A spliced and connectorized highly nonlinear and anomalously dispersive bismuth-oxide glass holey fiber

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Abstract: We demonstrate the operation of a small core, connectorized bismuth-oxide glass holey fiber. The splicing losses achieved were improved relative to butt-coupling by 0.9 dB.

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Bismuth-oxide-based glasses are attractive materials for fiber devices. They exhibit a high nonlinearity and can be used for the implementation of extremely broadband and compact erbium-doped amplifiers. They do not contain any toxic elements and bismuth-oxide-based fibers can be fusion spliced to silica fibers [1]. They also exhibit a low melting temperature, which allows the application of extrusion techniques for the fabrication of holey fiber (HF) preforms. We have recently demonstrated the fabrication of a small-core bismuth-oxide glass extruded HF (Bi-HF) exhibiting an extremely high nonlinearity [2]. In this work we present the progress we have achieved on splicing Bi-HF to silica patchcords to make practical fiber-connectorized devices. Splicing is shown to improve the fundamental mode excitation in multi-mode small core structures relative to free-space coupling. We demonstrate significant spectral broadening and higher-order soliton effects at 1550 nm in a short connectorized section of Bi-HF which shows that such fibers can possess anomalous dispersion at these wavelengths despite the large normal dispersion of the bulk material.

The fiber design we used is similar to previous designs we have successfully used for other compound glass extruded HFs [3]. The small core is supported by three fine struts, each ~5 μm long. In this work we used a Bi-HF with a core diameter of 2.0 μm and a loss of 3.0 dB/m, a significant improvement relative to our previously reported fibers in Ref. [2]. The combination of the small core and the high refractive index of this glass ($n = 2.02$ at 1550 nm) result in an extremely small effective mode area A_{eff}. In order to reduce the losses when splicing this fiber to a silica SMF28 patchcord, we used two intermediate buffer stages to reduce the overall mode-mismatch loss. The Bi-HF itself was spliced to a silica fiber with $A_{eff} \approx 14 - 15$ μm^2. High quality cleaving of the Bi-HF was achieved using a conventional mechanical cleaver with tension control. An SEM of the cleaved facet of the Bi-HF is shown in Fig.1a. Due to the much lower melting temperature of the Bi-HF relative to the silica fiber, very small values for the fusion time and current were used. The splices achieved were mechanically strong, especially with respect to applied strain in the axial direction (Fig.1b). After splicing the coupling losses between the two fibers were reduced by 0.9 dB relative to simple butt-coupling. Although the total splicing losses achieved to date are still quite high - 5.8 dB - they can largely be accounted for by individual mode-mismatches at the various buffer fibers interfaces (minimum 3.8 dB, without taking into account the mismatch in the mode shape) and an additional 0.1 dB due to Fresnel reflection at the Bi-HF:silica interface. There is considerable scope for reducing the Fresnel reflections using accurately controlled angled cleaves at the silica:Bi-HF splice [1]. We also expect that the introduction of an additional silica HF-based buffer stage will help to considerably further reduce the mode mismatch.

It is theoretically predicted that this Bi-HF should support more than one mode at 1550 nm and indeed evidence of this fact was observed in earlier free space coupling experiments of this fiber. An IR image of the far end of the connectorized Bi-HF when laser pulses at 1558 nm were fed onto it showed that only the fundamental mode was excited (Fig.2). The image also shows the triangular mode shape, characteristic of this structure. We used a 1.4 m connectorized Bi-HF piece to study the nonlinear dynamics of the fiber. ~2.5 ps soliton pulses at 1558 nm with a 2.5 GHz repetition rate were generated from a mode-locked erbium-fiber laser. The pulses were amplified and coupled onto the Bi-HF. As we increased the average power to a maximum of 300mW at the Bi-HF input we observed significant spectral broadening due to self-phase modulation, which extended mainly to the longer wavelengths as higher-order soliton effects came into play. This allowed us to conclude that the fiber is anomalously dispersive at these wavelengths as anticipated from previous modeling [2]. We consider the connectorization of high nonlinearity compound glass holey fibers to be a significant development since it greatly enhances the practicality and range of potential uses of this exciting new technology.

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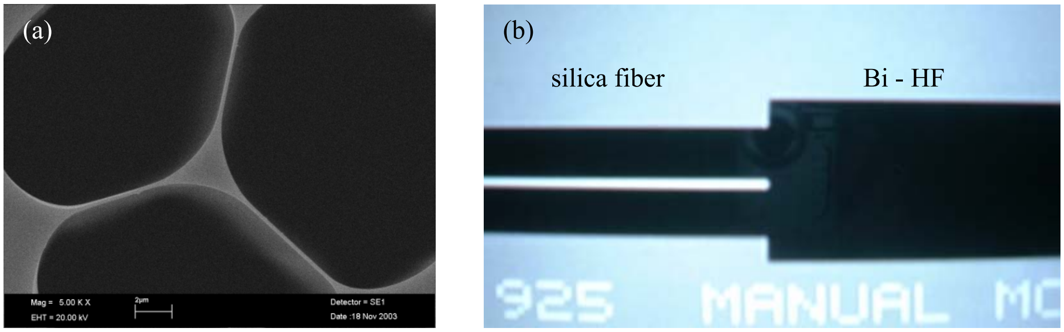

Fig. 1 (a) Mechanically cleaved end of the Bi-HF; (b) Microscope image of the silica fiber to Bi-HF splice.

Fig. 2 IR image of the near-field pattern of the connectorized Bi-HF.

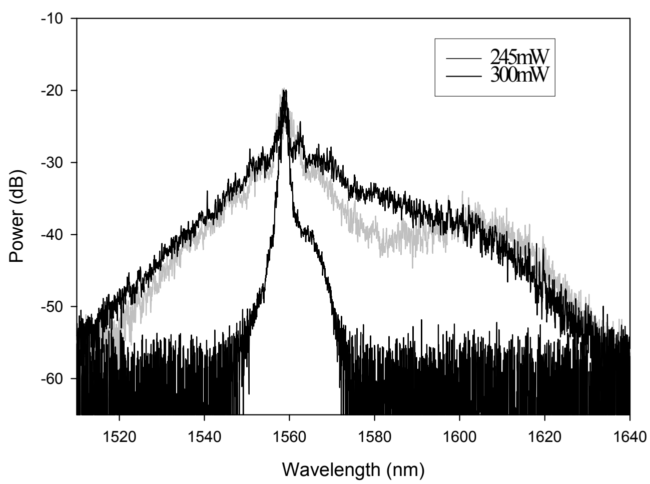

Fig. 3 Spectrum traces at the output of the 1.4 m of Bi-HF for two values of average input pulse powers. The spectrum of the incoming amplified pulses is also shown for reference.

References

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