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Temperature sensor and fiber laser based on optical microfiber knot resonator

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ABSTRACT

An easy method to fabricate microfiber-knot resonator (MKR) is designed and its application as a temperature sensor and multi-wavelength fiber laser (MWFL) is demonstrated. The MKR has a temperature sensitivity of 14.5 pm/°C over a temperature range of 27–95 °C, and experimental results show good linearity between the temperature and resonant wavelength shifts. As an MWFL on the other hand, up to four lasing lines with a channel spacing of 4.29 nm are obtained. These results confirm that the MKR could be employed as a high performance comb filter to realize compact optical sensor and MWFL designs.

1. Introduction

Microfiber resonators have recently gained increasing research interest for their potential applications in integrated photonic circuits designs to serve a multitude of applications ranging from wavelength conversion and modulation [1,2], tunable laser outputs [3,4] and to create optical time delays [5], as well as in sensing applications such as temperature [6–8] and magnetic fields [9]. As a result of its flexibility and wide range of applications, multiple microfiber resonators designs and configurations have been explored, including micro-ring resonators [10–12], Mach-Zehnder interferometers [13] and micro-knot resonators (MKRs) [14–26] among others. However, it is the MKR in particular that shows the highest potential for manipulation and configuration due to its firm structure, as well as being able to support single-mode transmissions and exhibiting stable light coupling, thus making it a highly preferred microfiber design.

MKR based sensors excel in the measurement of temperature, as even a minor change in temperature will see a major shift of the output spectrum from the MKR. The MKR has been successfully operated as a temperature sensor, exhibiting a responsivity of 0.27 nm/°C [27], while a microfiber loop resonator was shown to have a linear extinction ratio reduction against temperature at a rate of approximately 0.043 dB/°C when embedded in low refractive index polymer [22]. Though higher temperature resolutions can be achieved using other fiber based sensor designs, such as a photonic crystal fiber with a sensitivity of 54.3 nm/ °C [28], the corresponding measurement windows are typically narrow, thus rendering these sensor designs only useful for measurements of short temperature ranges. Furthermore, the fabrication process of the afore-mentioned sensors are more-often than not highly complex, require intensive processes such as femtosecond laser micromachining [29] as compared to the MKR which can easily fabricated and therefore at a much lower cost.

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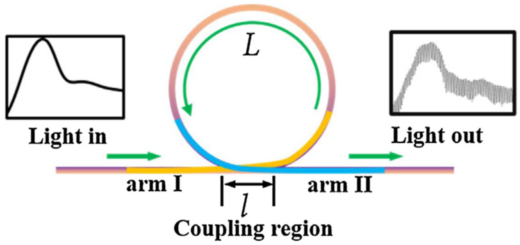

Fig. 1. Transmission spectrum of light before and after passing through the MKR.

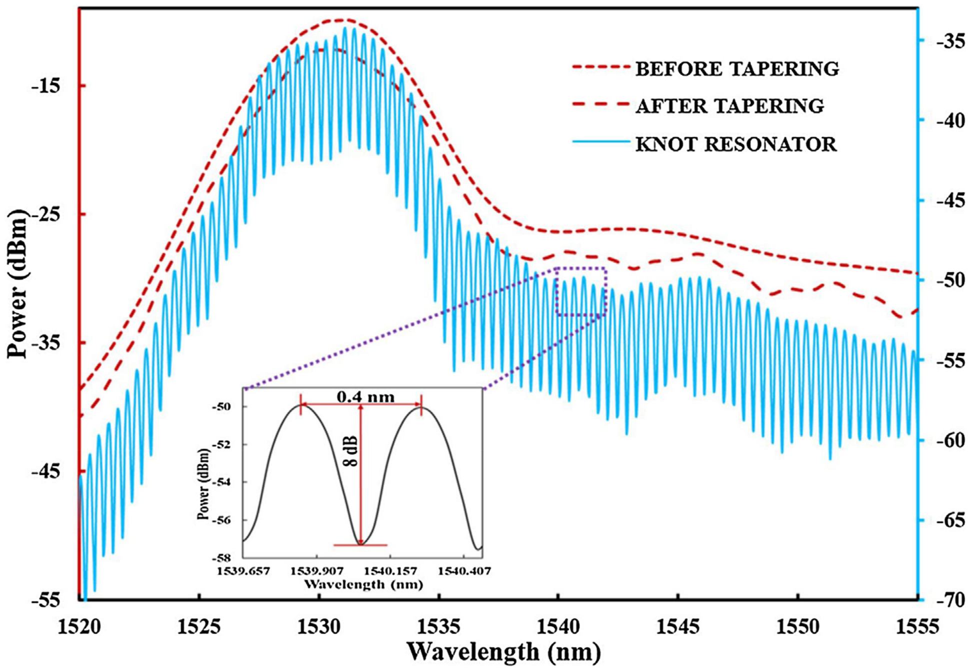

Fig. 2. Output ASE spectrum before tapering, after tapering and after the fabrication of the MKR.

In this work, an MKR designed to operate as both a temperature sensor and fiber laser is proposed and demonstrated. The primary advantage of the proposed MKR is that it can be easily fabricated, thus allowing for significant cost-savings to be realized as well as allowing for a compact and rugged sensor and laser system to be developed. Furthermore, MKR based sensors also enjoys significant advantages over conventional temperature sensors through passive operation and electromagnetic immunity, thus giving it significant potential for real-world applications.

2. Background

The MKR's theory of operation is similar to that of a loop resonator in a single loop. In this manner, the microfiber in the loop is represented by the two arms, which represent the in-going and out-going signals as shown in Fig. 1. L is the length of the microfiber in which the electromagnetic field propagates along, and can be described by the equation [30–33]:

$$F(r) = exp\left[\left(\mathrm{i}\int\int_0^1 \beta(L)\,dL(r)\right]\quad (1)$$

where $\beta(L)$ represents the propagation constant and F(r) is the local transverse mode that corresponds to the propagation constant. The coupling region has a coefficient of k and represents the mode interaction loss between the coupled microfiber arms. Thus, $k = 0$ indicates no cross-coupling interaction between the two arms while $k = 1$ indicates complete cross-coupling between the modes propagating in the MKR's two arms.