An SMS fiber structure based on chalcogenide multimode fiber

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Abstract

We theoretically and experimentally investigate a singlemode-multimode-singlemode (SMS) structure based on chalcogenide (As_2S_3) multimode fiber and conventional silica singlemode fibers. The experimental results show a general agreement with the numerical simulation results based on a wide angle-beam propagation method (WA-BPM). The chalcogenide fiber and silica fibers were mechanically spliced and packaged using a UV cured polymer with a low refractive index on a microscope slide. Multimode interference variation was observed by photo-induced refractive index changes resulting from both a localized laser irradiation at a wavelength of 405 nm and a UV lamp. Our result provides a platform for the development of compact, high-optical-quality, and robust photonic nonlinear devices.

Keywords: Fiber optics, Multimode interference, Nonlinear fiber, Photosensitivity

1. INTRODUCTION

Multimode interference (MMI) has been intensively investigated in photonic integrated waveguides and the unique performance of self-imaging of the input light field is well known and widely employed in beam splitters, combiners and multiplexers for optical communications [1-3]. Recently, multimode interference occurring in a single-mode–multimode–single-mode (SMS) fiber structure has been studied for applications in novel optical devices, e.g., displacement sensor [4], stain and temperature sensor [5], refractometer sensor [6] and edge filter for wavelength measurements [7]. These optical devices, based on such an SMS fiber structure, offer all-fiber solutions for optical communications and optical sensing with the advantages of ease of packaging and connection to optical fiber system.

Chalcogenides are rapidly establishing themselves as technologically superior materials for emerging applications in non-volatile memory and high speed switching [8] and have been considered for a range of other optoelectronic technologies. Chalcogenide glasses offer a wealth of attractive properties such as exceptionally high nonlinearity, photosensitivity, ultrafast nonlinear response, a low phonon energy matrix, the ability to be doped with active elements including lanthanides and transitional metals and the possibility to form detectors, lasers and amplifiers. Unlike any other optical material, they have been formed into a multitude of shapes, including optical fibers, thin films, bulk optical components, microsphere resonators, metamaterials and nanoparticles, patterned by CMOS compatible processing at the sub-micron scale. To date, applications including ultrafast all-optical switching, supercontinuum generation, broadband

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wavelength conversion, all-optical signal processing, ultrafast pulse characterization and Raman fiber lasers have been demonstrated extensively using chalcogenide glass fibers [9-11].

In this paper, we present an investigation of light propagation within an SMS fiber structure based on chalcogenide and silica fibers, which has not been addressed so far in the literature. The chalcogenide fiber based multimode interference device is fabricated and packaged by using UV curing. Due to the photo-induced refractive index changes in the chalcogenide glass material, the spectral response achieved for multimode interference also varies with both power and irradiation position for a localized laser irradiation with a maximum output power of 10 mW at a wavelength of 405 nm. The peak shift of the spectral responses of 2 nm has been realized and we also achieved a power variation at 1565.4 nm as high as 8.94 dB depending on different localized laser irradiation positions along the chalcogenide fiber. The fabricated device offers the potential for low-cost, robustly assembled fully integrated all-optical switching and tunable filter devices due to its unique high nonlinearity and ease of fabrication.

2. THEORETICAL ANALYSIS

An SMS fiber structure consists of input and output silica singlemode fibers with a short section of multimode fiber sandwiched between them as shown in Fig. 1. A chalcogenide multimode fiber section was sandwiched between two standard silica singlemode fibers and forms a typical fiber multimode interferometer.

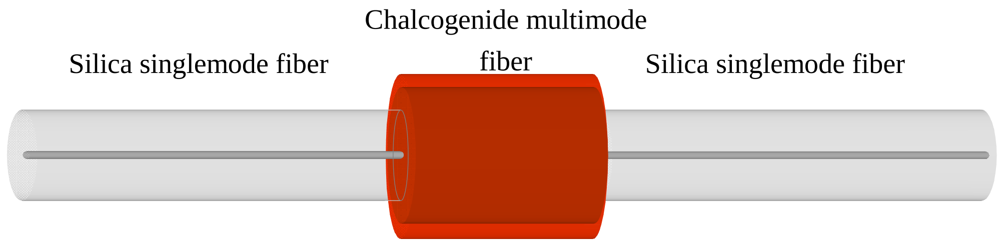


Figure 1. Schematic of an SMS fiber structure based on silica singlemode fiber-chalcogenide multimode fiber-silica singlemode fiber.

Based on the numerical models using a WA-BPM presented in [12], Fig. 2 (a) and (b) present the amplitude distributions of the propagating optical fields and the corresponding coupling loss to the output singlemode fiber as a function of propagation distance for the MMI device. From Fig. 2 (a) and (b), one can see that the first significant multimode interference for the numerical sample of MMF occurs when the propagation distance is longer than 10 mm and the coupling loss reaches a maximum value of -50 dB at a propagation position of Z=18.91 mm. The calculated results show that the eigenmode interference within the MMF section is determined by both the size and the refractive index of the MMF core.

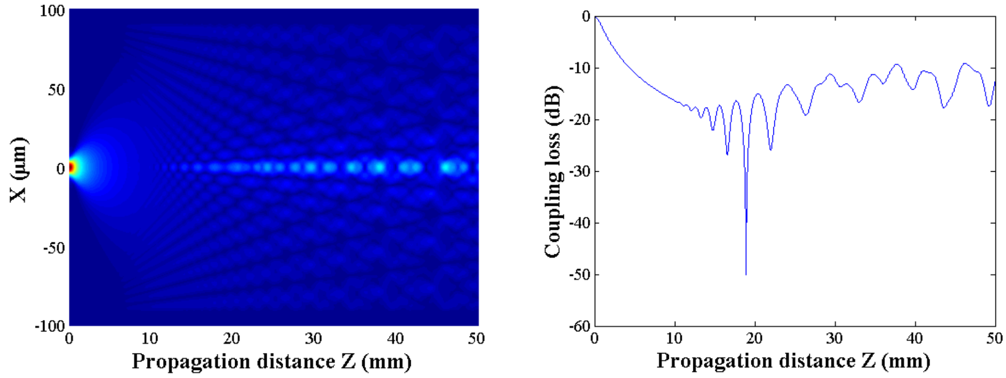


Fig. 2. (a) Light propagation within the chalcogenide multimode fiber; (b) Calculated coupling loss to output singlemode fiber for different chalcogenide multimode fiber lengths when the wavelength of input light is 1550 nm.

3. EXPERIMENTAL RESULTS AND DISCUSSION

The chalcogenide fiber used in the experiments is a commercial step-index multimode fiber provided by Oxford Electronics, with an As_2S_3 core (OD=180 μm) and As_xS_{1-x} cladding of lower refractive index (OD=275 μm). The chalcogenide multimode fiber cross section is shown in Fig 3.

Fig. 3. Microscope image of chalcogenide multimode fiber cross section.

The SMS sample was manufactured by sandwiching the commercial chalcogenide multimode fiber between two silica single mode fibers (SMF). The fiber cores were aligned using 3D translation stages, and alignment was fixed by embedding the fibers in UV curable polymer with a low refractive index. Figure 4 shows the resulting hybrid SMS structure manufactured from a 48.4mm long chalcogenide multimode fiber packaged on a microscope slide. The transmission spectra of the fabricated hybrid SMS device were then recorded using a broadband Erbium Doped Fiber Amplifier (EDFA) source (1520~1570 nm) and an optical spectrum analyzer (YOKOGAWA AQ6370).

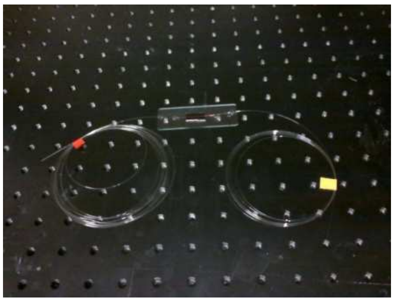
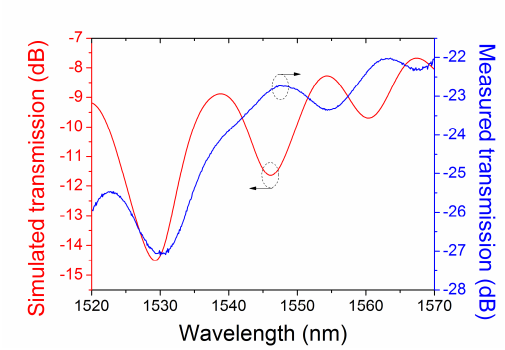
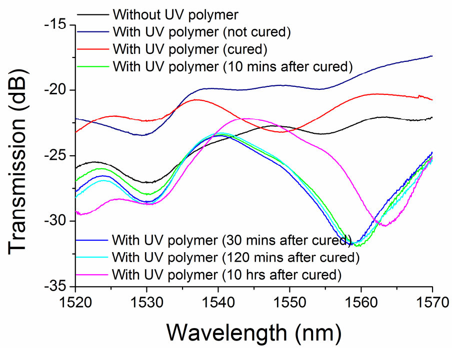


Fig. 4. Image of a chalcogenide multimode fiber with a length of circa 48.4 mm sandwiched between two silica singlemode fibers and packaged on a microscope slide.

Figure 5 (a) presents the calculated and measured transmission spectra of the hybrid SMS structure: the measured insertion loss is circa -13 dB. Results show a general agreement with theoretical predictions. The discrepancy between the calculated and measured results could be due to both the alignment between SMFs and MMF and the approximations made in the calculation (simulated transmission for an SMS includes some approximations, such as the Padé (3, 3) approximate operator). In order to demonstrate the stability of the SMS fabricated, Fig. 5 (b) presents the transmission spectra of SMS device as they vary with time before/after the UV glue curing process. The changes in the transmission spectra are due to the temperature change and further curing of the polymer glue.



(a)



(b)

Figure 5. (a) Calculated and measured spectral responses of the hybrid SMS device over a wavelength range of 1520~1570 nm; (b) change in the SMS transmission spectra before/after UV glue curing.

It is well known that a chalcogenide glass has a high photosensitivity, and thus its refractive index can vary with external laser irradiation. Therefore the spectral response achieved from the multimode interference within the SMS device can also vary with a laser irradiation. To demonstrate this effect, the chalcogenide MMF were irradiated and scanned by a localized CW laser with a maximum output power of 10 mW and operating wavelength of 405 nm. The laser spot size on the chalcogenide MMF was estimated to be circa 7×10^{-4} cm^2, providing an irradiation intensity of 1.43×10^4 mW/cm^2. The resulting changes in the transmission spectrum were monitored by the OSA in real time. Fig. 6 shows that the spectral response red-shifts by 2 nm and power variations as high as 8.94 dB at λ=1565.4 nm were observed for different localized laser irradiation positions along the chalcogenide fiber. The entire chalcogenide MMF was then irradiated by a UV lamp (Hamamatsu L9588-02A, wavelength range: 240-400 nm) with an average output power of 410 mW/cm^2. Fig. 6 shows that significant changes of the SMS spectrum occur and a power variation at 1563.3 nm as high as 7.57 dB can be achieved.

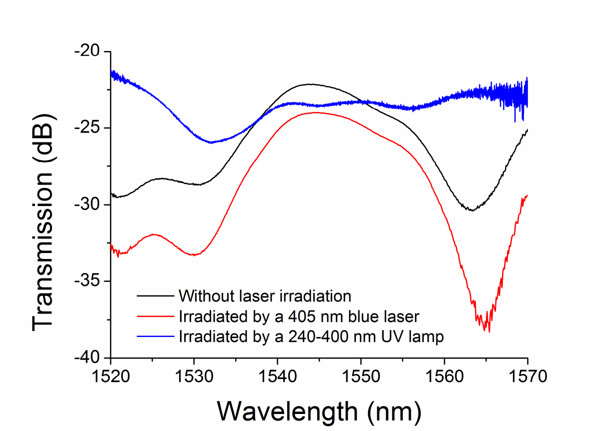


Figure 6. Transmission spectra of the chalcogenide SMS device before/after irradiation by a 405 nm laser and a UV lamp.

4. CONCLUSION

In conclusion, as a first proof of concept, we have proposed and demonstrated a chalcogenide MMF based SMS structure. An acceptable agreement between the experimental characterization and numerical simulation of the structure has been realized. Due to the high photosensitivity of the chalcogenide glass material itself, the chalcogenide SMS structure can be utilized to form a range of functionalities over near- and mid-IR wavelength ranges, such as tunable filter and all-optical switching fiber device. This geometry may also be considered as a promising platform for linear signal processing devices with thresholds orders of magnitudes lower compared to conventional silica based fiber devices.

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