Highly Hygroscopic Polymer Microcavity Fiber Fizeau Interferometer for Humidity Sensing

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Abstract— This work demonstrates a highly hygroscopic polymer microcavity fiber Fizeau interferometer (PMFFI) that uses a single-mode fiber (SMF) tip with very little polymer attached. The polymers with specific porous structures have good hygroscopicity which is very useful for the humidity sensing application. We utilized a general laser diode (LD) with a single wavelength which is monitoring the spectral reflections of the proposed sensor. The sensing capabilities of the developed PMFFI have been experimentally investigated. Experimental results illustrate that the laser power rises when in the ascent of humidity, besides a good linear response of sensitivity and favorable spectral property are also achieved by the proposed configuration.

1. INTRODUCTION

Several fiber-optic relative humidity (RH) sensors have been developed and widely utilized in practical sensing applications, food processing, biomedical technology, electronic processing because of their many encouraging characteristics such as corrosion resistance, immunity to electromagnetic interference, high resolution, high sensitivity, small size and long distance sensing and monitoring [1–10]. Many kinds of optical fibers and fiber devices coated on different humidity-sensitive materials have been reported for the humidity sensing. They are included no core fibers [1], hollow core fibers [2], photonic crystal fibers (PCF) [3, 4], photonic bandgap fibers (PBF) [5] long period fiber gratings (LPGs) [6, 7], fiber interferometers [8, 9] and fiber Bragg gratings (FBGs) [10].

In this paper, for the first time, a simple fiber-optic RH sensor based on a highly hygroscopic polymer microcavity fiber Fizeau interferometer has been developed. The fiber sensor head using a SMF endface attaches droplet of a kind of UV-cured gel (monomer). The monomer, Norland optical adhesive 61 (NOA61) is a photo polymerizable liquid that can be cured by UV light with a maximum absorption in the range 350–380 nm. The monomer can be formed as solid and hard polymer and makes the structure permanent by the UV exposing processes. The layer of the proposed polymer NOA61 acts as a microcavity with two reflective interfaces, which reflects the optical signals back into the SMF again so that reflection interference operation is achieved. Compared with other previously reported fiber humidity sensors, our sensor structure has the advantages of easy fabrication, miniature, high sensitivity, and arbitrary structure. Experimental results demonstrate that greatly variation of the interference wavelength shift as well as highly sensitive property of the sensors can be obtained by the hygroscopic capability of the used polymer.

2. EXPERIMENTS AND RESULTS

In the experiment, the endfaces of SMFs were firstly attached little monomer NOA61 by using a particular method to control the thickness of monomer. After attaching (coating), the endface of SMF was exposed to UV light with an intensity of approximately $50\,\mathrm{W/cm^2}$ for 30 s at room temperature. The refractive index of the solid polymer is around 1.56 in the measured wavelengths. The structures of the fabricated PMFFIs and reflection spectra are shown in Fig. 1. In the inset of Fig. 1, L is microcavity of the polymer. The arc shape of the fabricated polymer surface is created because the cohesion force of monomer liquid material. Adhesive force between the SMF and the polymer would be very well if it was fully cured and well aged.

We used the highly hygroscopic polymer with porous structure enables absorbing the water molecules effectively. Due to the hygroscopic capability of the polymer NOA61, the proposed PMFFI is employed to measure the surrounding RH, with the purpose of assessing the effectiveness of the sensor. In the measurement, a broadband light source (BLS) is launched into the fiber device and the reflection spectra are readily measured by using an optical spectrum analyzer (OSA). The device is placed inside a temperature and humidity controlling chamber (Resolution: 1%RH and 0.5°C) as the humidity is increased from 20 $\sim$ 80%RH with fixed temperature of 25°C, as shown in Fig. 2. The adsorption process would expand the polymer as well as increases the effective index of microcavity to make the optical path of interference increase for shifting the interference wavelengths. Fig. 3 plots the shifts of the interference dip for a PMFFI with $L = 24\,\mu\mathrm{m}$ as ascending humidity at wavelength around 1530 nm. The optical path of the microcavity increases as RH increases that causes a red-shift of interference fringes, as shown in Fig. 3(a). Fig. 3(b) plots

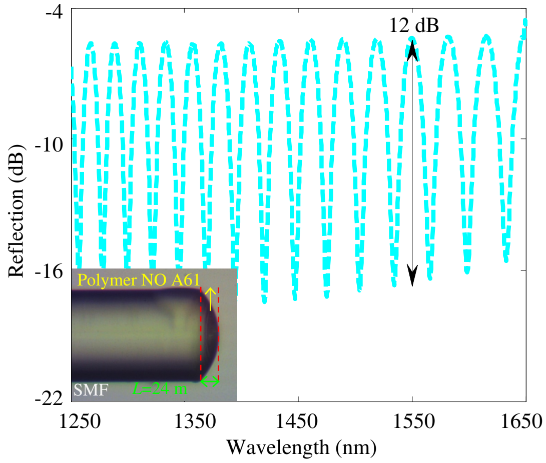

Figure 1: Interference spectra of the fabricated PMFFI. Inset presents the sensor head with microcavity of $L = 24\,\mu$m.

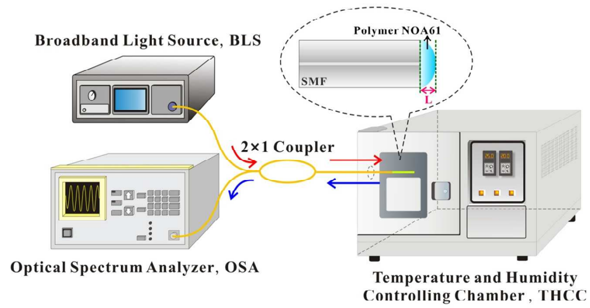

Figure 2: Experimental setup for the RH measurement. Inset shows schematic diagram of the sensor head.

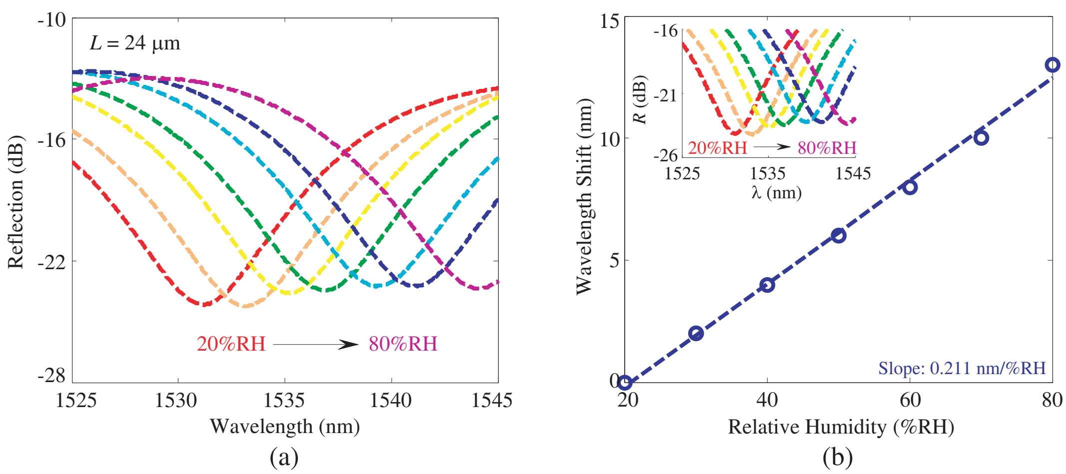

Figure 3: (a) Reflection spectra of the $L = 24\,\mu$m PMFFI with RH increase. (b) RH sensitivities for the adsorption process. Inset shows red shift of the interference wavelength dips.

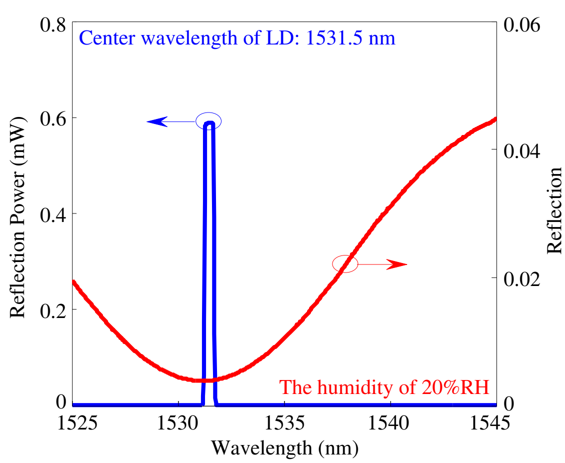

Figure 4: Wavelength location and optical power of the input LD (blue line) and spectral interference dip of the sensor when in the humidity of 20%RH (red line).

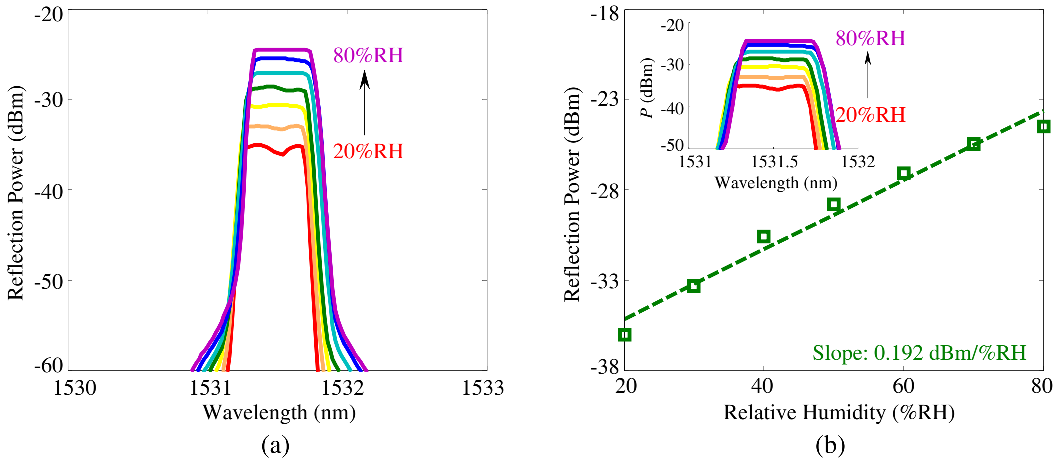

Figure 5: (a) Reflection spectra of the $L = 24\,\mu m$ PMFFI with increase of humidity by using the LD light source. (b) Humidity sensitivities of the LD peak power to the increase of humidity. Inset shows the spectral variations of the LD peak power.

the linear humidity sensitivity of wavelength shift with 0.211 nm/%RH of the adsorption processes for the proposed sensor with $L = 24\,\mu m$.

For reducing cost of the measurement system for the relative humidity sensor, we just utilized a general LD that replaced the former source, BLS. The LD with the optical power of about 0.58 mW and central wavelength of 1531 nm inputs the fiber sensor and the laser spectrum is shown in the blue line of Fig. 4. In Fig. 5(a), peak power of the measured laser changes with linearity when the humidity is increased. It can be predicted that a very cheap photodetector (PD) can be used to measure the optical power of the LD. The sensitivity with 0.192 dBm/%RH of peak power responses for our sensor has been achieved, as plotted in Fig. 5(b).

3. CONCLUSIONS

This study has presented a novel and miniature PMFFI based on the SMF tip with hygroscopic polymer attachment to measure the surrounding RH with high sensitivity. The used polymers with particular porous structures have good moisture absorption, so that can be used for fiber-optic RH sensing applications. A simple laser diode has been applied to monitor the spectral reflections and demonstrated the good sensing capabilities for the developed PMFFIs humidity sensor. Experimental results show that good linear response of sensitivity and the rise of peak power with the increase of the humidity have been investigated. Additionally, the ease of fabrication and lack of fiber alignment for the all-fiber devices are distinctive in the humidity sensing technology.

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