Cloning of a fully functional Si-based photonic integrated circuit by ultraviolet nanoimprint lithography

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Silicon (Si)-based photonic integrated circuits (PICs) operating in the relevant 1.55 μm wavelength range are emerging as a really promising tool in the field of data transmission [1]. Si waveguides (WGs), in which light is confined and guided by total internal reflection, are key elements of these PICs [1]. Due to the great span in feature size of the photonic structures (nm to cm), it is crucial to find one low-cost fabrication process for all feature size regimes [2, 3].
In the present work, we demonstrate the feasibility of ultraviolet nanoimprint lithography (UV-NIL) as fabrication method for Si-based PICs and, for the first time, the cloning of a sample which was not designed for the usage as master in UV-NIL, but instead contains fully functional, high-quality Si photonic structures. Further, this approach offers the possibility to directly quantify the structural fidelity of imprint and pattern transfer by comparing the optical properties of the clone with the master's. The original sample was purchased from AMO GmbH and is a silicon-on-insulator (SOI) structure, containing single-mode vertically slotted WGs and resonators in the top Si layer. The WGs are 600 nm wide at the ring resonator area and about 1 cm long. Their height of 220 nm is determined by the thickness of the top Si layer. The smallest feature size is the 100-nm-wide slot. The quality of the original sample was determined by transmission measurements (Fig. 2, black/upper curve) with a standard WG setup, before it was used as master for UV-NIL processing. The stamp fabrication was performed using a PFPE material and a glass backplane. Then, the stamps were used to imprint the mr-UVCur06® resist on SOI wafers, with identical parameters as the original SOI sample. After UV-NIL, the resist structures have the same height as the top Si layer of the substrate. Therefore, an etch selectivity greater than 1 has to be achieved for the pattern transfer into the Si and down to the oxide. This is established by ICP-RIE in a gas mixture of SF_6/O_2, where we optimized the etching approach of Ref. [4] to obtain vertical and smooth sidewalls for our material system [Fig. 1 (b)]. By using this method, we successfully cloned vertically slotted Si WGs and resonators with UV-NIL. The success is demonstrated by comparing the quality factor (Q_{factor}) values of the resonances of the ring resonators of the cloned and original sample, which were determined by transmission measurements at wavelengths from 1500 nm to 1515 nm (Fig. 2). The cloned sample has a Q_{factor} as high as the original sample of about 6500.

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[3] T. Kim et al. IEEE J. Quantum Electron. 13 (2007) 177.
[4] Y. Wu et al. Microelectron. Eng. 88 (2011) 2785.

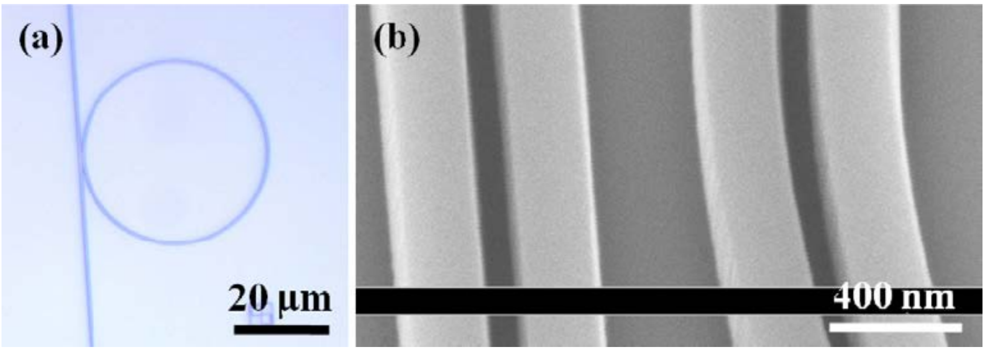

Figure 1: (a) Optical and (b) scanning electron microscope image of a vertically slotted ring resonator with a radius R = 20 µm and a ring-waveguide gap of 250 nm on the cloned sample. The width of the waveguide and the slot trench is 600 nm and 100 nm, respectively.

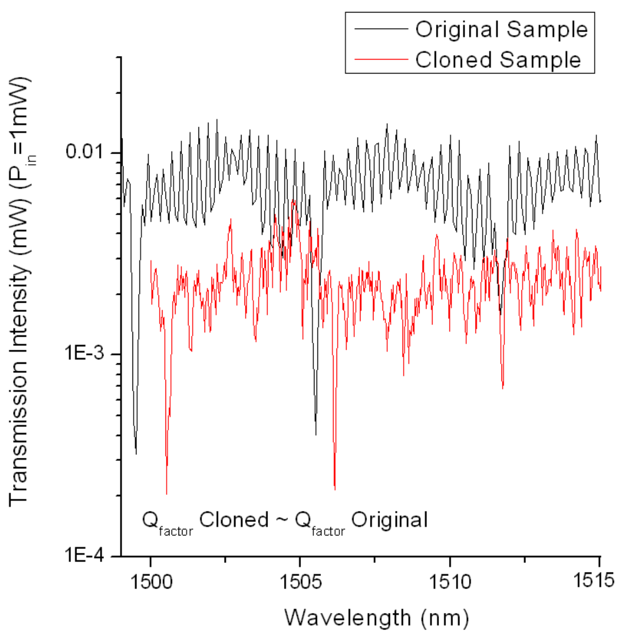

Figure 2: Transmission measurements in TE polarization of a vertically slotted ring resonator with radius R = 20 µm and a ring-waveguide gap of 350 nm for the original sample (black/upper curve) and its clone (red/lower curve). Resonances are observed with a quality factor of Q_{factor} ~ 6500.