WGM Microbubble Cavity for Laser Power Measurement

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Abstract: We demonstrate a laser power meter using the hydrogel-based microbubble cavity operating near the phase transition point. The power sensitivity is 124 pm/mW, achieving a 4-fold performance improvement compared to before the phase transition. © 2024 The Author(s)

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1. Introduction

Real-time and precise laser power measurement plays a crucial role in scientific research and industrial development, including optical communication, laser processing, biomedical, and modern national defense. Several optical techniques have been proposed for real-time laser power measurement, such as force sensors based on measuring laser beam radiation pressure and metal-coated optical fiber sensors [1-3]. These schemes are commonly employed for measuring moderate or high laser power ranging from a few watts to several kilowatts, yet their complex structures present challenges for easy integration. Recently, whispering gallery mode (WGM) microbubble cavities with high quality (*Q*) factors and small mode volumes have been widely used in optical sensing, such as temperature sensing [4], pressure sensing [5], and phase transition dynamics monitoring of the hydrogel [6]. With simple structures and fast response, WGM microcavity provide an ideal platform for integrated optical power measurement applications.

In this work, we demonstrate a laser power meter based on a WGM microbubble cavity filled with poly(N-isopropylacrylamide)-based hydrogel (PNIPA). When the laser irradiates microbubble cavity, the light is absorbed by PNIPA, leading to an increase in the temperature of the test system due to the photo-thermal conversion. Therefore, the laser power can be measured by tracking the shift of resonant mode. The power sensitivity of 124 pm/mW is obtained when the power meter operates near the phase transition point, which is a 4-fold performance improvement compared to pre-phase transition. This work demonstrates the feasibility of enhancing sensing performance by combining microcavities with materials, which provides a new platform for laser power measurement.

2. Results and discussion

The experimental setup for laser power measurement is shown in Fig. 1(a). Here, the microbubble cavity is used due to the natural microfluidic channel, which is fabricated by pressurizing the interior of the tapered silica hollow capillary and heating the tapered region using two counter-propagating carbon dioxide laser beams. A tunable laser with a wavelength near the 780 nm band is used as probe light, which is evanescently coupled into the microbubble cavity via a fiber taper for exciting the WGMs. PNIPA is a vital thermosensitive phase transition material, and the inset of Fig .1(a) depicts the optical image of the microbubble cavity before (left) and after (right) phase transition. A fiber polarization controller is employed to precisely adjust the polarization state of the signal light to ensure that the optimal optical coupling efficiency. The output signal light is collected by a low-noise photodetector and its transmission spectrum is monitored in real time via an oscilloscope. A data acquisition (DAQ) system is utilized to record experimental results in real time. Additionally, an arbitrary function generator is employed to generate triangular waveform signals with a frequency of 50 Hz for finely scanning the wavelength of the tunable laser. As a proof-of-principle, the laser power measurement is implemented in near infrared. The irradiation laser at 1550-nm wavelength band is divided into two paths via a 50:50 coupler. One of the light is implemented to irradiate the microbubble cavity through a single-mode fiber, and the other is connected to a commercial power meter for reference measurements. The variable optical attenuators are applied to conveniently regulate the output light intensity.

Figure 1(b) shows the typical transmission spectrum of a microbubble cavity filled with 25% PNIPA solution near 776 nm. The *Q*-factor of $\sim 9.2\times10^6$ is obtained through Lorentz fitting. By continuously adjusting the irradiation laser power used for heating, the temperature of the microbubble cavity can be effectively changed, thereby accurately controlling the phase transition process of the PNIPA solution. Fig. 2(a) illustrates the evolution of the transmission spectrum as the heating light power increases from 0.33 mW to 0.956 mW, exhibiting a collective red shift of the resonant modes in the transmission spectrum. In order to quantitatively analyze the laser power measurement performance of the microbubble cavity, a specific resonant wavelength shift is monitored, which is marked with the blue shaded area in Fig. 2(a). It is obvious that the resonant

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wavelength shift increases significantly once the irradiation laser power exceeds ~ 0.66 mW. This is attributed to the sharp increase of the intrinsic refractive index during the phase transition of the PNIPA [6]. The dependence of the resonant mode wavelength on the irradiation laser power is shown in Figs. 2(b)-(c), to which the experimental data are linearly fitted. Figure 2(b) shows a power sensitivity of 30 pm/mW before the phase transition, validating the feasibility of the power measurement scheme. In addition, the power sensitivity increases to 124 pm/mW during the PNIPA phase transition, achieving a 4-fold improvement in sensitivity performance, as illustrated in Fig. 2(c). With the increased sensitivity, this work shows the potential of composite microcavities for applications in high-performance optical devices.

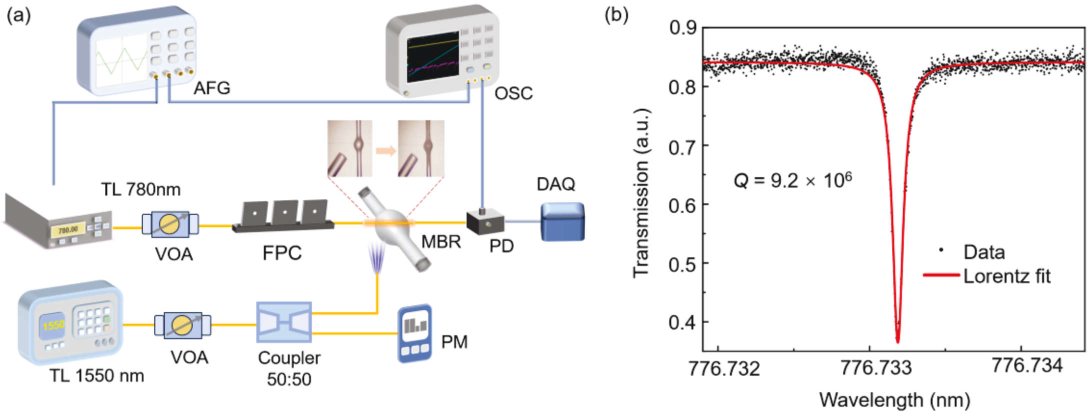

Fig. 1 (a) Power measurement experimental setup. TL, tunable laser; FPC, fiber polarization controller; VOA, variable optical attenuator; MBR, microbubble resonator; PD, photodetector; DAQ, data acquisition card; OSC, oscilloscope; AFG, arbitrary function generator; PM, power meter. Inset: optical images of the microbubble cavity filled with PNIPA before (left) and after (right) the phase transition. (b) Measured and fitted transmission spectrum of the microbubble cavity.

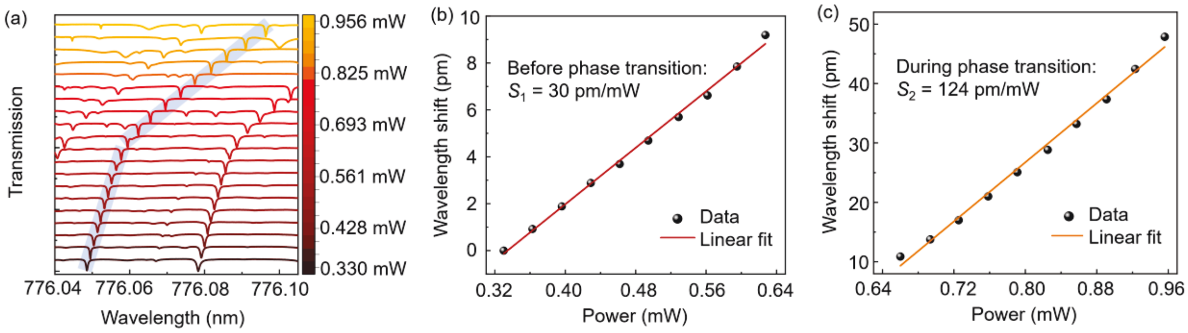

Fig. 2 (a) Evolution of transmission spectrum as power increases from 0.33 mW to 0.956 mW. (b) Wavelength-power dependence of the resonant mode marked with the blue shaded area in (a) before phase transition and (c) During phase transition.

In conclusion, we achieve a laser power meter based on a WGM microbubble cavity filled with PNIPA. A power sensitivity of 30 pm/mW is obtained before the phase transition, while the sensitivity is increased to 124 pm/mW when the PNIPA-based microbubble cavity operates near the phase transition point. This work possesses the advantages of simple structure and easy integration, and has the potential to be a laser power measurement scheme in optical communications and laser printing.

3. Acknowledgements

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4. References

[1] A. B. Artusio-Glimpse, et al. “Miniature force sensor for absolute laser power measurements via radiation pressure at hundreds of watts,” Optic Express, 28, 13310-13322 (2020).
[2] P. A. Williams, et al. “Radiation-pressure-enabled traceable laser sources at CW powers up to 50 kW,” IEEE Trans Instrum, 68, 1833-1839 (2019).
[3] I. Khramov, et al. “Metal-coated fiber sensor for laser radiation power measurements,” Optical Engineering, 58, 072012-072012 (2019).
[4] L. Jie, et al. “Optical whispering-gallery mode barcodes for high-precision and wide-range temperature measurements,” Light: Sci. Appl. 10, 32 (2021).
[5] B. Duan, et al. “High-precision whispering gallery microsensors with ergodic spectra empowered by machine learning,” Photonics Res. 10, 2343-2348 (2022).
[6] D. Q. Yang, et al. “Operando monitoring transition dynamics of responsive polymer using optofluidic microcavities,” Light: Sci. Appl. 10, 128 (2021).