

Investigation of an inkjet printed optical resonator as an environmental sensor

Marc-Antoine Bianki, Régis Guertin, Cédric Lemieux-Leduc and Yves-Alain Peter

Department of Engineering Physics

Polytechnique Montréal

Canada

marc-antoine.bianki@polymtl.ca

Abstract—We investigated an inkjet-printed polymer optical resonator as an environmental sensor. The fabrication method combines additive manufacturing and microfabrication techniques to obtain a suspended SU-8 microdroplet on a silicon pillar. Sensitivity for temperature ($-41.4 \text{ pm}/^\circ\text{C}$) and humidity sensitivity (0.22 pm/ppm) are measured.

Index Terms—Whispering gallery mode resonators, Optical resonators, Inkjet printing, Optical polymers, Temperature sensors, Humidity measurement, Microfabrication

I. INTRODUCTION

Polymers make for an excellent sensing platform due to their sensitivity to environmental changes. However, this sensitivity can also lead to cross-sensitivity issues. It is often necessary to have multiple different polymers to decouple the effect of each variable on the system [1]. Inkjet printing of polymer is a new additive fabrication method that allows multiple different polymers on the same microchip such as PDMS [2] and PMMA [3]. Inkjet printing has been used to print microresonators for lasing [4] and to fabricate electronic volatile organic compounds (VOC) sensors [5].

Suspended polymer microdroplets are being investigated as a novel sensing platform. The SU-8 was selected for this study as optical resonators and sensors based on this polymer were previously fabricated [6]–[8]. Furthermore, it has already been inkjet printed for the fabrication of microlenses [9]. The sensitivity of the microdroplets to a change in temperature and humidity is measured.

II. FABRICATION AND METHOD

The process of microfabrication depicted in Fig. 1a begins with a silicon wafer that has been cleaned and has had a layer of hexamethyldisilazane (HMDS) deposited on it. Microdroplets of SU-8 diluted in cyclopentanone are then inkjet printed using an inkjet printer (Microdrop MD-P-XYZ-C-E-12-09), with a voltage of 85 V, a pulse duration of $25 \mu\text{s}$, and a nozzle diameter of $100 \mu\text{m}$ (Dispenser Head MD-K-140). These parameters produce microdroplets with a radius of approximately $45 \mu\text{m}$ prior to landing (Fig. 1b). The microdroplets then undergo a soft bake and a UV-curing step. A final post-exposure bake is performed before isotropic plasma etching of the silicon substrate with SF_6 . The resulting structure is a suspended SU-8 microdroplet on a silicon pillar,

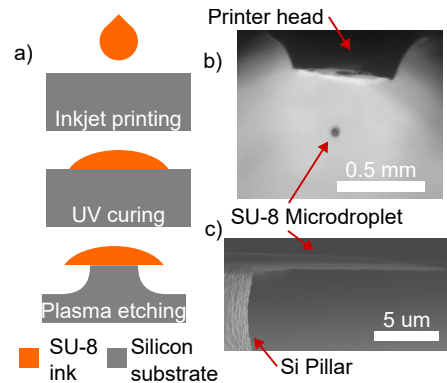


Fig. 1. a) Microfabrication process. SU-8 inkjet printing on silicon substrate. UV curing. Silicon plasma etch. b) SU-8 drop image while printing. c) Side-view SEM image of suspended SU-8 microdroplet.

featuring a $12.6 \mu\text{m}$ underetch and a radius of $52.7 \mu\text{m}$, as observed by scanning electron microscopy (SEM) in Fig. 1c.

The experimental setup shown in Fig. 2a consists of the following components to measure the transmission spectrum of SU-8 microresonators: a tunable laser source (TLS), an isolator (I), a polarization controller (PC), and an optical power meter (PM) that is synchronized with the TLS to collect the transmission optical spectrum. Humidity is regulated by using a pure nitrogen flow that is controlled with mass flow controllers (MFC). To humidify the nitrogen flow, a portion of the flow is passed through a water bubbler (B). Temperature is controlled in two different locations: the sample temperature is modulated using a thermoelectric device, while the gas flow temperature is adjusted using a copper gas heater (GH). The flow temperature is measured just before it reaches the sample to control the loop of the gas heater. The 3-sigma noise levels for the flow temperature, Peltier device, and humidity are 0.05°C , 0.01°C , and 10 ppmv , respectively.

To couple light in and out of the resonator, a tapered optical fiber with a radius of approximately $1 \mu\text{m}$ is positioned at the edge of the resonator using both 5-axis and 3-axis stages. To control the gas temperature and humidity surrounding the sample, a small gas box is placed directly over it, with the gas flow directed onto the sample. To prevent any outside contamination, all equipment is enclosed within a larger box, which includes extraction.

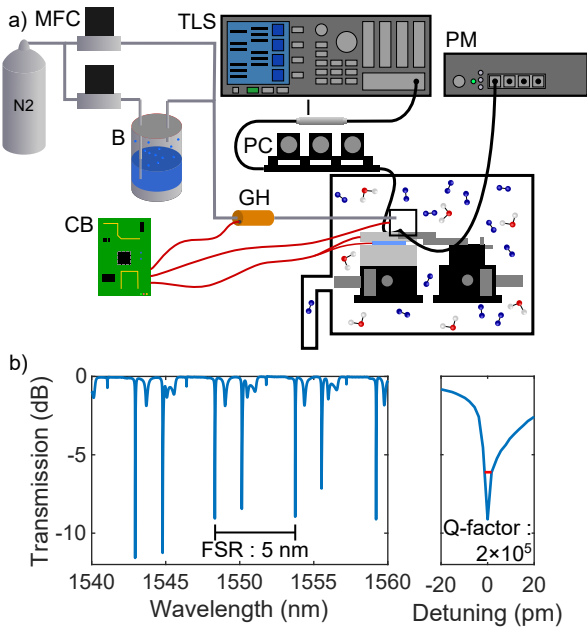


Fig. 2. a) Experimental setup. Gas tubes in gray, optical fibers in black and electrical wires in red. b) Transmission optical spectrum of an SU-8 resonator.

Figure 2b displays the transmission spectrum ranging from 1540 nm to 1560 nm. The free spectral range (FSR) is 5 nm, and the Q-factor reaches up to 2×10^5 .

III. RESULTS AND DISCUSSION

To measure the temperature sensitivity, the gas flow and sample temperatures were varied while acquiring multiple transmission spectra. The data was processed by tracking the peaks over time. Specifically, the sample was exposed to a nitrogen flow without humidity, and two temperature ramps were conducted, increasing from 30 °C to 44 °C. The first ramp was used to degas the resonator as gas absorption and desorption in polymers can alter the refractive index and cause expansion, which affects peak position. Fig. 3a illustrates the position of one peak near 1556 nm against the controlled temperature. The position errors were calculated from nine spectra obtained during the ascending and descending ramps. Using linear regression, a sensitivity of $-41.4 \text{ pm}/^\circ\text{C}$ was obtained.

The procedure for measuring humidity sensitivity is similar to that used for temperature sensitivity. Peak positions were recorded for a blank sample and samples of different concentrations spanning from 0 to 700 ppmv. The position of a selected peak versus humidity concentration is depicted in Fig. 3b. Linear regression analysis yielded a sensitivity of 0.22 pm/ppmv and a limit of detection (LOD) of 30 ppmv.

IV. CONCLUSION

Temperature and humidity sensitivity are reported for an SU-8 microdroplet on a pillar. A combination of inkjet printing and traditional microfabrication techniques were used to deposit and suspend the SU-8 microdroplets. This enables

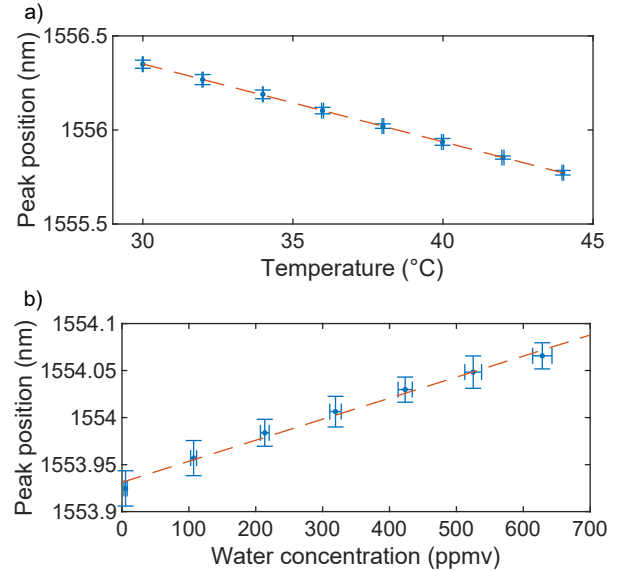


Fig. 3. Temperature (a) and humidity (b) sensitivity. Experimental data in blue with error bars, and linear regression in orange dashed lines.

different polymers on the same chip, which reduces cross sensitivity for artificial nose applications.

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