VARIABLE LIQUID-CORE FIBER OPTICAL ATTENUATOR BASED ON LASER HEATING

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1. Introduction

The variable fiber optical attenuators (VFOA) are optical components, integrating variable optical attenuators and optical fibers, used to adjust optical power level in applications such as fiber-optical communications systems, photonic signal processing and sensing.

In recent years various types of VFOA have been developed with a variety of technologies such as liquid crystal technology [1], micro-electro-mechanical systems technology [2], optofluidical technology [3] etc. Developing of optofluidic technology creates platform for optical and microfluidical science attractive for novel optical devices [4]. One of the most attractive results of the optofluidic activity is the realization of tunable optofluidic devices using a large variety of physical mechanisms. Liquid-core optical fibers (LCOF) form a group of optofluidic waveguides, which have a circular cross-section with hollow core filled with liquid in common. The cladding of LCOF usually consists of solid, microstructured glass, and polymer material, respectively. Due to the solid cladding of LCOF and high refractive index liquids in the core, light guiding trough the core is based on the total internal reflection (TIR) at core-cladding interface of optical fiber. Refractive index contrast change between core and cladding opens wide application area in optofluidic technology.

In this paper, we describe a new type of VFOA based on thermo-optical effect. Presented VFOA consists of hollow core fused quartz fiber, where the core is filled with mineral oil with slightly higher refractive index in comparison with the fused quartz cladding. Due to the thermo-optical effect, a refractive index contrast between core and LCOF cladding is changed with temperature, what enables to change the propagating optical signal power in core of LCOF. This temperature effect on refraction index contrast in LCOF was theoretically approached in [5].

2. Experiment and results

The attenuation of optical power transferred by LCOF core in presented VFOA is due to the thermo-optical effect, where thermal changes are realized by local optical heating of absorption layer deposited on the LCOF cladding.

The VFOA consists of 20 mm long hollow core fused quartz fiber with outer and inner diameter 130 μm and 5.6 μm, respectively, with core filled with Cargille fused silica matching liquid code 50350 [6]. The cladding is coated with an acrylate primary coating of outer diameter 250 μm. The stripped middle part of hollow core fused quartz fiber was etched in hydrogen fluoride acid to obtain the outer diameter 15 μm instead of 130 μm. Afterwards, the copper absorption layer of thickness app. 1 μm was evaporated on the etched part of the fiber.

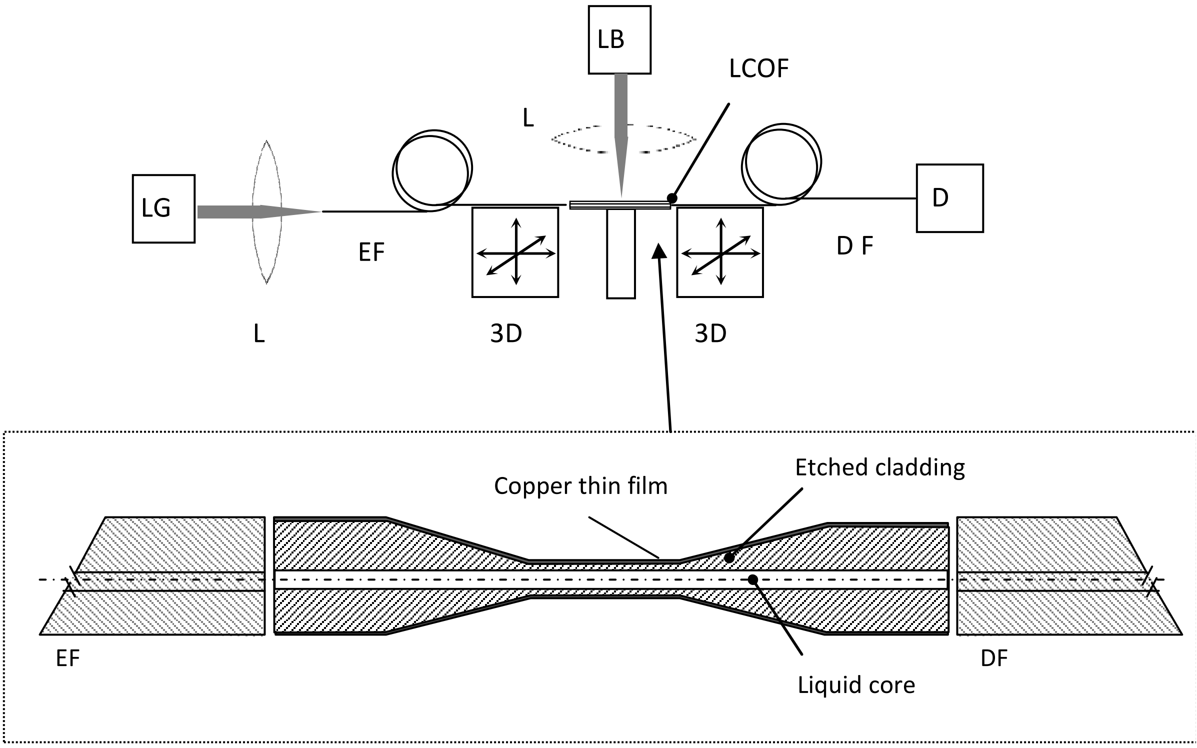

Fig.1: *Experimental configuration for local spectral analysis of LCOF – liquid core optical fiber, LG – DPSS laser (532 nm), LB – DPSS laser (473 nm), L- lens, EF – excitation optical fiber, DF –detection optical fiber, 3D – nanopositioning stage, D – Si detector.*

The copper layer heating was realized by DPSS laser source with adjustable power up to 20 mW and wavelength 473 nm. Laser beam of heating laser was oriented perpendicularly to the optical axis of LCOF and was focused by microscope objective. Experimental setup for VFOA in the LCOF is shown in Fig. 1. The light from excitation DPSS laser (532 nm, 20 mW) was focused and coupled into the excitation optical fiber with the core diameter of 6 μm and fixed on nanopositioning stage with possibility of the 3D axis motion. Output optical power from the LCOF is detected via detection optical fiber with core diameter of 6 μm and the Si detector of type PDA 36A 350-1100 nm.

Then the output optical power from the LCOF core can be controlled by the temperature. Reflectivity of copper layer at wavelength 473 nm for normal light incidence is app. 57% and the extinction coefficient is 2.5. The absorbed heating laser light causes a heating of copper layer and the tapered part of LCOF. Hence, the light induced increase of LCOF temperature causes the decrease of core-cladding refractive index contrast due to thermo-optical effect which results in an attenuation of output optical signal power. Although the focused laser beam induces only local heating of LCOF at length lower than 300 μm, this effect is sufficient to cause significant attenuation of output optical signal power, as it is documented in following experimental results.

Fig. 2 shows the dependence of output optical signal power on optical power of heating DPSS laser (473 nm) at wavelength 532 nm and room temperature 22.5 ^{o}C.

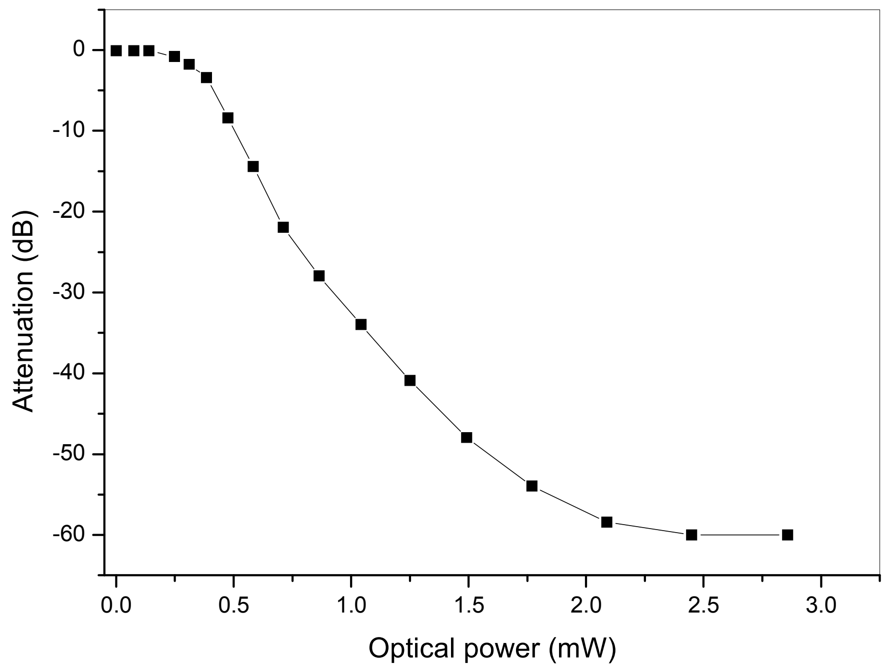

Fig. 2: *Static attenuation of VFOA vs. optical power of heating DPSS laser (473 nm).*

The Fig. 2 documents evident attenuation of optical output as the intensity of heating laser beam increases. Low excitation light power of focused heating laser up to 0.3 mW induces inefficient thermal increase and the LCOF shows well propagating properties, what documents only slow drop in this interval. Higher excitation light power causes the thermal increase of LCOF, what induces the attenuation of optical output power up to 2 mW, where the LCOF attenuation is nearly 60 dB. Fig. 2 documents the possibility of setting any desired value of the LCOF attenuation from maximal to minimal value by simple adjusting of heating laser power. The arrangement with copper as an absorption layer allows using any visible or infrared laser as a heating source because of appropriate copper reflection and absorption characteristics in wide spectral range.

3. Conclusion

A new type of VFOA was proposed and experimentally realized using hollow core fused quartz fiber, where the core is filled with Cargille fused silica matching liquid code 50350. The attenuation is based on thermo-optical effect induced by application of external focused laser source as a heater. The attenuation characteristic documents high sensitivity of VFOA on the heating laser optical power, where the 60 dB attenuation was achieved by only 2 mW optical power focused laser beam with good precision of adjustable attenuation level.

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