

Polymer Ring Resonator Fabricated by Nanoimprint for Ultrasound Detection

Marc-Antoine Bianki, Ahmed S. Bahgat, Jonathan Porée, Jean Provost and Yves-Alain Peter

Department of Engineering Physics

Polytechnique Montréal, Canada

marc-antoine.bianki@polymtl.ca

Abstract—This paper presents a polymer SU-8 ring resonator fabricated via nanoimprint lithography for ultrasound detection. The device exhibits a Q-factor of 3.95×10^3 and a sensitivity of 34 mV/kPa. Experimental results demonstrate a broad detection bandwidth exceeding 24 MHz, validating its potential for high-speed ultrasound imaging.

Index Terms—Optical ring resonators, Ultrasound, Nanoimprint lithography, Polymer

I. INTRODUCTION

Ultrasound is a vital tool for non-invasive deep-tissue imaging [1]. Recently, 3D ultrafast ultrasound imaging has emerged as a technique, enabling the real-time mapping of tissue stiffness, blood flow, and functional brain activity at rates of thousands of volumes per second [2]. While piezoelectric transducers are the clinical standard, the high-density matrix arrays required for these ultrafast applications face significant challenges; piezoelectric sensitivity typically scales with element size, and the massive channel counts lead to extreme electronic and cabling complexity. Optical microcavities circumvent this limitation by offering size-independent sensitivity and a wide bandwidth, allowing for high-resolution imaging without the need for complex, bulky electronic shielding [3]. By utilizing a dual optical frequency comb for interrogation, large sensor arrays can be managed with lower system complexity and a smaller physical footprint [4].

The sensing mechanism is based on acousto-optic transduction within the microcavity. Incident acoustic pressure mechanically deforms the waveguide and modulates its refractive index via the elasto-optic effect. This combined perturbation of the effective refractive index ($\frac{dn_{\text{eff}}}{dP}$) induces a shift in the resonance wavelength ($\frac{d\lambda_0}{dn_{\text{eff}}}$).

Compared to chalcogenide and silicon-on-insulator (SOI) platforms, polymer-based optical resonators deform more easily under acoustic pressure due to their significantly lower Young's modulus. This high mechanical compliance enhances the sensor's acousto-optic response, making polymers an ideal material for high-sensitivity ultrasound detection [5], [6]. Moreover, polymers offer better acoustic impedance matching

with water-coupled environments, which minimizes acoustic reflections.

To realize the large-scale arrays required for comb-based interrogation, fabrication must be both high-resolution and high-throughput. Nanoimprint lithography (NIL) satisfies these requirements, providing a cost-effective path to mass-produce dense resonator arrays with the nanometric precision necessary for critical coupling [7].

We present the development and characterization of a polymer ring resonator for ultrasound sensing, utilizing nanoimprint lithography to ensure a scalable fabrication process. By exploiting the low Young's modulus of SU-8, a photosensitive epoxy, we achieved high sensitivity and broad bandwidth. This work focuses on the performance of a single-ring prototype, establishing a baseline for its eventual deployment in high-density 3D ultrasound imaging systems.

II. FABRICATION AND EXPERIMENTAL SETUP

The device microfabrication employs a nanoimprint lithography process. This technique utilizes a PDMS stamp cast from a silicon master mold, which is patterned via electron beam lithography to achieve the high resolution required to resolve the coupling gap between the ring resonator and the bus waveguide. Both the silicon master and the PDMS stamp permit multiple reuses, thereby reducing fabrication costs.

The fabrication process, illustrated in Fig. 1(a), begins on a silicon substrate featuring a 5 μm thick layer of wet silicon dioxide, which serves as the bottom cladding. The process involves spin-coating SU-8, a photosensitive epoxy, onto the substrate. During the nanoimprint stage, a PDMS stamp is applied to the SU-8 layer at 90 °C for 30 minutes, allowing the stamp to deform the polymer. Following a cooling period, the stamp is peeled off and the SU-8 is UV cured. Finally, a 5 μm thick PDMS cladding (15:1 ratio) is spin-coated over the structure to protect the device and ensure acoustic impedance matching with water. Light is edge-coupled to the waveguides via SMF-28 single-mode fibers secured with adhesive. The device is subsequently packaged within a 3D-printed plastic holder for mechanical stability.

The device is submerged in a deionized water tank maintained at a constant temperature of 25 °C. The optical interrogation setup comprises a tunable laser source (TLS), a polarization controller, and a photodetector (PD) coupled to an amplifier and an oscilloscope. Optical transmission spectra

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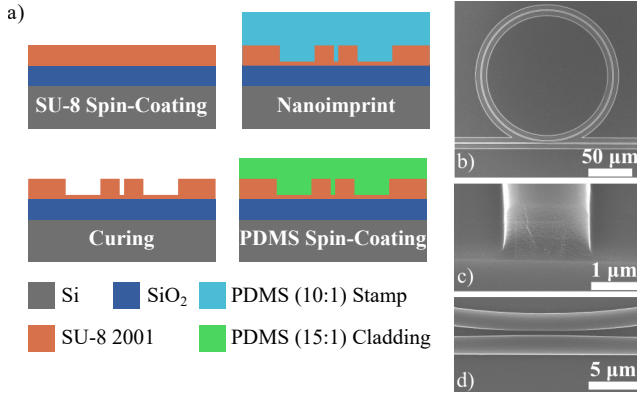


Fig. 1. Device fabrication and characterization. a) Nanoimprint process flow schematic. b) Top-view SEM of the ring resonator. c) Waveguide cross-section SEM. d) SEM close-up of the coupling gap.

are acquired by synchronizing the PD with the TLS scan. For ultrasound measurements, the TLS wavelength is fixed at the inflection point (the maximum slope) of a resonance peak. The device is positioned at the focal point of an ultrasound probe (Philips P4-1, Philips P7-4, or GE L6-24-D), which delivers three-cycle ultrasound pulses.

III. RESULTS AND DISCUSSION

The ring resonator has a radius of $77\mu\text{m}$, as shown in the top-view SEM image in Fig. 1(b). The waveguide dimensions comprise a thickness of $1.4\mu\text{m}$ and a width of $2\mu\text{m}$, including a 109nm residual slab layer, which is illustrated in the cross-section in Fig. 1(c). Finally, the coupling gap between the resonator and the bus waveguide is 450nm , as detailed in the close-up view in Fig. 1(d).

Figure 2(a) displays a representative experimental optical transmission spectrum of the packaged ring resonator. The resonance peak, centered near 1550nm , exhibits a full width at half maximum (FWHM) of 0.39nm , corresponding to a quality factor of 3.95×10^3 . An incident ultrasound wave induces a shift in this resonance wavelength. By maintaining the TLS at a fixed wavelength, this spectral shift is transduced into a measurable change in optical power. A resonator with a high-quality factor provides enhanced sensitivity due to its steeper resonance slope. The free spectral range (FSR) of the device is 3.34nm which correspond to an effective refractive index of 1.49 .

To determine sensitivity at a specific frequency, the device is exposed to ultrasound pulses of varying amplitudes. Figure 2(b) illustrates the device's response at three distinct frequencies using different probes: 2MHz (P4-1), 5MHz (P7-4), and 15MHz (L6-24D). The sensor response remains linear provided the ultrasound-induced resonance shift is confined to the peak's linear slope. Higher acoustic pressures move the shift into the curved extrema of the resonance, resulting in non-linear saturation. Under linear conditions, the device achieves a maximum sensitivity of 34mV/kPa at 2MHz (P4-1 probe).

Characterization across multiple ultrasonic probes confirms a broadband response from 1 to 25MHz , with the detected

signal consistently exceeding the $25\mu\text{V}$ noise floor. While a useful bandwidth of over 24MHz was recorded, this limit is likely imposed by the frequency response of the piezoelectric reference probes rather than the intrinsic mechanical resonance of the SU-8 ring. Over this frequency range, the sensor demonstrates a noise equivalent pressure (NEP) of 310Pa .

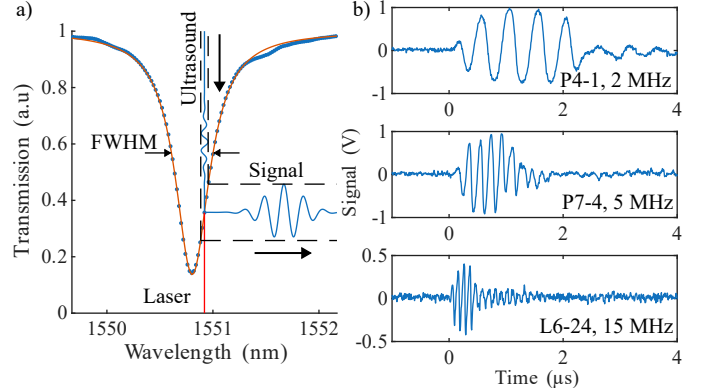


Fig. 2. Optical and acoustic characterization. a) Experimental optical transmission spectrum and Lorentzian fit with an illustration of the sensing principle. b) Ultrasound response signals at 2, 5, and 15 MHz showing sensitivity above the noise floor.

IV. CONCLUSION

This work demonstrated SU-8 polymer ring resonators fabricated via high-throughput nanoimprint lithography. The sensors achieved a Q -factor of 3.95×10^3 , a sensitivity of 34mV/kPa , and a broad detection bandwidth exceeding 24MHz . These results validate polymer-based resonators as a scalable, high-performance platform for ultrafast ultrasound imaging. Future work will focus on scaling these devices into dense 2D arrays and integrating them with frequency comb interrogation for real-time 3D imaging applications.

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