3D printing of chalcogenide glasses: an original way for the elaboration of microstructured preforms and optical fibers

Julie Carcreff, François Cheviré, Elodie Galdo, Ronan Lebullenger, Antoine Gautier, Jean-Luc Adam, Laurent Brilland, Gilles Renversez, Johann Troles

3D-printing of chalcogenide preforms: a novel process for the elaboration of chalcogenide microstructured optical fibers

Julie Carcreff [a], François Cheviré [a], Elodie Galdo [a], Ronan Lebullenger [a], Antoine Gautier [a], Jean-Luc Adam [a] Laurent Brilland [b], Gilles Renversez [c] and Johann Troles*[a]

[a]Univ Rennes, CNRS, ISCR-UMR 6226, F-35000 Rennes, France
[b] Selenoptics, 263 Avenue Gal Leclerc, 35042 Rennes, France
[c]Aix–Marseille Univ, CNRS, Centrale Marseille, Institut Fresnel, UMR 7249, 13013 Marseille, France

Abstract

The elaboration of chalcogenide microstructured optical fibers (MOFs) permits to combine the mid-infrared transmission of chalcogenide glasses up to 18 µm to the unique optical properties of MOFs due to the high degree of freedom in the design of their geometrical structure. In this context, we have shown that chalcogenide preforms can be obtained by an original additive manufacturing process, and that such as-prepared preforms can be drawn into chalcogenide optical fibers. Those results open a new way for the elaboration of chalcogenide MOFs, especially for hollow-core chalcogenide MOFs

Keywords: chalcogenide glasses, microstructured optical fibers, 3D printing

I Introduction

In recent years, a growing interest has settled for optical materials and fibers for the mid infrared (mid-IR) region. This interest originates from societal needs for health and environment for instance, and also from demand for defense applications. Indeed, the mid-IR spectral region contains the atmospheric transparent windows (3-5 µm) and (8-12 µm) where thermal imaging (military and civilian) can take place. Furthermore, the infrared window is well-suited for sensing (bio)-molecules, whose fingerprints are located at wavelengths between 2 and 15 µm. The development of mid-IR transparent materials and optical fibers is essential. Chalcogenide glasses are good candidates for the realization of new and innovative mid-IR systems. In this context, chalcogenide fibers have attracted great interest in the field of versatile mid-IR fiber transmission, supercontinuum generation , and sensing [1].

An original way to obtain fibers is to design microstructured optical fibers (MOFs). Such fibers present unique optical properties thanks to the high degree of freedom in the design of their geometrical structure. The elaboration of chalcogenide MOFs permits to combine the mid-IR transmission of chalcogenide glasses to the light propagation properties of MOFs. Different methods for the realization of chalcogenide preforms and microstructured fibers have been reported, such as the stack and draw method [2], drilling method [3], extrusion processes [4] and molding method [5].

We have investigated an alternative way for fabricating complex microstructured preform by using an original 3D printing process. It has been shown recently that bulk As_2S_3 can be obtained by additive manufacturing process [6]. In the present study, we have 3D-printed a holey chalcogenide preform, and shown that this preform can be drawn into a chalcogenide optical fiber that can transmit light. The attenuation of the printed fiber will be compared to the optical transmission of chalcogenide fiber drawn from a classical melt-quenched preform.

II Elaboration of chalcogenide preform and fiber by 3D printing

1. 3D manufacturing of the preform

A new method has been investigated for producing preform for mid-IR fibers: the additive manufacturing. This method can be implemented with $Te_{20}As_{30}Se_{50}$ glass (TAS), which is very stable against crystallization. Likewise, its low glass transition temperature (T_g) facilitates its shaping at low temperature and makes it a good candidate to explore 3D printing of chalcogenide glasses

The thermal properties of TAS, i.e. T_g around 140°C and an extrusion temperature around 270-300°C are close to the ones of commercial printable polycarbonate (T_g around 140-150°C and extrusion temperature around 260-310°C). In order to manufacture TAS glass preforms, a customizable commercial RepRap-style 3D printer (Anet A8) has been modified accordingly with a copper hot end (nozzle diameter = 0.4mm) that can reach printing temperature up to 400°C and a sodalime glass bed that can be heated slightly above the TAS T_g for adhesion purpose. 400-mm long TAS rods (1.75 and 3 mm in diameter), produced by the fiber-drawing method, were utilized to supply the feeding mechanism especially customized for brittle materials. As a proof of concept of the printability of chalcogenide glass preforms, a basic tube of glass has been elaborated, at first. The material is deposited uniformly layer by layer in a continuous circular motion at constant linear speed and extrusion rate under ambient conditions. The resulting piece has an external diameter of 8.2 mm and an internal diameter of 3 mm for a height of 15mm. The tube surface is bright, suggesting that neither crystallization, nor defects are discernible to the naked eye. Only the stripes due to the different layers of the additive process are clearly visible, as can be seen in Figure 1.

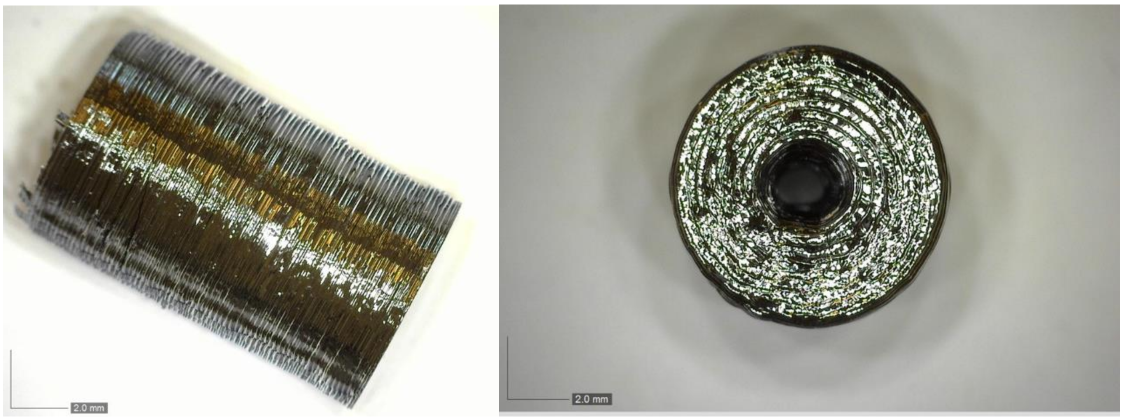

Fig 1. Photos of the chalcogenide glass hollow preform obtained by 3D printing.

2. Drawing and optical characterizations of the “printed” fiber

The printed preform has been drawn into a hollow-core fiber by using a drawing tower especially built for soft glasses such as chalcogenide glasses. Few meters long samples with an inner diameter around 70 µm and an outer diameter around 280 µm (Fig2a) have been produced. The attenuation curve of the “printed” fibers has been recorded and compared to the attenuation losses measured in the TAS glass cane used for printing the preform (fig 2b). The measured optical losses for the “printed” fiber are much higher than the initial optical losses, by nearly a factor of 4 in the 7-8 µm region. The additional losses are mainly due to scattering effects induced by the presence of bubbles (fig 2) and also water and oxygen pollution during the 3D printing that takes place in air. One can note that the initial glass used for this first attempt was not a high purity chalcogenide glass.

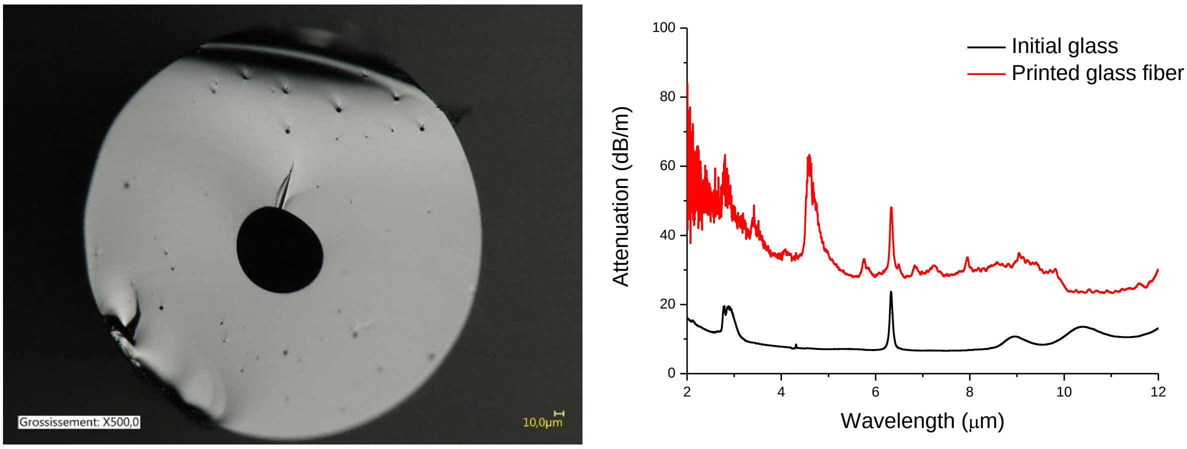

Fig 2 : 3D-printed chalcogenide hollow fiber : (a) fiber cross section, (b) : Optical loss of the chalcogenide (black) and the printed hollow fiber (red).

Those results open a new way for the elaboration of chalcogenide MOFs, especially for the preparation of hollow core chalcogenide MOFs.

References

[1] G. Tao, H. Ebendorff-Heidepriem, A. M. Stolyarov *et al.*, "Infrared fibers," Advances in Optics and Photonics, 7(2), 379-458 (2015).

[2] L. Brilland, J. Troles, P. Houizot *et al.*, "Interfaces impact on the transmission of chalcogenide photonic crystal fibres," Journal of the Ceramic Society of Japan, 116(10), (2008).

[3] M. El-Amraoui, G. Gadret, J. C. Jules *et al.*, "Microstructured chalcogenide optical fibers from As2S3 glass: towards new IR broadband sources," Opt. Express, 18(25), 26655-26665 (2010).

[4] B. Wu, Z. M. Zhao, X. S. Wang *et al.*, "Mid-infrared supercontinuum generation in a suspended-core tellurium-based chalcogenide fiber," Optical Materials Express, 8(5), 1341-1348 (2018).

[5] P. Toupin, L. Brilland, J. Trolès *et al.*, "Small core Ge-As-Se microstructured optical fiber with single-mode propagation and low optical losses," Optical Materials Express, 2(10), 1359-1366 (2012).

[6] E. Baudet, Y. Ledemi, P. Larochelle *et al.*, "3D-printing of arsenic sulfide chalcogenide glasses," Optical Materials Express, 9(5), 2307-2317 (2019).