Experimental and theoretical analysis of side-polished fiber optofluidic variable attenuator

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ABSTRACT

We report a broadband variable optical attenuator employing a side-polished single-mode optical fiber placed on an electrowetting-on-dielectric (EWOD) platform. Both experimental and theoretical analysis has been applied to this system. Experimentally, a maximum attenuation of 25 dB was obtained in the wavelength range between 1520 nm and 1560 nm. This compares to a predicted maximum theoretical attenuation of 28 dB.

INTRODUCTION

Single-mode fiber (SMF) variable optical attenuators (VOAs) are one of the most important elements in fibre optic communication networks[1]. To date, nearly all VOA are MEMS types device, that use moving fibers[2], shutters[3] and mirror[4] to attenuate the optical signal. Very few examples of optofluidic VOAs have been reported. One of example is a tunable microfluidic device consisting of an electrowetting-on-dielectric (EWOD) pump combined with a long period grating (LPG)[5], it is a narrowband VOA, with attenuation of 20 dB at the LPG resonant wavelength peak of 1538 nm, and a FWHM of 10 nm. A different type of optofluidic VOA was presented by Reza and Riza[6] that is a lensed fibre gap device with a variable focus liquid lens in the gap. The achieved attenuation was up to 40 dB. In this paper, we report a theoretical analysis of our optofluidic VOA based on a side-polished single-mode optical fiber placed on an electrowetting-on-dielectric (EWOD) platform, and demonstrate an improvement in performance from 14 dB previously reported[7] to 25 dB.

DEVICE OPERATION

An in-line fibre optic broadband VOA may be constructed using a side-polished SMF attached to a dielectric platform (Fig.1a). The platform is designed to translate a fluid droplet along the polished surface of the fibre using electrowetting actuation. The position of discrete 2 μL and 0.3 μL volume droplets on the polished surface determines how much light can be coupled out from the fibre. As illustrated in Fig 1b, if the droplet position is moved closer to the core (from 1 to 3), transmission through the fibre will progressively decrease if the fdroplet has refractive index close to the core index.

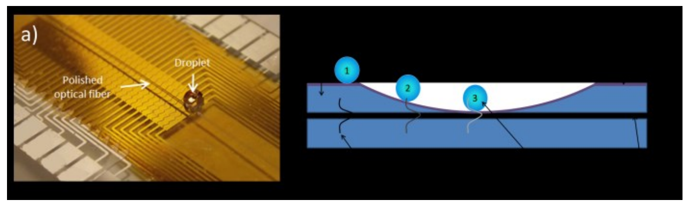

Figure 1. a) Variable optical attenuator formed from a side-polished fiber mounted on an EWOD platform. b) Illustration of the topology of a side-polished fiber

THEORETICAL MODULATION

A theoretical analysis was carried out to estimate how the guided optical power in a polished fiber will change according to changing cladding thickness, refractive index of the droplet, and the size of the interaction length of the polished region and the droplet. The output power P_{out} of the polished fiber can be related to the input power P_{in} by[8]:

$$\frac{P_{out}}{P_{in}} = R^{\eta z}$$

where R is reflectivity, η is the number of reflections at the upper boundary per unit length, and z is the propagation direction (Fig. 2). The reflectivity depends on the refractive index of the core, cladding and surrounding medium and, critically, on the remaining cladding thickness[9].

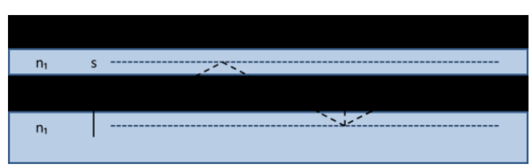

Figure 2. Schematic of the ray optics approach applied to a side-polished optical fiber.

EXPERIMENTAL CHARACTERISATION

A square waveform of amplitude 180 volts was sequentially applied to the electrodes which translated glycerine-water solution droplets along the polished region of the fiber. A light source (EDFA) and an Optical Spectrum Analyser (Agilent 86140B) was used as a photoreceiver. Two fibers were tested. Fiber 1 was a commercial side-polished fiber from Phoenix Photonics Ltd (UK). In comparison fiber 2 was fabricated in-house to less remaining cladding. The 2 μL droplets had a measured 1.2 mm interaction length with polished region and three different refractive indexes were used (1.4596, 1.4602, 1.4606). The smaller droplet of 0.3 μL had an interaction length of 0.6 mm and a refractive index of 1.4596. For the fiber 2 the experiment was limited to the one size of the droplet of interaction length of 1.2 mm but two different refractive indexes. It can be seen from figure 3 that the size of the droplet has significant influence on the results. If the interaction length decreases by half the attenuation will decrease from 7 dB to 4 dB.

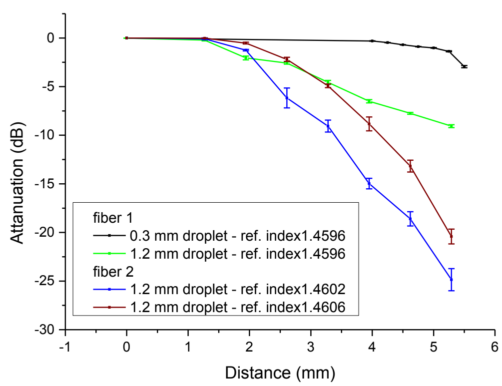

Figure 3. Experimental results for different refractive index and size of the droplet.

A theoretical analysis was performed using the physical parameters of the experiments, and is shown in figure 4. By comparing figures 3 and 4 it estimated that the remaining cladding thickness of fiber 1 and 2 were approximately 300 nm and 130 nm repectively. It can also be observed that if the refractive index is closer to the refractive index of the core (1.46) the attenuation increases from 20 dB to 25 dB (fiber 2). From the theoretical analysis the maximum attenuation that can be achieved for a refractive index of 1.4602 would be 28 dB, for no remaining cladding. Theoretical analysis also reveals that by increasing the interaction length of the droplet with the fiber the attenuation can double from 28 dB to 55 dB.

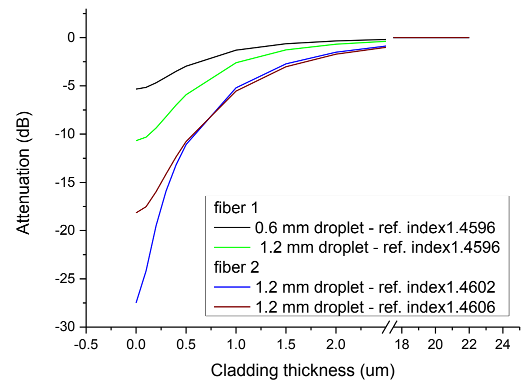

Figure 4. Theoretical results for different refractive index and size of the droplet.

CONCLUSION

We have theoretically and experimentally demonstrated an optofluidic broadband optical fiber VOA. This VOA achieved an experimental attenuation range up to 25 dB, whilst 28 dB was predicted theoretically. The size of the droplet was shown to have a strong influence on the maximum attenuation that can be achieved. The attenuation can be improved up to 55 dB when the droplet size is doubled.

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