Hybrid Chalcogenide-Silicon Subwavelength Grating Waveguides Microring Resonators

Philippe Jean, Alexandre Douaud, Sophie LaRochelle, Younès Messaddeq and Wei Shi

Centre d'Optique, Photonique et Laser (COPL), Université Laval, Québec, QC, Canada

wei.shi@gel.ulaval.ca

Abstract: We present the fabrication and optical measurement of hybrid chalcogenide-silicon subwavelength grating waveguides microring resonators. The ring resonators exhibit nearly athermal behavior with $d\lambda_r/dT = -2.87$ pm/K and intrinsic quality factor of $Q_i >$ 50000.

Silicon subwavelength grating waveguides (SWG) are one-dimensional periodic waveguides that propagate diffraction-less Bloch modes by operating at wavelengths longer than their band gap [1]. These unique structures enable new design horizons in silicon structures by adding a degree of freedom in controlling their dimensions along the periodic axis while their low-confinement behavior and full trench inter-silicon void gaps make them attractive for heterogeneous integration of exotic materials. Chalcogenide (ChG) glasses provides unique properties that can find applications in integrated optics such as their photosensitivity or their rare earth solubility [2]. Therefore, the combination of silicon SWG and ChG glass can provide a hybrid waveguide with extended functionalities and many promising applications such as reconfigurable devices or on-chip amplifiers. In this work, we report the fabrication and characterization of hybrid chalcogenide-on-silicon SWG microring resonators (SWGMR) with high quality factor and low thermal dependence. The $As_{20}S_{80}$ composition is chosen for its low loss, negative thermo-optic coefficient (TOC) and polymer-like behavior towards thermal treatment ($T_g \approx$ 100 °C).

The chips were fabricated at Applied Nanotools (ANT) through the SiEPICfab consortium. The glass preparation and deposition were performed in-house at COPL using the methods described in [3]. Following deposition, the samples were annealing in a N_2/Ar environment at 150 °C for 120 s. The resulting SWGMR are presented in Fig.1. The waveguide considered here has a width $w = 300$ nm, thickness $t = 220$ nm and duty-cycle of $\delta = l/\Lambda = 0.5$ for a period of $\Lambda = 250$ nm. The devices were imaged before and after the deposition using a scanning electron microscope (SEM) and focused ion beam (FIB), the resulting images are shown in Fig.1(b) through (d). We draw special attention to the difference between Fig.1(c) and (d), which shows excellent filling of the chalcogenide glass in the small 125 nm gaps following annealing.

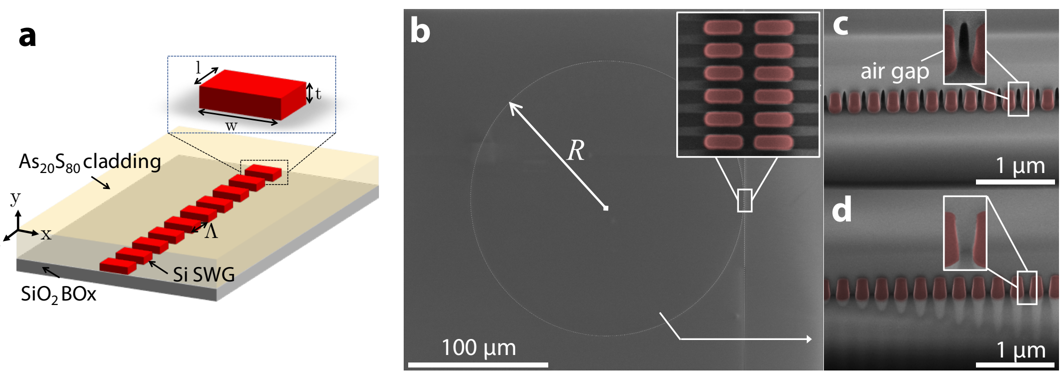

Fig. 1. (a) Schematic perspective view of a chalcogenide-silicon hybrid waveguide of width w, thickness t and period Λ. (b) Top view SEM image of the SWGMR of radius R with the coupling section shown as inset before deposition. FIB side cut along the SWG propagation axis after deposition and (c) before and (d) after thermal annealing. The insets in (c) and (d) show a close-up of the gap between Si blocks. The silicon is false colored red in (b,c,d) to enhance visibility.

The SWGMR were characterized using an optical vector analyzer (OVA) from LUNA and tapered fibers for coupling light to and from the chip. The chip was placed on a temperature controller (TEC) to stabilize its temperature. The transmittance over the C+L band is plotted in Fig.2 and show near critical coupling condition with large extinction ratio (ER) over 23 dB. The associated group delay is presented in Fig.2(b) and confirms that the SWGMR operates in the undercoupled regime at shorter wavelengths and approaches critical coupling at longer wavelengths. The group index is plotted in Fig.2(c) and shows that the SWGMR operates in normal dispersion. Undercoupled operation allows for direct calculation of the intrinsic quality factor, shown in Fig.2(d) and the associated waveguide propagation loss, shown in Fig.2(e). The minimum propagation loss measured is about 9 dB/cm, which agrees with similar demonstrations of hybrid SWG using oxide [4]. The absence of sharp increase in the group index and losses at shorter wavelengths suggests that the SWG operates within the first dielectric band away from the band edge, as designed [5]. Finally, the thermal dependence of the SWGMR was measured by varying the TEC temperature from 21 °C to 36 °C and fitting a linear relation to the resonant wavelength shift, the resulting thermal coefficient $d\lambda_r/dT$ is presented in Fig.2(f). Interestingly, the thermal dependence of the SWGMR is negative, indicating that the Bloch mode light is sufficiently confined inside the negative TOC $As_{20}S_{80}$ to compensate the high TOC of silicon ($dn_{Si}/dT \approx 1.8 \times 10^{-4}$).

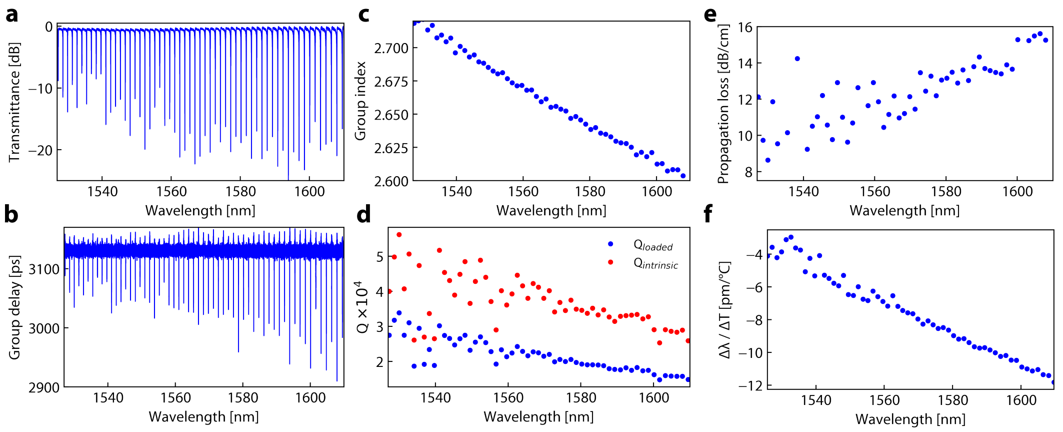

Fig. 2. Measured optical properties of the SWGMR: (a) Transmittance, (b) group delay, (c) group index, (d) waveguide propagation loss, (e) quality factor and (f) thermally induced resonant wavelength shift coefficient.

In summary, we reported the fabrication and measurement of hybrid chalcogenide-silicon subwavelength grating waveguide microring resonators that exhibit nearly athermal behavior and low-loss. These results are promising for further applications leveraging the chalcogenide unique properties such as its photosensitivity or nonlinearity.

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