Extended Abstracts of the 2014 International Conference on Solid State Devices and Materials, Tsukuba, 2014, pp160-161

A Novel Method of Fabricating Silicon Microsphere Resonators for High Quality-Factor Whispering-Gallery-Mode Generation

Che-An Lin[1], Jian-Hong Chen[1] and Lon A. Wang[1]

[1] Graduate Institute of Photonics and Optoelectronics,
National Taiwan University,
No.1, Sec. 4, Roosevelt Road, Taipei, 10617, Taiwan (R.O.C.)
Phone: +886-2-3366-3618 Email: lon@ntu.edu.tw

Abstract

A novel method was realized to fabricate silicon (Si) microsphere resonator from a Si-cored fiber by using a CO_2 laser reformation process. Whispering gallery modes (WGMs) in a Si microsphere resonator were obtained with quality factor (QF) as high as 1 x 10^5.

1. Introduction

Over the past decade, WGMs resonators [1] have been intensively investigated in dielectric and semiconductor materials with different shape geometries due to their high QF, small mode volume, and tunable resonance wavelength. Recently, Si WGMs resonators particularly attracted more attention due to its much higher optical nonlinearities compared to the commonly used silica materials, boarder transparency window extending to mid infrared region (λ= 1.5-7 μm) [2], and full compatibility with the existing Si plateform.

Si WGMs resonators with disk and ring structures fabricated by using the standard semiconductor process on a silicon-on-insulator (SOI) substrate have been reported to show high QF's [3,4]. Most of those high QF resonator require complex, time-consuming steps and expensive clean-room facilities. In this work we report an alternative which offers rapid and effective fabrication of high QF Si resonators. Firstly, a Si-cored fiber was made in an unconventional way. Secondly, a portion of the fiber's cladding was removed to expose the Si core. Thirdly, the CO_2 laser reformation was applied to the exposed Si core to form a Si microsphere. The overall fabrication time could be reduced to minutes as compared to hours long needed for the conventional semiconductor processing. QF as high as 1 x 10^5 and ~96% coupling efficiency were obtained at ~1551 nm wavelength by the tapered fiber coupling method to a Si microsphere whose diameter was 42 μm.

2. Experimental Results

A Si-cored fiber was made by a combined techniques of powder-in-tube and vertical-drawing. Polycrystalline Si powders (99.999% purity) were packed in a fused silica tube, which was inserted in the heated zone and drawn from a homemade fiber drawing tower. The temperature was controlled in such a way that the Si powders were completely molten. The liquefied Si was encapsulated by the softened silica cladding, and then transformed to the solid core when the fiber was drawn out from the heated zone. The Si-cored fiber could be more than 1 meter long, and the Si core and silica cladding diameters were in the range of ~10-30 and ~100-300 μm, respectively.

A Si-cored fiber with core and cladding diameters 21 and 195 μm as shown in Fig. 1(a) was used in this work to fabricate Si microspheres. Firstly, the silica cladding of Si-cored fiber was etched away by buffered hydrofluoric acid (HF) solution. After etching the Si core was released from the silica cladding, as shown in Fig. 1(b). Then a 10W CO_2 laser beam (λ=10.6 μm) was focused onto the released Si-core region. A situation could be reached so that the Si-core's phase was transformed from solid to liquid. The surface tension shaped the molten Si into a Si microsphere standing on the end of the Si-cored fiber. No obvious inhomogeneity or defect on the surface of the microsphere could be observed as shown in Fig. 1(c).

A tapered fiber with a diameter of 1.5 μm in the waist section was used to couple light in and out of the Si microsphere resonator. The tapered fiber was placed on a 3-axis precision transitional stage equipped with feedback system in order to achieve the best coupling efficiency between the tapered fiber and the Si microsphere. We used a tunable continuous wave laser diode controlled via a desktop computer to scan near the wavelength around 1.55 μm. An isolator was used to prevent the laser diode from damage because of back-reflection. A microscope equipped with a CCD camera was placed on the top of coupling system to monitor. The output resonance spectrum was detected by using the built-in power detector in the same tunable laser source.

As seen in Fig. 2(a), the measured transmission spectrum for the Si-microsphere with diameter of 42 μm clearly shows several deep resonance dips in the wavelength range from 1549 to 1554 nm. The highest QF obtained in this system was 1 x 10^5 near 1551 nm wavelength. It is worth noting that no obvious mode splitting or double dips is observed in the transmission spectrum. The undesired mode splitting is attributed to the scattering off the surface roughness which lifts the degeneracy of clockwise and counterclockwise propagating WGMs. Such mode splitting usually can be found in some resonators fabricated by the standard semiconductor process. Therefore, the CO_2 laser

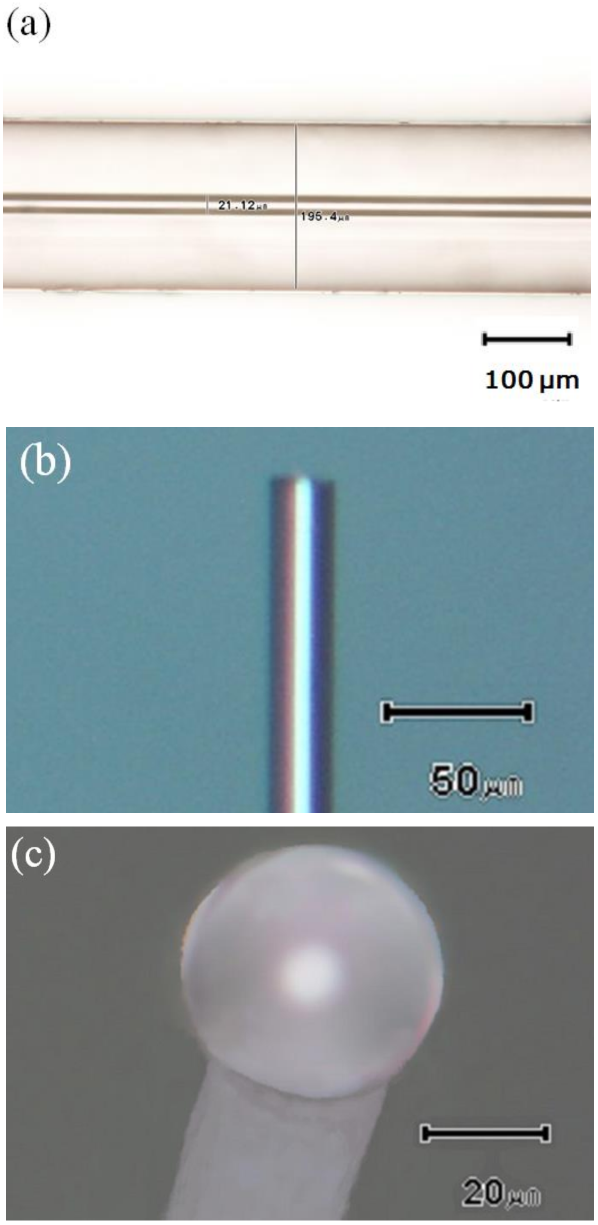

Fig. 1 Microscope pictures: (a) a Si-cored fiber with 21 μm diameter in Si core and 195 μm diameter in silica cladding, (b) a released Si core after its cladding being removed, (c) a Si microsphere in diameter of 42 μm after CO_2 laser exposure.

molten Si microsphere indicated its surface was smooth enough to sustain WGMs. In Fig. 2(b), the enlarged spectrum shows a single resonant dip at λ=1551.594 nm with ~96% best coupling efficiency. The Lorentzian curve fitting was applied for the resonant dip to determining its bandwidth, leading a QF (λ/Δλ) as high as~1 x 10^5.

3. Summary

A Si microsphere resonator was fabricated by using CO_2 laser reformation method over a Si-cored fiber without silica cladding. The WGMs were successfully excited in the Si microsphere, and high QF was obtained. Such a fabrication method would provide an alternative way to obtain a

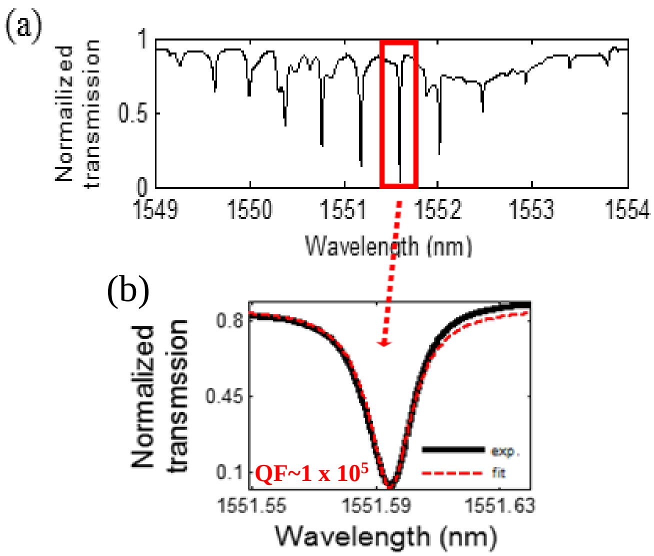

Fig. 2 (a) The normalized WGM spectrum scanned from 1549 to 1554 nm for a Si microsphere of 42 μm in diameter. (b) The enlarged spectrum shows that a single resonant dip at λ=1551.594 nm.

high QF Si microsphere resonator with smooth surface in short time without the need of expensive clean-room facilities.

Acknowledgements

This work was supported by the Ministry of Science and Technology (NSC101-2221-E-002-079-MY2) and National Taiwan University (NTU-ICRP-102R7558).

References

[1] K. J. Vahala, Nature **424**, 839 (2003).
[2] O. Boyraz and B. Jalali, Opt. Express **12**, 5269 (2004).
[3] M. Soltani, S. Yegnanarayanan and A. Adibi, Opt. Express **15**, 4694 (2007) .
[4] H. Yi, D. S. Citrin, and Z. Zhou, Opt. Express **18**, 2967 (2010) .
[5] M. Eichenfield, C. P. Michael, R. Perahia and O. Painter, Nat. Photonics **1**, 416 (2007) .