High-Q suspended optical resonators in 3C-SiC obtained by thermal annealing

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Abstract: We fabricate suspended single-mode optical waveguides and ring resonators in 3C-SiC that operate at telecommunication wavelength, leverage post-fabrication thermal annealing to minimize optical propagation losses and demonstrate Q of over 41,000.

Cubic silicon carbide (3C-SiC) has been gaining momentum as a platform to realize many optical functionalities due to its diverse properties such as wide band gap (2.2 eV) , large second order nonlinear susceptibility [1], large Kerr nonlinear refractive index [2], high refractive index (~2.56), tolerance to high optical power, large bulk Young's modulus and CMOS compatibility [3] make it a viable alternative to silicon with potential for integration of optoelectronics. Suspended SiC photonic structures, such as waveguides, micro-disks [4] and photonic crystal cavities [5] are of interest for opto-mechanical experiments [6], accelerometry, large-surface applications e.g. sensing and coupling of phonons to quantum emitters [7]. Suspended SiC structures fabricated on standard SiC on Si substrates are compatible with high temperature thermal annealing due to the absence of intermediate layers, as the thermal expansion coefficient of SiC and Si are of the same order in magnitude [8]. This is useful for increasing the crystal purity for lowered scattering or absorption losses from imperfect material growth, oxidation-smoothing of sidewalls with oxygen annealing or implantation of ions such as vanadium or rare earths [9] which are useful for creating optically active emitters or doped optical amplifiers.

Up to now, suspended 3C-SiC ring resonators feature optical quality (Q) factors below 24,000 [10,11], where the latest results show waveguides featuring propagation losses of 21 dB/cm using 1550 nm light [11]. We show that the waveguide loss in these types of structures can be reduced by post fabrication thermal annealing. A root-mean-squared (RMS) roughness of 1.7 nm on top of the fabricated waveguide is achieved after annealing. Our results show a reduction in loss from 24 dB/cm to 7 dB/cm at 1550 nm by annealing the waveguides in a high temperature oxygen atmosphere corresponding to an intrinsic Q factor of over 41,000.

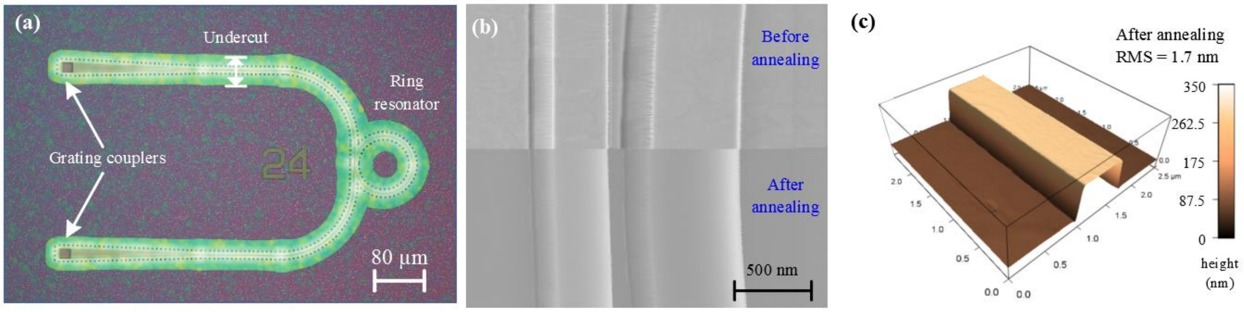

Fig. 1. (a) Optical micrograph of the fabricated device (b) scanning electron micrograph of the coupling region between the bus waveguide and ring waveguide with a 40 um radius, 0.8 um waveguide width and 100 nm coupling gap (c) atomic force micrograph of the waveguide surface after annealing

We fabricate waveguide coupled suspended microring resonators with a bending radius of 40 μm, and various coupling gaps ranging from 100 nm up to 400 nm (increments of 50 nm) to cater for waveguide losses with microring waveguide widths of 0.8, 1, 1.5, 1.8 and 2 um totaling 40 resonators with each input and output coupled to a vertical grating coupler (VGC) as shown in Fig. 1a with the undercut region visible as a green translucent area surrounding the waveguides. The samples are annealed in an oxygen atmosphere at 1100ºC for 2 hours. Scanning electron microscopy (SEM) images with 30° tilt of the bus waveguide and ring resonator coupling region before and after thermal annealing are shown in Fig. 1b. A clear reduction in sidewall roughness of the waveguides is observed after the annealing step. Atomic force microscopy (AFM) is used to measure the surface roughness of the waveguides which shows an RMS roughness of 1.7 nm (Fig. 1c) measured on the top surface of the waveguide compared to 2.4 nm RMS measured before annealing.

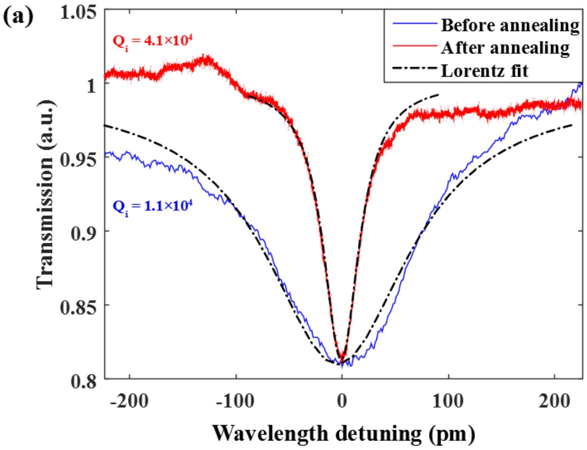

Fig. 2. (a) Lorentzian fit of the resonance of the third order mode before (1520.5 nm) and after annealing (1532.7 nm) indicating a significant reduction in linewidth

Critically, we determine the optical quality factor of the fabricated ring resonators prior to and subsequently after annealing to determine any impact of annealing on waveguide propagation loss. The comparatively large waveguide width is chosen to reduce the impact of sidewall scattering losses to the measured Q-factor such that intrinsic material limited loss can be inferred. The highest Q factors are observed in higher-order modes, suggesting intrinsic scattering may contribute more to loss than sidewall roughness. The same spatio-longitudinal mode, which features the highest intrinsic Q when compared to all other longitudinal modes, was compared to that before and after annealing as shown in Fig. 2a. A 146 pm linewidth was measured before annealing, corresponding to an intrinsic Q of 1.1×10^4 indicates linear propagation losses of around 24 dB/cm. After annealing the linewidth is reduced to 39 pm, corresponding to an intrinsic Q factor of over 4.1×10^4 which is the result of an estimated linear propagation loss of 7 dB/cm, a 340% improvement.

In conclusion, we show that post fabrication thermal annealing is an effective and viable method for reducing optical propagation loss in 3C-SiC microring resonators. We find that thermal annealing can reduce sidewall roughness and potentially lead to a reduction in crystal defects which have traditionally been the dominate contributors to optical loss in 3C-SiC grown on Si. This work paves the way toward low loss suspended devices in 3C-SiC which are important for optomechanical devices and opens the possibility for new experiments such as stimulated Brillouin scattering and surface acoustic devices which could utilize the excellent mechanical properties of this platform. This work was carried out at the Harvard Center for Nanoscale Systems (CNS), a member of the National Nanotechnology Infrastructure Network (NNIN).

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