Ultra-thin microdisk resonator fabricated with MPW

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***Abstract*—An ultra-thin suspended microdisk resonator, subwavelength grating-cladding waveguide, and subwavelength grating couplers were fabricated with a multi-project wafer service. A quality factor of ~10^3 with a ~43-dB extinction ratio was demonstrated at 2250 nm wavelengths.**

Keywords—Mid-IR devices, ultra-thin, suspended photonic waveguides, silicon-on-insulator, microdisk resonator.

I. Introduction

Suspended silicon photonic devices have received substantial research interest in the previous decades [1]-[3]. Compared with conventional waveguide configurations, suspended photonic structures have a few essential advantages including enhanced optomechanical and photo-thermal-mechanical dynamic interactions [4], lower absorption optical losses after removing buried oxide and silica claddings to extend the transparency window to the mid-infrared wave band [5], and high sensitivity to the variation of devices' environmental conditions for sensing applications [6]. As a result, suspended silicon photonic integrated circuits have been widely explored in vast applications of developing nano-opto-electro-mechanical components [7], optomechanical devices [8], waveguide-coupled photonic cavities in mid-infrared wavelengths [9], and on-chip photonic gas sensors [6].

Silicon-on-insulator wafers provide excellent platforms to develop mid-infrared silicon photonics. Due to the strong optical absorption of silica to mid-infrared light [10], researchers usually use wet etching processes to remove silica cladding and buried oxide on silicon chips to form suspended photonic structures. Then, it is possible to greatly extend the transparency windows of silicon waveguides to a wavelength of 8 μm [11]. Moreover, the suspended photonic devices could show improved performances [12] and device compactness [13], still benefiting from high-quality silicon-on-insulator materials and CMOS-compatible fabrication techniques. To date, suspended silicon waveguides [9], subwavelength grating couplers [14], microring resonators [15], microdisk resonators[16], and photonic crystal devices[17] have been reported. The thicknesses of reported suspended silicon devices developed on a silicon-on-insulator wafer are typically in the range of hundred nanometers. Compared with thick silicon devices, tens-of-nanometers thin silicon waveguide devices can exhibit giant evanescent-field energy proportions and optical mode areas [18], providing great potential in developing applications of sensing, nonlinear optics, and optoelectronics. However, ultra-thin suspended membrane silicon devices have seldom been explored in the mid-infrared range.

In this paper, we demonstrated an ultra-thin suspended microdisk resonator based on a silicon-on-insulator wafer for mid-infrared applications. The devices were fabricated

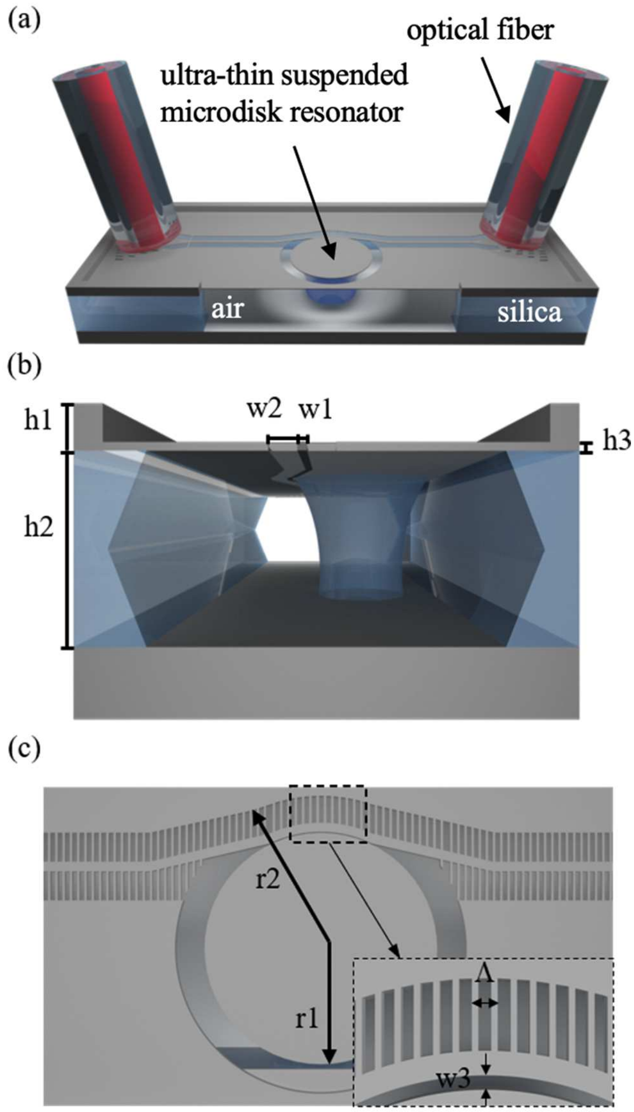

Fig. 1. Schematic of the ultra-thin suspended silicon devices. (a) 3D view of the integration of ultra-thin suspended microdisk resonator, subwavelength grating coupler, and subwavelength-grating-cladding waveguide. (b) Cross-section view of the ultra-thin suspended silicon devices. (c) Top view of the ultra-thin suspended microdisk resonator.

based on a standard multi-project wafer (MPW) service followed by a wet-etching process. A quality factor of ~10^3 with a ~43-dB extinction ratio was demonstrated at 2250 nm wavelengths. Our work is expected to advance the development of ultra-thin photonic integrated circuits for mid-infrared applications.

II. Design and Fabrication

A schematic of the ultra-thin suspended silicon devices is given in Fig. 1(a). The light was coupled into/out of the device by using a focusing subwavelength grating coupler

[19]. The devices were designed on a silicon-on-insulator wafer with a 70-nm thick (h1) top silicon layer and 3-μm

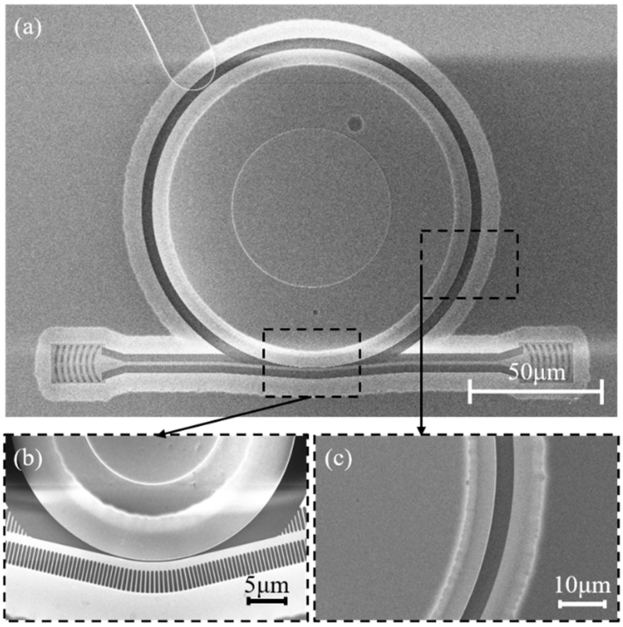

Fig. 2. SEM images of the fabricated devices (a) Ultra-thin suspended microdisk resonator coupled by using the subwavelength grating coupler and subwavelength-grating-cladding waveguide. (b) Zoom-in view of the ultra-thin suspended microdisk resonator coupled with the subwavelength-grating-cladding waveguide. (c) Zoom-in view of the edge of the ultra-thin suspended microdisk resonator.

thick (h2) buried oxide, as indicated in Fig. 1(b). Moreover, the widths of the coupled bus waveguide (w1) and subwavelength-grating-cladding (w2) were designed as 1.2 μm and 3 μm. The microdisk radius, bending waveguide radius, period of the subwavelength-grating-cladding, and the gap between the coupling bus waveguide and microdisk were selected as 60 μm (r1), 64 μm (r2), 0.55μm (Λ), and 0.21 μm (w3), respectively, as indicated in Fig. 1(c). According to the simulation, only a fundamental transverse electric mode (TE_0) can be supported in the designed waveguide. It is worthwhile to note that, besides the microdisk resonator, the thicknesses of the subwavelength grating coupler and subwavelength-grating-cladding waveguide were also designed as 70 nm (h3), which has been reported in our previous study [20]. The thickness and device feature sizes are compatible with the commercial MPW service, in which a 220-nm thick top silicon layer can be etched to 70 nm thick by using the provided 150-nm depth dry etching process.

Fig. 2(a) displays scanning electron microscopy (SEM) images of the fabricated ultra-thin suspended silicon devices. The silica cladding and buried oxide beneath the ultra-thin microdisk resonator, subwavelength-grating-cladding bus waveguide, and subwavelength grating couplers have been locally removed by soaking the silicon chip in a dilute hydrofluoric acid solution. While the microdisk and coupling waveguide can be supported by using the remaining silica pedestal and silicon subwavelength grating cladding. As shown in Fig.2 (b) and Fig.2 (c), the fabricated device exhibits moderate roughness and displays a distinct air gap between the bus waveguide and microdisk resonator. The light in the ultra-thin fundamental mode waveguide could be evanescently side-coupled into the ultra-thin suspended microdisk resonator.

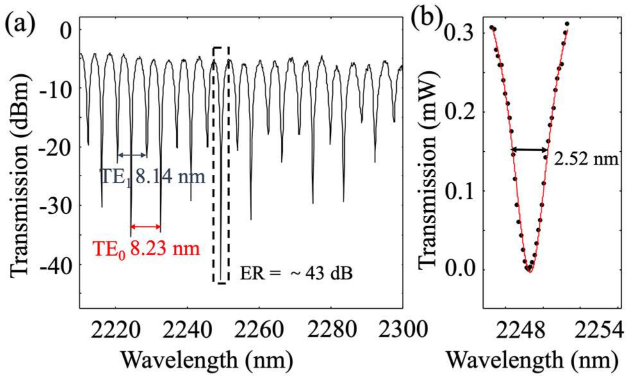

Fig. 3. Normalized transmission spectrum of the fabricated ultra-thin suspended microdisk resonator. (a) Normalized transmission spectrum of the device over a wavelength range from 2210 nm to 2300 nm. (c) Zoom-in spectrum of the device around the wavelength of 2249.32nm and the fitting curve by using a Lorentzian function.

III. Measurement and Discussion

We experimentally measured the fabricated ultra-thin suspended microdisk resonator in the wavelength range from 2210 nm and 2300 nm. The transmission spectrum was normalized by using the coupling spectrum of the subwavelength grating coupler, as shown in Fig. 3(a). According to the result, two free spectrum ranges, namely, 8.23 nm and 8.14 nm, were measured with the fabricated microdisk resonator. Therefore, two groups of resonant modes, namely, TE_0 and TE_1, may exist in the ultra-thin suspended microdisk resonator. Moreover, due to different coupling conditions and optical losses, the resonant spectra of the two types of modes provide various extinction ratios (ERs) and quality factors (Q factors). Figure 3 (b) shows that the loaded Q factor with an ER of ~43 dB was measured to be ~10^3 at a wavelength of 2249.32 nm for the TE_0 mode. According to Fig. 2 (b), the bending waveguide was applied to increase the coupling between the subwavelength-grating-cladding waveguide and ultra-thin microdisk resonator to achieve a critical coupling condition. More results will be reported at the conference.

IV. Conclusions

We designed and demonstrated a mid-infrared ultra-thin suspended microdisk resonator integrated with subwavelength grating couplers and subwavelength-grating-cladding waveguide on a silicon-on-insulator wafer. The ultra-thin suspended microdisk resonator with a maximum Q factor of ~10^3 and ER of ~43 dB was experimentally measured at 2250 nm wavelengths. Our study is expected to pave the way for boosting mid-infrared applications based on silicon photonics.

Acknowledgment

The work was partly supported by the National Natural Science Foundation of China (62175179, 62161160335), and the National Natural Science Foundation of Guangdong Province (2022B1515130002).

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