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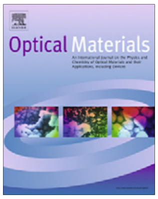

Suspended core tellurite glass optical fibers for infrared supercontinuum generation

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ABSTRACT

We report the fabrication and characterization of tellurite TeO_2–ZnO–Na_2O (TZN) microstructured suspended core optical fibers (MOFs). These fibers are designed for infrared supercontinuum generation with zero dispersion wavelength (ZDW) at 1.45 μm. The measured losses at this wavelength are approximately 6 dB/m for a MOF with a 2.2 μm diameter core. The effective area of a particular fiber is 3.5 μm^2 and the nonlinear coefficient is calculated to be 437 $W^{-1}km^{-1}$. By pumping a 20 cm long fiber at 1.56 μm with a sub-nJ femtosecond laser source, we generate a supercontinuum (SC) spanning over 800 nm in the 1–2 μm wavelength range.

1. Introduction

During the last 20 years and more especially in the recent past years, soft oxide glasses have been involved into a stimulating research process because of their strong nonlinear optical properties, which are of great interest in view of broadband infrared laser sources and potential applications in diverse areas of science and technology [1–4]. In present time, mid-IR sources are based either on optical parametric oscillators, which require large lasers and can be rather complex, costly to maintain and hard to scale up in power, or on low power quantum cascade lasers for instance. The solution to these difficulties started to appear since the first report of broadband supercontinuum generation in microstructured optical fibers (MOFs) [5]. This type of fibers generated broad interest due to their unique guidance properties, high nonlinearities and dispersion management [6,7]. The use of MOFs for supercontinuum generation is particularly attractive since tight mode confinement can be realized increasing fiber nonlinearity and because the zero-dispersion wavelength (ZDW) can be tailored to optimize supercontinuum generation for a given pump wavelength [3,8].

At the same time we observe the development of new materials that combine desirable thermo-mechanical properties with good optical quality that are necessary conditions in order to get high performance lasers. Lots of works on glass composition have been reported in silicate, borate and phosphate glasses, but tellurite glasses deserve the greatest interest due to their potential for nonlinear optical devices. Wang et al. have established a detailed comparison of tellurite, silica, fluoride and chalcogenide glasses properties [9], Snitzer et al. have presented the compositions of glasses for fibers fabrication [10] and numerous glass compositions [11–13] have been developed for nonlinear optics.

Our goal is to acquire a good control of tellurite MOF fabrication and of their nonlinear optical properties for the development of efficient broadband laser sources in the mid-IR. We report here our first attempt in that field. We have fabricated tellurite MOFs from TZN glass and have carried out their optical characterizations. Robust guidance at 1.55 μm was confirmed by optical measurement. We have then used a femtosecond (fs) pulsed laser at 1.56 μm to pump a tellurite fiber presenting a ZDW around 1.45 μm and an attenuation of 6.3 dB/m at 1.55 μm together with a quite small effective mode area (A_{eff}) of 3.5 μm^2. By pumping a 20 cm long sample of this fiber, we observed an infrared supercontinuum generation expanded over 800 nm between 1 and 2 μm.

2. Experimental

2.1. Glass preparation

Tellurite bulk glass preforms were prepared using the following raw materials: tellurium (IV) oxide (Alfa Aesar, 99.99%), zinc oxide

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(Alfa Aesar, 99.99%), sodium carbonate (Alfa Aesar, 99.99%). At this stage of our synthesis process, no additional in-house purification procedures were employed to reduce moisture or to eliminate trace levels of contaminants remaining in the commercial raw materials. Mixed batches were melted in platinum crucibles at 875 °C for 1 h, in an adequate ratio of raw materials corresponding to the molar composition 80% TeO_2, 10% ZnO, 10% Na_2O (TZN). We have chosen this composition because it shows a good potential for the drawing of nonlinear optical fibers [14]. In order to improve the homogeneity of the obtained glass, a stirring operation was carried out by opening the furnace and shaking the crucible during the glass melting process. The melts were poured in a brass mould preheated at 190 °C and subsequently annealed at approximately the glass transition temperature (T_g) for 8 h. Note that all the synthesis process was realized in room atmosphere. The glass samples were then cooled down slowly to room temperature. A typical batch weight was 70 g. The obtained glass rods preforms were typically 7 cm long for a diameter of 16 mm. These preforms were polished in view of fiber drawing. Small cylindrical slices were taken from them as spectral measurements samples.

2.2. Thermal and optical properties of the glass

Differential scanning calorimetry (DSC Q20 V24.4 Build 116) was used to determine the glass transition temperature T_g and the crystallization onset temperature T_x of the vitreous samples. The DSC curves were recorded in the 20–475 °C range at a constant heating rate of 10 °C/min, in N_2 atmosphere and at a constant gas flux of 50 ml/min. Approximately 10 mg of fine grain sample were used for measurements.

Four millimeter thickness slices were cut in the glass preforms and optically polished. The absorption spectra of the glasses were recorded at room temperature using an UV–VIS–NIR spectrophotometer (Perkin–Elmer Lambda 900) in the 200–1350 nm spectral range and a FTIR spectrophotometer (Perkin–Elmer Spectrum One) in the 1300–6700 nm range.

2.3. Fiber design

The aim of our investigation was to get a tellurite MOF able to generate an infrared supercontinuum. For that purpose, we experimentally pumped the fiber near its zero dispersion wavelength (ZDW) by means of a fs pulsed source at 1.56 μm. Thus it appeared necessary to downward shift the ZDW of the glass close to the pump wavelength with the help of an adequate MOF profile for which the waveguide dispersion is able to compensate for the material dispersion. Such a control of the chromatic dispersion can be obtained using two kinds of MOF profiles: the conventional one, based on a triangular lattice of holes and the suspended core one [15]. The former design requires many rings of air holes around the core to get guiding losses below material ones, even for high index glasses [16]. This implies a more complex preform fabrication and handling. Thus the suspended core profile was more suitable to reach our objective. Note that the dispersion slope of MOFs with large size air holes (much larger than the fiber core diameter) is larger than the dispersion slope of MOFs with small size air holes [17]. So, in this work, we have targeted tellurite MOFs with small air holes to reduce the dispersion slope in order to get a quite flattened SC [18].

2.4. Fiber fabrication

The fabrication of soft-glass microstructured optical fibers is a difficult process due to the narrow working temperature range and because of the necessity to realize a microstructured preform [19]. Very often, the stack-and-draw technique is used for that purpose. But this fabrication way presents many disadvantages and can lead to a poor optical quality of the microstructured preform. Typically, if we use the stack and draw procedure for a tellurite MOF fabrication, we encounter a glass surface degradation caused by handy manipulations, and the occurence of interstitial holes [20]. Thus, other techniques for tellurite MOFs fabrication have been developed by different research groups [21]. Here we have chosen an alternative technique that we have already successfully used for chalcogenide glass MOFs fabrication, and more precisely for the drawing of chalcogenide suspended core fibers [15,22]. Indeed, after annealing, the glass rod undergoes a mechanical machining in order to get three 0.8 mm diameter and 30 mm length holes surrounding a solid core (Fig. 1).

The prepared preforms were then drawn into fibers following the usual way. Many parameters were controlled during this process, such as preform temperature and translation speed, fiber drawing speed, pressure in the holes and flow rate of inert gas circulating along the preform. By selecting suitable sets of parameters, we could vary core, outer and holes diameter and obtain a complete control of fiber profiles. After fiber drawing, we have taken some pictures of the fibers core-sections with the help of a scanning electron microscope (SEM), in order to check the geometrical parameters of the fibers. Sections of several MOFs drawn from the preforms obtained using our mechanical machining technique are shown in Fig. 2a. These pictures allowed measurement of the core diameters, defined as the diameter of the circle inscribed in the triangular core. The fibers external diameters were around 85–130 μm and core diameters varied within the range from 1.5 to 3 μm.

3. Results and discussion

3.1. Thermal and optical properties of the glass

To be considered as a suitable candidate for fiber drawing, the glass must have a good thermo-mechanical resistance to casting and a good stability against crystallization. This resistance to crystallization can be estimated by measuring the bulk glass thermal properties, its glass transition temperature T_g and its crystallization temperature T_x. The difference between these values, $\Delta T = T_x - T_g$, provides a gauge of the glass resistance to crystallization, and should be as large as possible to ensure that the glass will form

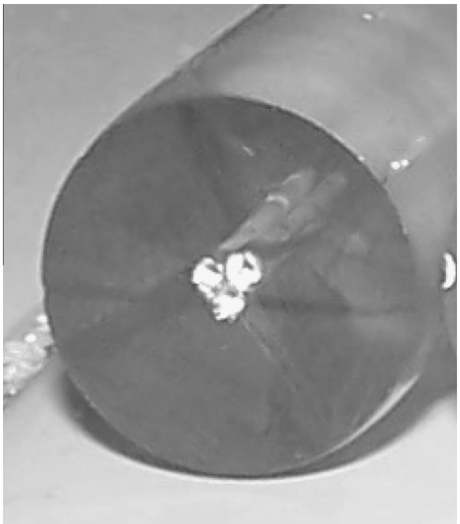

Fig. 1. Picture of a 16 mm outer diameter tellurite glass preform with three air holes around a solid core elaborated by mechanical manufacturing.