Boosting the thermo-optic efficiency of silicon nitride waveguides

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Abstract: The thermal tuning efficiency of silicon nitride devices is enhanced by about four times by integrating a high-refractive index coating of silicon oxycarbide (SiOC) with a record thermo-optic coefficient of 2.5×10^{-4} °C^{-1}.

Introduction

Silicon nitride (Si_3N_4) is one of the most established photonic platforms, offering a good tradeoff between high scale of integration, low loss, low polarization sensitivity and efficient fiber–coupling. One of the strongest weaknesses of Si_3N_4 is the low thermo-optic coefficient (TOC), that is on the order of 10^{-5} °C^{-1}, which results in long (mm-scale) thermal actuators, requiring high electrical power (hundreds of mW for π phase shift) [1] and high working temperatures, and leading to severe thermal crosstalk issues.

Recently, we demonstrated that silicon oxycarbide (SiOC) enables the realization of high-index-contrast dielectric waveguides with a record TOC of 2.5×10^{-4} °C^{-1} [2], which is about 10 times larger than that of Si_3N_4. Here we show that the integration of a SiOC film on a conventional Si_3N_4 waveguide can enhance the effective TOC by about four times, thus providing a remarkable improvement of the thermo-optic tuning efficiency.

Thermooptic effect in SiOC

The SiOC films employed in this work were deposited by reactive RF magnetron sputtering from a SiC target, according to the process described in [3]. By changing the process parameters (RF power and O_2 flow), the SiOC refractive index can be tuned from that of SiO_2 (1.45) to that of SiC (above 3) by increasing the C content. To maintain transparency in the neat-IR range, we selected a material composition of $Si_{0.45}O_{0.27}C_{0.27}$, resulting in a refractive index of 2.2 in the near-IR range.

SiOC optical waveguides were fabricated by depositing a 175-nm-thick SiOC film (core) on a silica substrate [2], as shown in Fig. 1(a). After the SiOC core patterning, PECVD silica ($n = 1.45$) was deposited as upper cladding material. At a wavelength $\lambda_0 = 1550$ nm, the strip shaped waveguide has a group index $n_g = 1.93$ and propagation losss of 2 dB/cm for transverse electric (TE) polarized light. The TOC of the SiOC waveguides was evaluated by measuring the thermally-induced wavelength shift of unbalanced Mach-Zehnder interferometers (MZIs). Figure 1(b) shows the transmission of a MZIs, when the temperature T is increased from 25 °C to 35 °C. A wavelength shift $d\lambda/dT$ as large as 95 pm/°C is achieved, which corresponds to an effective TOC of the waveguide $K_{eff} = n_g\, d\lambda/\lambda_0\, dT = 1.2\times10^{-4}$ °C^{-1} that is one order of magnitude larger than typical dielectric waveguides. By considering the confinement factor of the optical mode in the waveguide core, we found that the TOC of SiOC, $K_{SiOC} = 2.5\times10^{-4}$ °C^{-1}, is the largest ever reported for a dielectric material employed in optical waveguides.

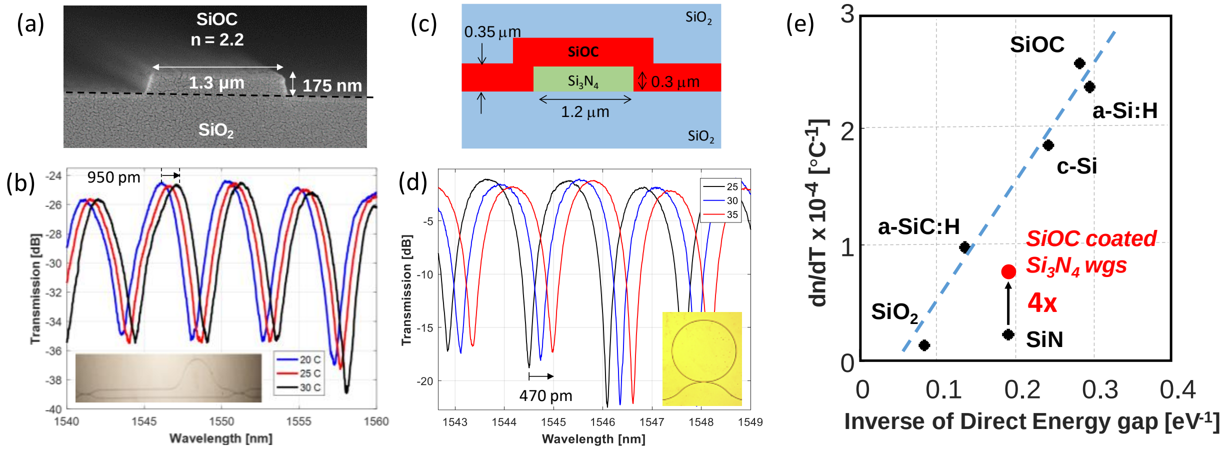

Fig. 1. (a) SEM image of a SIOC strip waveguide (before SiO_2 upper cladding deposition) and (b) thermally induced wavelength shift of the transmission of a SiOC MZI (inset). (c) Schematic cross-section of a SiOC-coated Si_3N_4 waveguide and (d) thermally induced wavelength shift of the transmission of a SiOC-coated Si_3N_4 microring resonator (inset). (c) Dependence of the TOC of several materials on the inverse of the direct-band-gap energy.

SiOC-coated Si_3N_4 waveguides

The high TOC of SiOC was exploited to enhance the thermal tuning efficiency of photonic devices fabricated with conventional Si_3N_4 waveguides. As shown in the schematic of Fig. 1(c), a 350-nm-thin SiOC layer (n = 2.2) was deposited on a Si_3N_4 strip waveguide (1.2 μm × 0.3 μm), which was then buried under a SiO_2 cladding. All-pass microring resonators [see inset of Fig. 1(d)] were fabricated by using SiOC-coated Si_3N_4 waveguides. Transmission measurements in Fig. 1(d) show a resonance shift by 470 pm when the temperature increases from 25 °C to 35 °C, resulting in an effective TOC of 7×10^{-5} °C^{-1}, which is about four times higher than the TOC of silica-buried Si_3N_4 waveguides (1.8×10^{-5} °C^{-1}).

The origin of the large TOC of SiOC is related to the increase of the dielectric polarizability near the transparency edge [4]. Figure 1(e) shows the TOC of various materials, which is almost linearly dependent on the inverse of direct energy gap E_g. The high TOC of SiOC, whose direct bandgap is around Eg = 3.5 eV, is well in line with this trend. The 4× TOC enhancement of SiOC-coated Si_3N_4 waveguides can be further increased by optimizing the waveguide shape to maximize the field overlap with the SiOC coating.

These results shows the potential of high-refractive-index SiOC for the realization of low-power-consumption thermally-tunable dielectric photonic platforms.

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4. References

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