Integrated Thermal Tuning of Suspended Micro-Resonators

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Abstract: We show the ability to tune the optical properties of clad-less suspended micro-resonator by fully integrating thermal heating circuit with platinum suspended wires, and without affecting the optical performance of the device.
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Micro-resonators are key components for on-chip photonic circuits and systems. Suspended micro-resonators are prominent in various applications such as sensing [1], frequency comb generation [2], and optomechanics [3, 4]. Furthermore, there has been growing interest in studying arrays of micro-resonators as they prove to be promising building blocks in integration of photonic circuits [5] and exhibit remarkable behaviors such as optomechanical synchronization [3].

The major technical challenge in using suspended resonators in many applications, however, is the inability to tune the optical properties of the resonators due to the absence of a cladding layer that isolates optically the device from adjacent structures and on which heaters or other tuning mechanisms can rest. This makes the device an inherently passive device where the optical properties are uncontrollable as it is prone to random fabrication variations, limiting its full potential. Therefore, in order for suspended micro-resonator to become more useful photonic component, its optical properties must be controllable. In an array of resonators, for example, tuning allows control over coupling strength among resonators, and consequently, the inter-device dynamics [3].

Several works have successfully tuned the optical properties of suspended micro-resonators by exploiting the thermo-optic effect, for example, by heating the stage or the sample chip using a Peltier element [6], or by focusing an out-of-plane laser onto the device [3] and transferring photon energy of the laser to thermal energy. In order to truly transform suspended micro-resonator into an active photonic component, however, a fully integrated tuning approach is required to allow scalable and selective on-chip tuning of the device.

Here we realize scalable and selective on-chip tuning of suspended micro-resonators by taking advantage of the thermo-optic effect and designing an electrical heating circuit that does not require a cladding layer and minimizes the perturbation to the optical field inside the resonators (Fig. 1a, b). In addition, the fabrication processes are standard CMOS processes, increasing the device compatibility with other photonic components.

We suspend platinum (Pt) bridge wires that connect the Pt heater deposited on each resonator to the electrical contacts, as illustrated in Fig. 1. The suspended Pt wires not only minimizes the perturbation to the optical modes, but also allow tuning the resonators without a cladding layer, and thus, a complete integration of the tuning circuit and the device. We select Pt for the heater and the suspended wires due to it is compatibility with buffered oxide etch (BOE) used to release the Si_3N_4 micro-resonator disk from the SiO_2 sacrificial layer. The thickness of SiO_2 sacrificial layer determines the gap between the suspended Pt wires and the micro-resonator. FDTD simulations of the suspended wires suggest that a gap greater than 1 μm between the metal wires and the micro-resonator is sufficient to prevent metal bridges from perturbing the optical mode profile as well as the quality (Q) factor inducing losses of less than 1 dB/cm. Here we make the gap equal to 1.2 μm, for which the simulated loss only due to the metal wires is less than 0.2 dB/cm.

We characterize the suspended micro-resonators by coupling a continuous laser using a tapered optical fiber and applying DC voltages to the metal contacts connecting the heaters through suspended Pt wires. For single micro-resonator of 20 μm radius, we observe a strong thermo-optic detuning of 9.6 GHz with 5.3 mW heater power (1.8 GHz/mW or 10.4 GHz/V^2), while maintaining a Q-factor of about 10^5 as shown in Fig. 2a.

To demonstrate scalability of our tuning scheme, we characterize a system of coupled micro-resonators with 25 μm radius. We couple the laser to one of the resonators using a tapered optical fiber and we power one of the heaters to observe the resonance shift. We observe the typical anti-crossing of the optical resonances of the coupled resonators as shown in Fig. 2b, achieving maximum coupling strength with 3.3 mW heater input power.

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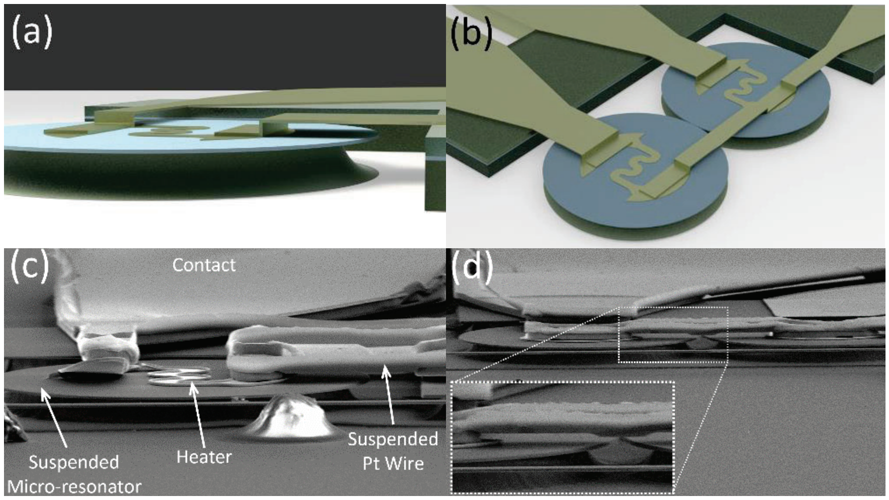

Fig. 1. (a) A schematic rendering of a suspended micro-resonator with thermal tuning circuit. The heater deposited at the center of the device is connected to the contacts by suspended metal wires. (b) A schematic of evanescently coupled suspended resonators where the heaters can control the coupling strength of these resonators. (c) SEM image of a single suspended micro-resonator with the tuning circuit. The suspended Pt wires are fully released. (d) SEM image of coupled resonators. The inset shows the magnified view of the suspended Pt wire connecting the two heaters to the ground contact.

The integration of suspended micro-resonators and the tuning circuit allows active control of variations in optical properties that arise due to random variations during fabrication. This makes suspended micro-resonator a more versatile component for on-chip photonics applications. In addition, our tuning approach allows active tuning without significantly affecting the device performance as shown by relatively constant Q-factor in fig. 2a. As the heaters are directly touching the resonators, our approach is also suitable for applications conducted under vacuum. Our tuning scheme, connecting heaters with fully suspended metal wires, may also be suitable for different clad-less devices where the properties can be thermally controlled.

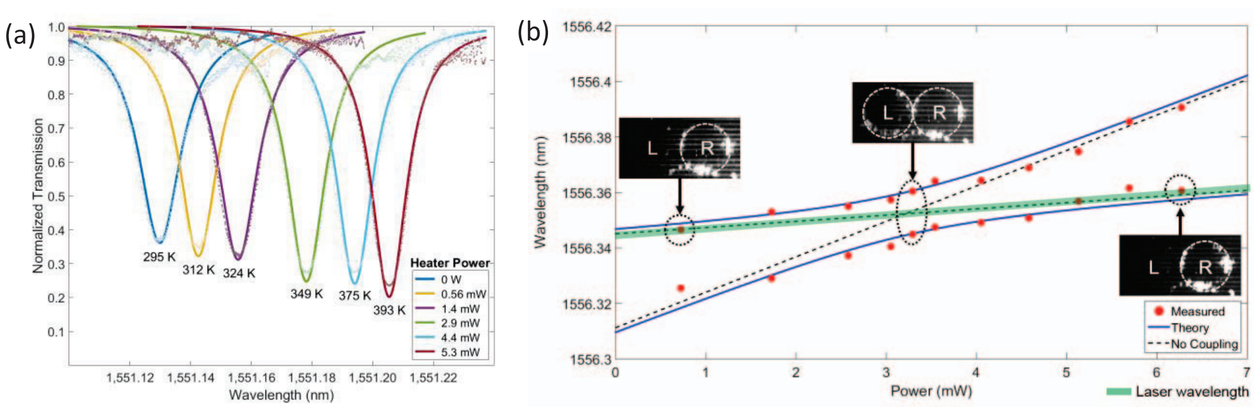

Fig. 2. (a) Optical transmission of single suspended micro-resonator. The solid lines are fitting to the measured data. The temperature at each heater power is also shown. (b) The two resonant wavelengths of evanescently coupled resonators plotted at different heater power. The laser is coupled into the right disk (R) using a tapered fiber while the heater of the left disk (L) is powered. The inset figures are infrared camera images of the coupled resonators system at different left (L) heater power. The green line indicates the laser wavelength used to couple light into the right disk (R).

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