Microring Resonator based Force Sensor, with Real-time Temperature-induced Resonance Shift Cancellation

Safarloo, Sahar; Westerveld, Wouter; Steeneken, Peter G.; Zadpoor, Amir A.; Mirzaali, Mohammad J.

DOI
10.1109/CLEO/EUROPE-EQEC65582.2025.11111392

Publication date
2025

Document Version
Final published version

Published in
Proceedings of the Conference on Lasers and Electro-Optics Europe and European Quantum Electronics Conference, CLEO/Europe-EQEC 2025

Microring Resonator based Force Sensor, with Real-time Temperature-induced Resonance Shift Cancellation

Sahar Safarloo[1], Wouter Westerveld[1], Peter G. Steeneken[1], Amir A. Zadpoor[1] , Mohammad J. Mirzaali[1]
1. Delft University of Technology, Delft, The Netherlands

Miniaturized optomechanical devices are well-suited for applications in the automotive, aerospace, and biomedical sectors due to their compact size and lightweight design, which make them ideal for measuring small forces [1]. The significant refractive index contrast between the silicon waveguide core and the silicon dioxide cladding in silicon-on-insulator (SOI) structures enables submicron core dimensions. This design supports single-mode propagation at a wavelength of 1.55 µm, with strong optical confinement that allows for sharp bends with radii as small as a few micrometers [2]. Micro-optical-electromechanical systems (MOEMS) offer several advantages over traditional micro-electromechanical systems (MEMS), including higher optical sensitivity, simplicity, cost-effectiveness, and suitability for use in electromagnetically active environments and ultra-high vacuum conditions [3].

In this work, we developed and analyzed a force sensor utilizing a novel approach. The device consisted of a sensing ring and a reference ring, positioned 3 mm apart on the chip. This spacing ensured that the reference ring remains unaffected by any localized forces applied to the sensing ring. Unlike previous studies that employed different cladding materials for the reference sensor [4], our design used a uniform polydimethylsiloxane (PDMS) cladding with a thickness of 2.5 µm across the entire chip. Both the rings and the access waveguides had a standard cross-section of 450 nm × 220 nm and were designed to operate in the quasi-TE fundamental mode. The coupling gap between the ring resonator waveguide and the bus waveguide was 200 nm. The force was detected through a change in the effective refractive index of the propagating mode induced by geometrical and photo-elastic effects in the PDMS layer.

To demonstrate the performance of the sensor, we performed real-time sensing experiments using a nanoindentation machine (Chiaro, Optics11life) equipped with a tip radius of 11 um to apply localized loads on the sensing ring (fig. 1 a). The experiment began with the tip positioned on the surface of the ring, followed by incremental movements towards the ring in 0.5 µm steps. At each step, a wavelength sweep was performed over the range of 1550–1555 nm. Fig. 1 b shows the relative resonance shift between the sensing and reference rings, which was solely attributed to the applied force, plotted against the load data obtained from the nanoindentation system. The results show a linear response with a sensitivity of 115 pm/µN.

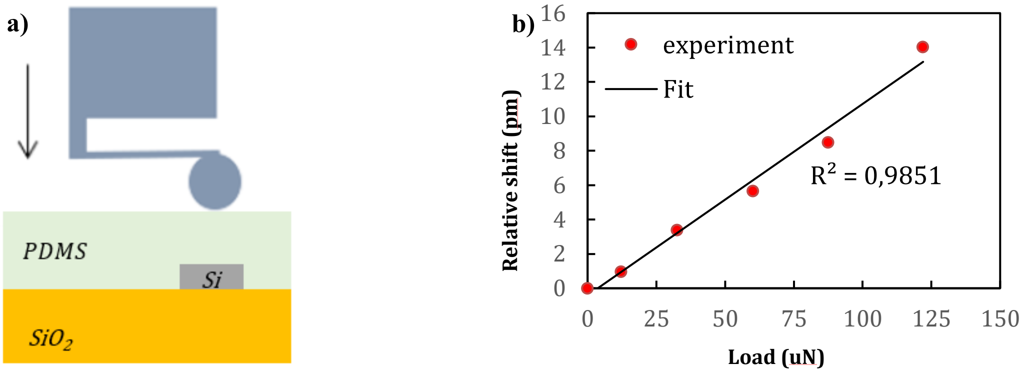

Fig. 1 a) schematic of waveguide under the applied load of nanoindenter, b) resonance shift sensitivity of the silicon photonic force sensor.

In conclusion, this work for the first time to the best of our knowledge, has demonstrated the ability to measure vertically applied forces using a silicon photonic platform. This achievement contributes to the advancement of high-resolution, high-sensitivity, and scalable silicon photonic force sensors, paving the way for their application across various sectors, including biomedical fields.

References

[1] T.-R. Hsu, *MEMS and Microsystems: Design, Manufacture, and Nanoscale Engineering*, 1st ed. (John Wiley & Sons, 2008).
[2] T. Tsuchizawa et al., "Microphotonics devices based on silicon microfabrication technology," IEEE J. Sel. Top. Quantum Electron. 11(1), 232–240 (2005).
[3] V. R. Kolli et al., "Design and analysis of serially coupled double microring resonator-based force sensor for 1 µN range measurement," Optik 131, 400–408 (2017).
[4] D.-X. Xu et al., "Real-time cancellation of temperature-induced resonance shifts in SOI wire waveguide ring resonator label-free biosensor arrays," Opt. Express 18, 22867–22879 (2010).