Optics & Laser Technology 44 (2012) 1186–1189

Contents lists available at SciVerse ScienceDirect

Optics & Laser Technology

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

Microfiber Mach-Zehnder interferometer embedded in low index polymer

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ARTICLE INFO

Article history:
Received 11 July 2011
Received in revised form
29 September 2011
Accepted 29 September 2011
Available online 1 November 2011

Keywords:
Microfiber
Microfiber devices

ABSTRACT

Microfiber Mach Zehnder Interferometer (MMZI) is demonstrated by micromanipulating an optical microfiber drawn from a single mode fiber (SMF) using a flame brushing technique. The MMZI shows good interference fringes with an extinction ratio of 13 dB and a free spectral range (FSR) of 0.52 nm at 1530 nm. The MMZI is then embedded in a polymer with the refractive index of 1.36 to increase the stability and robustnes of the device. It is found that the transmission spectrum of the packaged MMZI is changed by the polymer, which increases the FSR to 0.83 nm. The degradation in transmission loss and extinction ratio are attributed to the disturbance at the coupling area during the packaging. Compared with waveguide based mach zehnder interferometer, the proposed MMZI is favoured due to easy fabrication, compact size, and easy integration with the fiber system.

1. Introduction

Mach–Zehnder interferometer (MZI) as a typical optical interference structure has attracted considerable interest in the past years for a wide range of applications. Sensors and modulators based on MZI have long been demonstrated due to its phase sensitivity to the refractive index change of the waveguide and/or its surrounding medium [1,2]. Add–drop filters have also been realized using cascaded MZIs for optical communications [3]. MZI can be fabricated based on numerous techniques such as lithographic planar waveguides [4] and all- fiber configuration based on fiber couplers [5].

Recently, optical microfibers have been demonstrated and used as low-loss optical waveguides with a high fractional evanescent field, which enables strong coupling between a microfiber and its environment or another adjacent microfiber [6]. With the development of optical microfibers and nanofibers, evanescent-coupling-based devices such as optical couplers, loop interferometers, resonators, filters, lasers, and sensors have been developed [7–11]. In the previous work, Li and Tong [12] demonstrated a Microfiber based MZI (MMZI) using optical microfibers drawn from silica fibers and tellurite glasses, which were attracted on the MgF_2 substrate. In this paper, an MMZI is demonstrated by micromanipulating a microfiber drawn from a single mode fiber (SMF). The microfiber used was drawn from a single mode fiber (SMF) using a flame brushing technique. Compared with other implementations, the proposed MMZI is featured with easy fabrication, compact size, and easy integration with the fiber system. The fabricated MMZI is then embedded in a low index polymer for robustness. The effect of replacing the surrounding air by the polymer is investigated. This packaging technique is more robust compared to Ref. [12]. It implies also a lesser structural fragility.

2. Fabrication procedures

The silica microfiber was fabricated by drawing of a single-mode fiber using flame brushing technique. Fig. 1 shows the apparatus of the experimental setup where a coating stripped standard SMF was placed horizontally on the translation stage and held by two fiber holders. One of the fiber holders was held on a movable stage with a controllable stepper motor to stretch the fiber. The oxy-butane torch was fixed on another motorized stage, so that it moves in specified pattern along the uncoated segment of fiber while the fiber is being stretched. The moving torch provides a uniform heat to the fiber so that the microfiber is produced with good uniformity along the heat region. To monitor the transmission spectrum of the microfiber during the fabrication, wideband amplified spontaneous emission (ASE) source from an Erbium-doped fiber amplifier (EDFA) was injected into one end of the SMF while the other end was connected to the optical spectrum analyzer (OSA).

To construct an MMZI, a bi-conical microfiber with a uniform waist diameter was first fabricated. Fig. 2(a) and (b) shows the microscopic view of un-tapered fiber and tapered microfiber, respectively. The fabricated microfiber has length of 60 mm with a diameter of around 2 μm and a measured transmission loss of

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doi:10.1016/j.optlastec.2011.09.032

0.061 dB/mm. This microfiber was cut and separated into two equal parts. Using tweezers, the left part was vertically bent while the right part was stretched straight horizontally and coupled to the left part. The left arm was then manipulated under a microscope using tweezers with the help of van der Waal and electrostatic forces to construct the MMZI. By careful micromanipulation, two evanescent couplers between two microfiber parts can be formed, resulting in the microfiber assembled MMZI.

3. Embedding the MMZI in polymer

MMZIs are particularly simple in construction, but when directly surrounded by the air they are strongly affected by perturbations such as vibrations or dust. Moreover the physical structure of the device is rather fragile such that it can be easily broken especially at the coupling points adjoined together solely by the electrostatic or van der Waal force. Applications of the MMZI only can be accomplished at the fiber station, as it is impossible to move the sensor around due to its fragile nature. In this work, the fabricated MMZI was embedded in a low index polymer to alleviate this problem. This has allowed sensing through the evanescent field without direct contact with the liquid [13]. The polymer used is a commercially available 100% UV curable optical fiber cladding polymer solution (UV-OPTI-CLAD), which has a refractive index of 1.36 and a viscosity of 1800 cPs at room temperature. In the embedding process, firstly, a small piece of glass was covered with a drop of polymer resin having a refractive index of 1.36 at 1.5 μm. This refractive index is slightly smaller than that of the silica, which is about 1.42. The use of smaller refractive index is important to maintain the total internal reflection condition inside the microfiber. Then, the MMZI structure was placed over the polymer liquid layer and covered by another drop of uncured polymer resin. The thickness of the polymer is approximately 0.5 mm, which is thick enough to prevent leakage of optical power from the device to the glass plate. It is essentially important to ensure that minimum air bubbles and impurity are trapped around the MMZI area in the polymer. This is to prevent refractive index non-uniformity in the surrounding of MMZI that may introduce loss to the system. The polymer was then cured for about 5 min with a UV lamp. Finally, the embedded MMZI was sandwiched by another glass plate from the top followed by the application of the second UV curing process. As a result, the MMZI was fully embedded in a hard polymerized matrix. In this work, the effect of replacing the surrounding air by the polymer is investigated and the focus is on the spectral response of the MMZI.

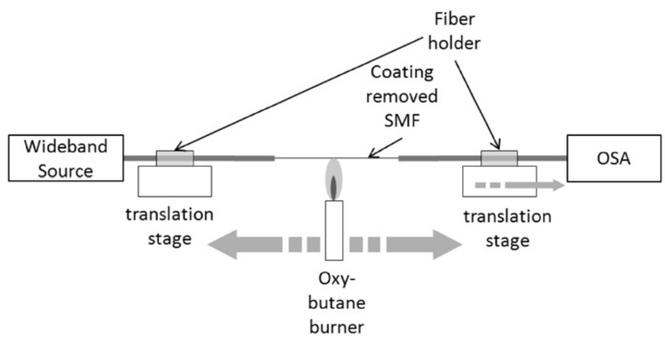

Fig. 1. Microfiber fabrication setup.

4. Result and discussion

Fig. 3 shows an optical microscopic image of the fabricated MMZI before embedding it in a low index polymer. The overlapping lengths of the two couplers can be tuned using micromanipulation under an optical microscope. Broadband light from ASE source is

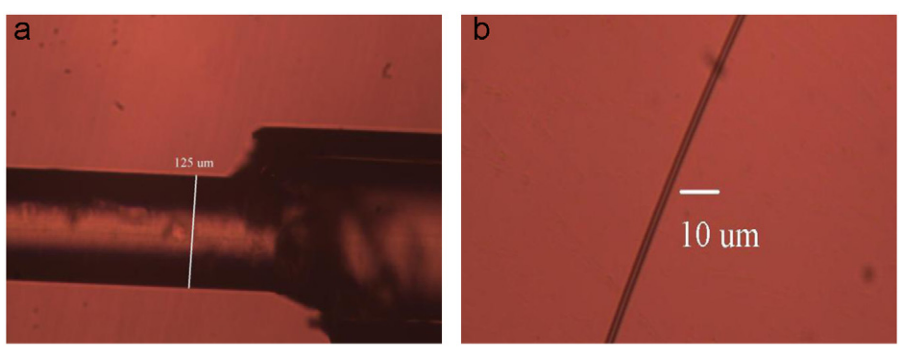

Fig. 2. Optical microscope image of (a) the stripped un-tapered fiber and the fabricated microfiber.

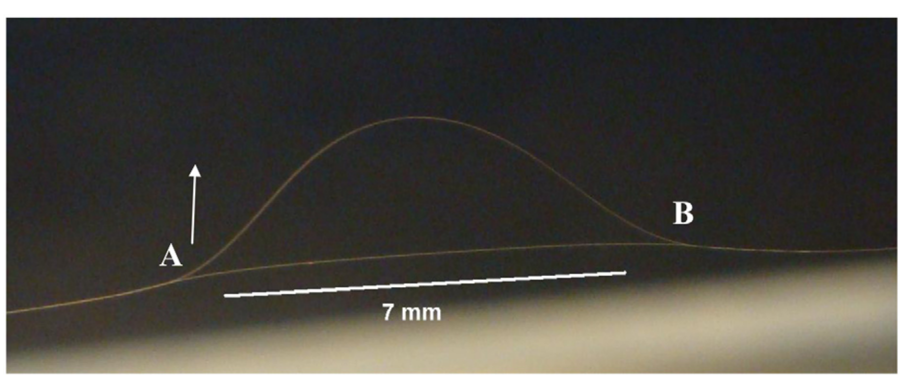

Fig. 3. Unpackaged MMZI structure fabricated using a flame brushing technique.