FABRICATION OF SILICON SPHERICAL MICROCAVITY BY LASER HEATING ON CHIP

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Optical microcavities have attracted considerable attention and played an important role in on-chip classic as well as quantum information processing during the past decades. High quality optical microcavities with Q factor $>10^7$ are mostly made from silica using techniques such as reflow, sophisticated etching to create wedged facet [1], etc. The transparent window for silica, however, is limited in the visible and near-infrared region. There are enormous vital applications in the mid-infrared region, where optical microcavities can be leveraged. Silicon is a transparent optical medium from near-infrared up-to 8μm in the mid-infrared region, and it has a very large nonlinear coefficient (e.g., its third-order nonlinearity susceptibility is 10^3 times higher than that of silica) [2]. Therefore silicon is an excellent candidate for fabricating optical microcavities in this wavelength region. In order to improve the quality factor of silicon microcavities, much effort has been devoted to reduce the scattering loss caused by surface roughness, which could include dry oxidation, wet chemical etching and hydrogenation [3-5].

Here, we propose to fabricate silicon spherical microcavities by laser heating inverted silicon cones under atmospheric pressure and at room temperature. Different etching processes are used in experiment to produce inverted cones on silicon-on-insulator (SOI) substrate, and then a careful direct laser heating step with proper influence reshapes the cones to spherical microcavites as a result of surface tension. The exact shape and morphology of the prepared silicon spherical microcavities are characterized using SEM and AFM.

A flow chart showing our fabrication procedures is illustrated in Figure 1. An AZ5214 resist layer is first used for the lithography process on a SOI wafer with a 16um silicon device layer and a 2um buried oxide layer. The etching processes are carried out by inductively coupled plasma (ICP) with two steps each with unique etching parameters, first to define silicon pillars and the second to under etch the pillar to form inverted cones. Figure 2(a) shows a typical etched inverted silicon cone. By using an in-house imaging and laser heating setup, the invert silicon cones are located on the chip and illuminated by a focused green laser beam with a controlled exposure. According to the front and top view shown in Figure 2(b) and (c), the silicon spherical microcavity has a diameter about 16μm with slight imperfection near the top. Such imperfection is consistent from sample to sample. It is thus speculated to be related with the crystallization of the silicon during the rapid cooling down period when the laser exposure is off. Nevertheless, the top view of such structure suggests that it has a well-defined round-shaped equator. AFM is used to examine the surface roughness of our fabricated silicon microcavities. The surface tomography of a typical sample is shown in Figure 3. It shows that the root-mean-square (RMS) roughness is about 0.6 nm, a very encouraging number, which has been to shown to support very low loss propagation in a waveguide configuration. It is very likely that this kind of silicon micocavites can support high Q whisper-gallery modes confined to near the equator, away from the imperfection seen in the SEM picture. Optical testing of these microcavities are currently being actively conducted. We believe that our approach for producing low surface roughness silicon microcavities will have a major impact in CMOS integrated photonics in future.

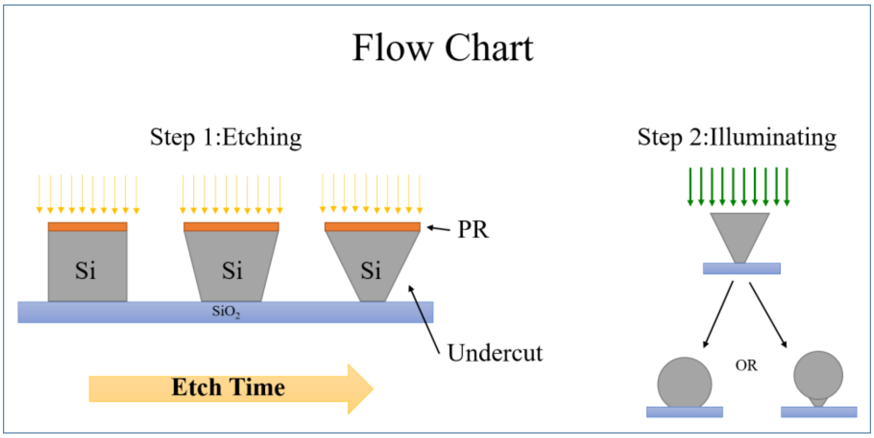

Fig.1 Flow chart of fabrication of micro silicon spherical cavity by laser heating on chip

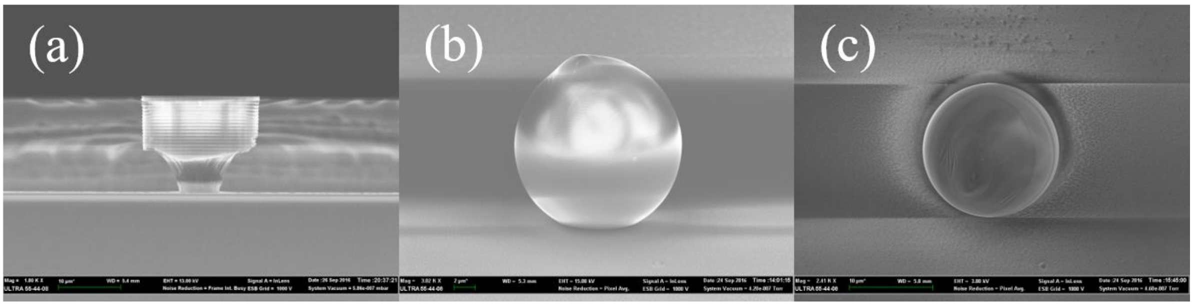

Fig. 2 SEM images of an inverted-cone silicon structure (a); front view (b); top view (c); edge part (d) of silicon spherical micro cavity.

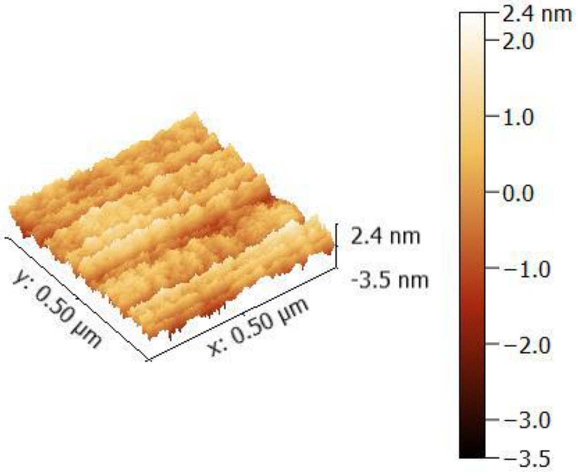

Fig. 3 AFM photo of the silicon spherical micro cavity

REFERENCES:

[1] H. Lee, T. Chen, J. Li, K. Yang, S. Jeon, O. Painter, and K. J. Vahala, “Chemically etched ultrahigh-Q wedge-resonator on a silicon chip,” Nat. Photonics. **2012**, 6, 369–373.

[2] G. P. Agrawal, *Nonlinear Fiber Optics*, 2nd edition (Academic Press, New York, **1995**).

[3] J. Takahashi, T. Tsuchizawa, T. Watanabe, S. Itabashi, "Oxidation-induced improvement in the sidewall morphology and cross-sectional profile of silicon wire waveguides," J. Vac. Sci. Technol. B **2004**, 22, 2522.

[4] D. K. Sparacin, S. J. Spector, L. C. Kimerling, "Silicon waveguide sidewall smoothing by wet chemical oxidation," J. Lightw. Technol. **2005**, 23, 2455.

[5] H. Kuribayashi, R. Hiruta, R. Shimizu, K. Sudoh, H. Iwasaki, "Shape transformation of silicon trenches during hydrogen annealing," J. Vac. Sci. Technol. A **2003**, 21, 1279.