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# Effects of Disorders on Ring Resonator-Based Topological Lasers at 1.55 µm

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**Abstract:** We investigate the disorders of microring resonators caused by conventional microfabrication technologies. Our experimental and theoretical results help understand the degree of the disorders in a ring array and their impact on topological insulator lasers. © 2022 The Author(s)

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Recently, there has been rapid development in the area of topological photonics motivated by a primary consideration of leveraging topological edge states to guide and manipulate light in a way that is robust against disorders. Implementing topological insulator lasers (TILs) is one of the most active directions of topological photonics, where a gain medium is inserted in a topological cavity to implement laser oscillations. Compared to conventional III-V diode lasers, the novel topological device concept provides an avenue to make lasers more efficient, more coherent, and more compact at the same time they become immune to all kinds of fabrication imperfections and defects [1, 2]. There are a series of works demonstrating lasers emitting from a 0D topological edge state in a 1D chain. However, there was no edge transport at all in the systems, hence no protection to onsite disorder, and the lasing was almost fully-confined to a single resonator. Early demonstrations of optically- and electrically-pumped lasers [3, 4] have shown the promise of topological lasers based on the quantum spin Hall effect but a systematic and quantitative study on the influence of disorders and allowable disorders towards achieving topological lasing is still missing. To assess the robustness of lasing to disorder, we theoretically and experimentally study the role of fabrication process-induced disorders present in InP-based optically-pumped microring devices emitting around 1.55 µm.

Figs. 1(a)-(b) show the angled scanning electron microscope (SEM) images of InGaAsP/InP ring structures which are dry etched using soft HSQ- and hard $SiO_2$-mask materials, respectively. From the insets of Figs. 1(a)-(b), the structures etched by soft resist mask exhibit a ~79° sidewall angle which is probably caused by mask erosion during the plasma etching. Using the same plasma chemistry, the structures masked by $SiO_2$ show nearly vertical sidewall angles. This is due to the high etch selectivity between $SiO_2$ and InGaAsP epitaxial layers. The high selectivity helped achieve not only vertical- but also smooth-sidewalls, with a flat bottom on III-V etched regions. After encapsulating the structures with 3-µm-thick $SiO_2$, attaching the samples to glass substrates and finally substrate removal, device fabrication steps were completed. The optical microscope images of the fully-processed ring devices masked by both HSQ and $SiO_2$ with the glass substrate side face-down are shown in Figs. 1(d)-(e). The insets show the non-uniform ring periphery as detected under the visible standard optical microscope. This could be attributed to nonuniform substrate removal implemented by non-selective wet etching.

One of the most straightforward ways to visualize the disorders of ring resonators is to measure the resonant wavelengths, and *Q* factors of each ring in an array and compare the values with each other. Ideally, all the resonators should oscillate at the same frequency. To examine the disorders within a whole topological laser system, we optically-pumped each individual ring in an array using a 980 nm pump source as shown in Fig. 2(a). Figs. 2(b)-(c) shows the summary of the spectral full-width at half-maximum (FWHM) versus resonant wavelengths of each ring in the processed samples. The spread of the disorders observed in these samples could be explained by a number of factors including ring radius variation causing localized effective refractive index changes due to roughness and other perturbations as well as the e-beam lithography process variation; sidewall angle variation from mask erosion during dry etching and substrate thickness variation after substrate removal. These fabrication process induced parameters and their influence on ring resonator device performance will be discussed and the associated theoretical results will be presented during the conference.

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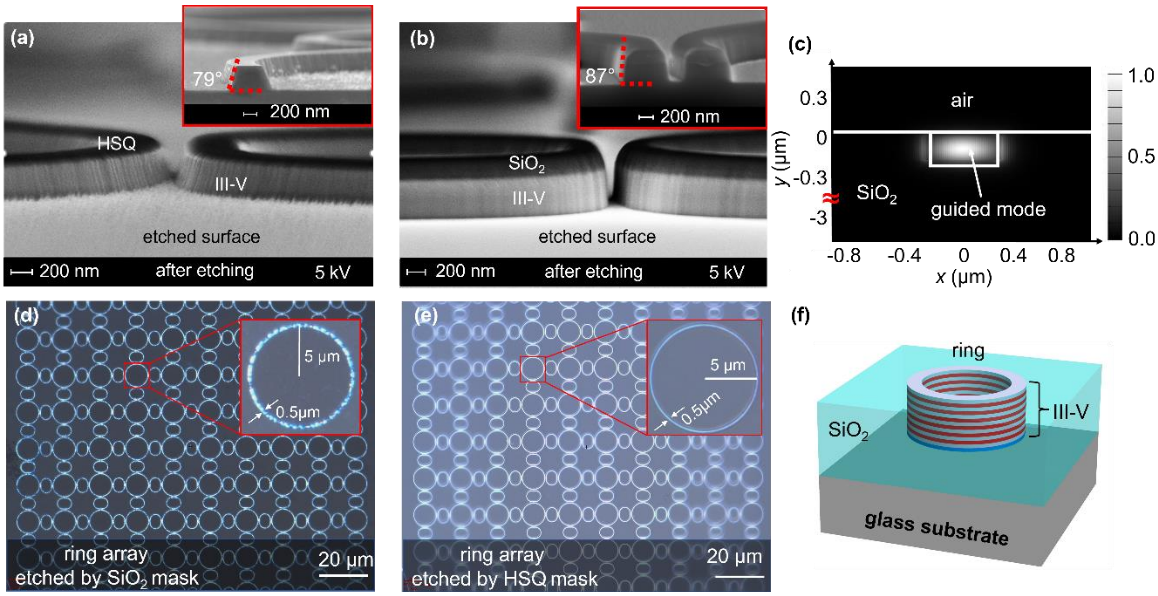


Fig. 1. (a-b) SEM images showing the variation of sidewall roughness with the masks. The insets show the angles of the etched ring waveguides; (c) Simulated transverse mode intensity profile of the ring resonator; Optical microscope image of the fully processed optically pumped devices (d) etched by $SiO_2$ mask; (e) by HSQ mask; The insets show the single ring at higher magnification; (f) schematic of the processed devices

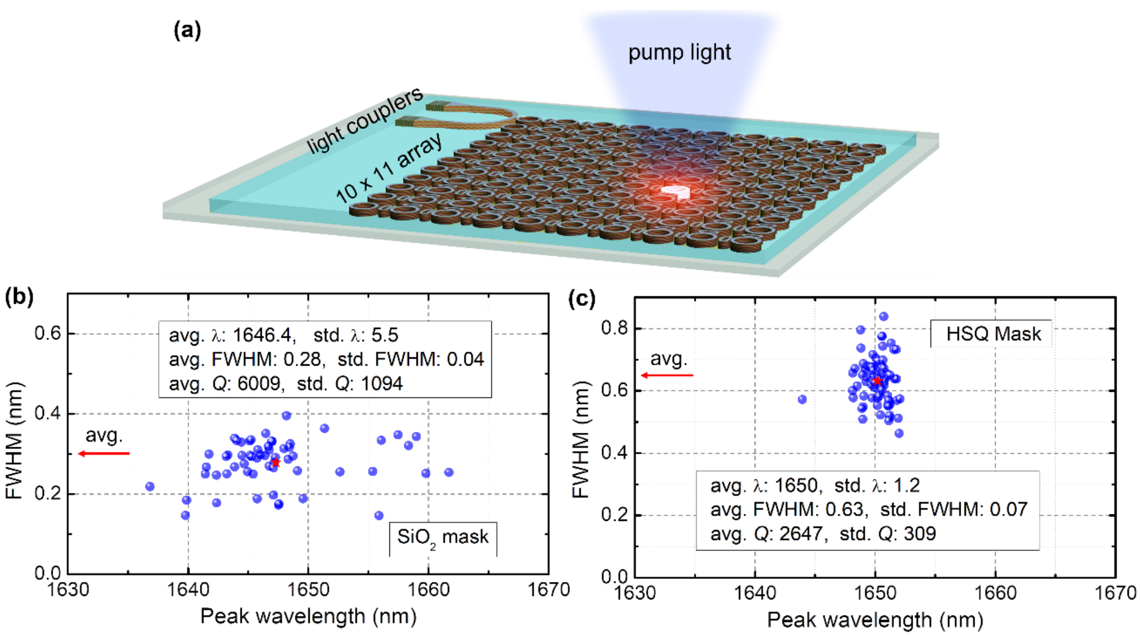


Fig. 2. (a) Schematic of a topological array when pumping each ring individually; resonance wavelengths and linewidths of all the rings etched by (b) $SiO_2$ hard mask and (c) HSQ soft mask. The measured data of each ring within the array are superimposed.

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