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Microarticle

# High sensitivity temperature probe based on elliptical microfiber knot ring

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ABSTRACT

In this paper, a non-uniformed diameter microfiber was used to construct an elliptical microfiber knot ring (E-MKR). Being encapsulated in polydimethylsiloxane (PDMS) film, the high temperature sensitivity of 24.6 nm/℃ was experimentally demonstrated. This E-MKR is easily to prepare, having the stable structure and higher sensitivity than the normal MKRs.

## Introduction

In general, the microfiber knot ring (MKR) is a circular ring with the uniform diameter [1]. This kind of stable structure has been verified by theory and experiment with the high sensitivity for sensing different targets [2,3]. The theoretical and experimental results revealed that either the smaller diameter of the microfiber in the coupling area, or the smaller ring length resulted in the higher the temperature sensitivity [4]. However, due to the uniformity diameter and different length of microfiber, as well as the ring length, the elliptical microfiber knot ring (E-MKR) with the obvious long and short axis was formed during the knotting process. In this paper, the E-MKR was proposed and its temperature sensing performance has been experimentally demonstrated after being encapsulated by polydimethylsiloxane (PDMS).

## Structure design and fabrication

The formation of E-MKR can be contributed to the inhomogeneous change of the microfiber diameter, that was, the inhomogeneous surface tension in microfiber. In this structure, both biconical microfiber and single-mode fiber become part of E-MKR. Here, an E-MKR was fabricated with a long axis diameter of 2 cm, a short axis diameter of 0.9 cm, and a diameter of 19 μm at the thinnest waist of the biconical microfiber. The elliptical ring was then encapsulated in the PDMS film, and the related method is reported in other works [5], and the corresponding micrograph is shown in the Inset of Fig. 1.

## Results and discussions

The temperature sensing characteristics were then verified in the temperature range from 45 ℃ to 32 ℃ by a step of 0.5 ℃, using the homemade temperature sensing system. Fig. 1 indicates the relationship of the wavelength shift of the resonance peak as a function of the temperature. Where, the wavelength movement and temperature interval are 25.0268 nm (from 1539.8251 nm to 1564.8519 nm) and 0.89 ℃, respectively. The temperature sensitivity was calculated as 28.12 nm/℃ in the range of 32.46 ℃ to 33.35 ℃. Furthermore, the free spectra range (FSR) is ~10 nm, which is ~370 folds bigger than the FSR of a circle resonator ($FSR = \lambda^2/2\pi nR$). Because the ring length of the E-MKR was too long and the knot region was composited by the single-mode fiber, the interference spectrum was generated by Mach-Zenhder interference between the core mode and the surface transmission mode of the biconical microfiber, instead of whispering gallery modes in MKR structure.

Fig. 2 refers to the temperature sensing characteristic curve by linear fitting the experimental data. The shift value ($\lambda_m$) of the resonance dip ($m_0$) is depended by the effect refractive index of higher-grade modes on the microfiber surface ($\Delta n_{eff}$) and coupling length ($L$): $\lambda_m = 2\Delta n_{eff}L/m_0$. The temperature will expert the impact on the wavelength shift through changing the coupling length and effective index: $\lambda_m = (\Delta L + \Delta n)_{temperature} = (\alpha_s + \Delta n_s \alpha_p + \Delta n_p)\Delta T$. $\alpha_s$, $\alpha_p$, $\Delta n_s$, $\Delta n_p$ refer to the thermal-expansion coefficients silica ($5.5 \times 10^{-7}$) and PDMS ($3 \times 10^{-4}$), and the thermal-optical coefficients of silica ($1.1 \times 10^{-5}$/℃) and PDMS ($-5 \times 10^{-4}$/℃). Therefore, the temperature increasing will reform the E-MKR and change the interference condition near the biconical region of the microfiber, resulting in the shift of the resonance dip. To explore the impact of microfiber on the temperature sensing performance, another E-MKR with the microfiber waist diameter of 49 μm was prepared and demonstrated with a sensitivity of 10.7 nm/℃. When this temperature probe was practically

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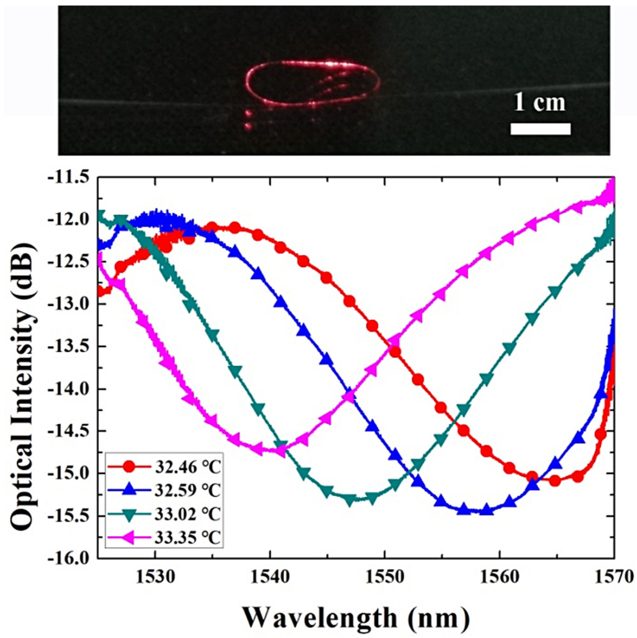


**Fig. 1.** Output spectra of elliptical MKR at different temperature. Inset: Microscope photo of E-MKR structure.

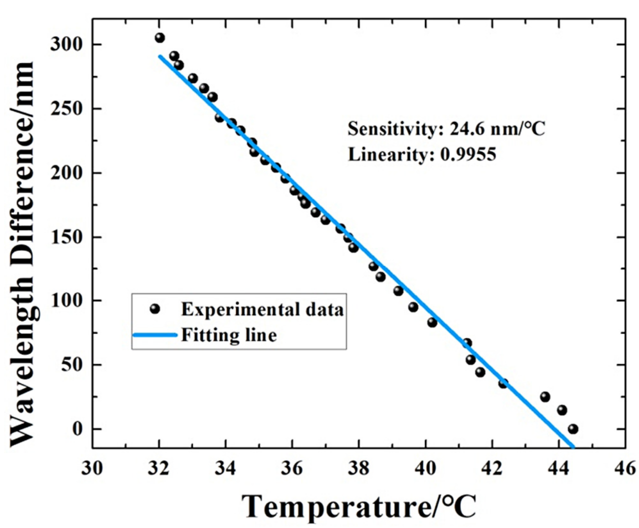


**Fig. 2.** Temperature sensing characteristics curve by linear fitting experimental data.

used, the potential impact on the cross-sensitivity maybe comes from the environmental humidity or other molecules. However, the whole temperature probe was encapsulated in the PDMS, the cross-sensitivity can be effectively eliminated.

## Conclusions

The E-MKR with stable structure and easy fabrication process was experimentally demonstrated. PDMS was introduced to encapsulate the E-MKR structure and improve its stability and the temperature sensing performance. The high sensitivity of 24.6 nm/℃ was obtained in the range of 45 ℃ to 32 ℃. Finer microfiber has a higher sensitivity because its light field is more easily leaked to the outside.

## CRediT authorship contribution statement

**Jin Li:** Funding acquisition, Project administration, Supervision, Writing - review & editing. **Zhoubing Li:** Data curation, Formal analysis, Writing - review & editing. **Juntong Yang:** Writing - original draft. **Yue Zhang:** Investigation, Methodology. **Chunqiao Ren:** Writing - original draft.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.rinp.2020.102953.

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