian propagation of the light intensity in the fiber.

3.2. Fiber losses

The losses of the two fibers were measured by the cut back method on 2 meter-long fibers (Fig. 4). The light is injected with a FTIR Bruker and detected with a cooled MCT sensor. The injection spot size is about 1 mm². The cladding modes are removed with a GaSn alloy applied on the external surface of the fibers and the camera imaging showed that light is guided only in the core. To avoid measurement errors, several spectra for different fiber cross sections have been registered and averaged.

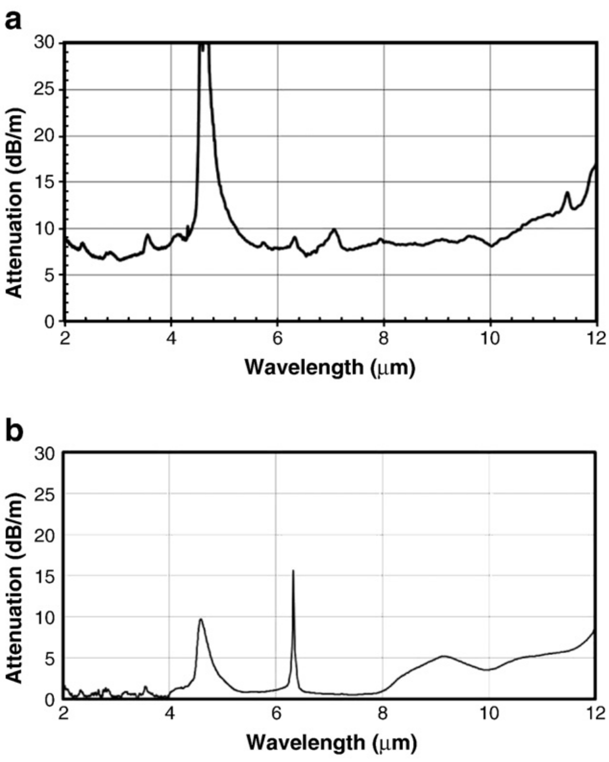

Fig. 4. Step index fiber (a) and MOF (b) optical losses.

The attenuation curves of the fibers are slightly different. The fibers present the same Se–H absorption band at 4.57 μm [16]. But the MOF presents also absorption bands at 6.3 and at 9.1 μm due to the presence of molecular water [16] and arsenic oxides [17] respectively. However, the loss background of the MOF is between 0.4 and 1 dB/m which corresponds to a single index fiber attenuation. The H_2O and As–O absorption bands can appear during the molding process if the silica mold was polluted by water. Studies have to be carried out for a better understanding of the molding process on the attenuation curve.

For the SIF, the minimum of losses reaches 6 dB/m at 3 μm. By the rod in tube technique, additional losses can be due to defects at the interface between the core and the clad, which induce light scattering. To improve the quality of the interfaces, the polishing of the rod and of the tube internal surfaces could be investigated.

Optimizations of the glass synthesis are in progress to improve the losses of the SIF and MOF, more particularly in the 8–12 infrared windows.

4. Conclusion

Transmission of high power Gaussian beams and nulling interferometry are examples of applications that can be achieved using infrared single mode waveguides. Two designs of single mode fibers were investigated: step index fiber and microstructured optical fiber. On one hand, we studied different compositions in the Te–As–Se system for the definition of two glasses having refractive indices compatible with the elaboration of a single mode SIF between 6 and 12 μm. This fiber was fabricated by the rod in tube method. On another hand, a three rings of holes MOF was fabricated by a molding method. Its d/Λ ratio equal to 0.35 allows broadband single mode behaviour. Single mode propagations were observed by near field imaging at 9.3 μm for both fibers. The Gaussian profile also observed at 3.39 μm in the MOF confirms broadband single mode properties. To our knowledge, for the first time, the broadband attenuations from 2 to 12 μm of single mode fiber cores are measured using a FTIR spectrometer.

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