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Large, deterministic and tunable thermo-optic shift for all photonic platforms

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ABSTRACT

Achieving high degree of tunability in photonic devices has been a focal point in the field of integrated photonics for several decades, enabling a wide range of applications from telecommunication and biochemical sensing to fundamental quantum photonic experiments. We introduce a novel technique to engineer the thermal response of photonic devices resulting in large and deterministic wavelength shifts across various photonic platforms, such as amorphous Silicon Carbide (a-SiC), Silicon Nitride (SiN) and Silicon-On-Insulator (SOI). In this paper, we demonstrate bi-directional thermal tuning of photonic devices fabricated on a single chip. Our method can be used to design high-sensitivity photonic temperature sensors, low-power Mach-Zehnder interferometers and more complex photonics circuits.

Keywords: thermo-optic coefficient, silicon carbide, strain, silicon dioxide, deterministic integration

1. INTRODUCTION

The advancement in integrated photonics has been pivotal in driving innovations across a multitude of sectors, including telecommunication, biochemical sensing, and quantum computing. Central to this progress is the development of photonic devices with a high degree of tunability, enabling precise control over their optical properties. Platforms based on amorphous silicon carbide and lithium niobate have been recently introduced to tackle several challenges in photonic technologies.[1–3] Recently, we have demonstrated high-quality a-SiC films deposited using low temperatures Inductively Coupled Plasma-Enhanced Chemical Vapor Deposition (ICPCVD). The low temperature deposition ensure compatibility with high quality single photon sources based on III-V materials[4,5] and the deterministic integration with platforms such as Silicon Nitride using adiabatic tapers.[6] One of the benefits of a-SiC is a thermo-optic shift of 33 pm/$^{\circ}C$, with a thermo-optic coefficient almost three times higher than SiN devices (TOC$_{a-SiC}$=5.1-7.3x10^{-5}/$^{\circ}C$). To increase the tunability a-SiC platform, a recent work has shown that varying the Si/C ratios towards Si-rich a-SiC can yield devices with large thermo-optic coefficient and similar to that of Si.[7] However, the optical properties are affected and the devices can present higher losses. In other platforms, depositing Silicon Oxycarbide (SiOC) claddings has demonstrated large thermo-optic shifts.[8] SiOC-coated Ge:SiO_2 exhibited thermal shifts of 130 pm/$^{\circ}C$ with an effective thermo-optic coefficient of 2.5x10^{-4}/$^{\circ}C$, double the thermo-optic shift of Silicon. Nevertheless, the high refractive index of this cladding (n=2.2) increases the bending losses and the footprint of photonic circuits. We are introducing a method to enhance the thermal tuning capabilities of photonic devices using Silicon Dioxide, a low refractive index cladding (n=1.44). Our approach is applicable across a variety of photonic platforms, including amorphous Silicon Carbide (a-SiC), Silicon Nitride (SiN), and Silicon-On-Insulator (SOI). In a-SiC optical devices, we demonstrate a bidirectional thermal response on a single chip. Our method has the potential to create highly sensitive photonic temperature sensors, low-power Mach-Zehnder interferometers and more complex photonics circuits.

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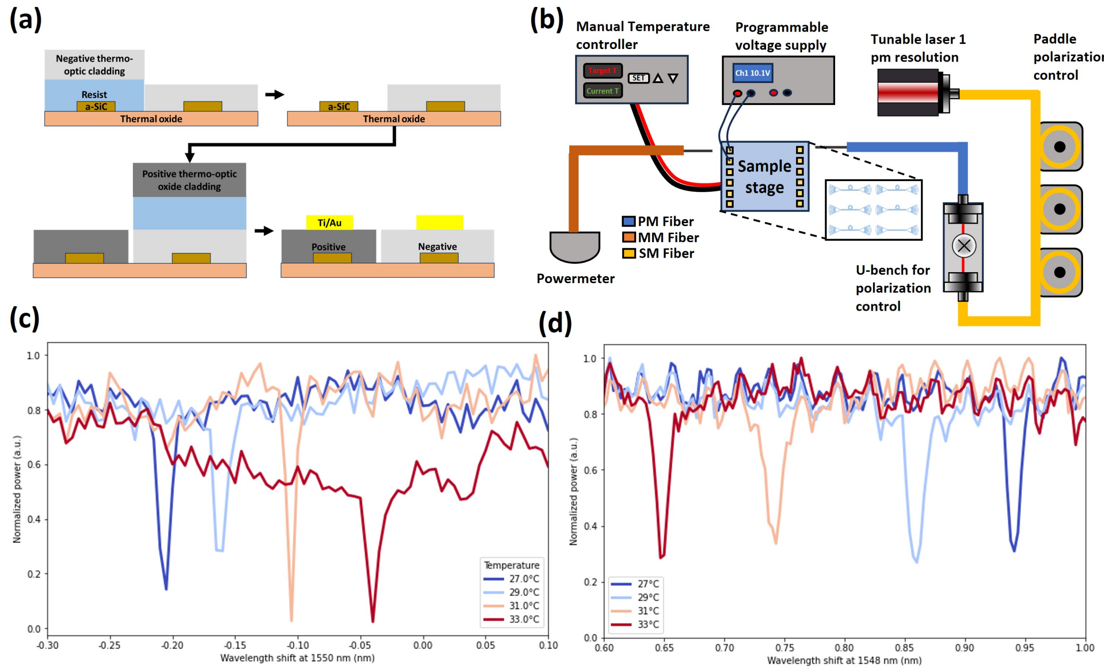

Figure 1. a) Fabrication steps for the deterministic integration of the claddings with different thermo-optic coefficients, b) schematic of the optical setup used to measure ring resonators in a grating coupling configuration with a temperature controller and a programmable DC voltage supply, c) wavelength shift as a function of the temperature for a standard oxide cladding and d) wavelength shift as a function of temperature for the device with a negative thermo-optic coefficient.

2. EXPERIMENTAL METHODS

Deterministic integration of the different claddings into a single chip was performed at deposition temperatures compatible with most e-beam and photo-resists. A schematic of the fabrication flow is shown in figure 1a. Temperature of the optical devices was set using a heater in the stage and controlled using a temperature sensor and a PID controller. The spectra at different temperatures were acquired using an optical spectrum analyzer (OSA Yokowaga AQ6374). In the cases where the peak could not be resolved, we used a tunable laser (Photonetics TUNICS-PRI 3642 HE 15) and a powermeter (Newport 818-IG-L) with a customized MATLAB script to retrieve the intensity as a function of the wavelength. An overview of the experimental setup is shown in figure 1b.

3. RESULTS

We fabricated multiple optical ring resonators on a-SiC photonic platform and covered the devices with silicon dioxide at different deposition temperatures and pressures. For the first time and on a single-chip, thermal shifts of 27.5 pm/$^{\circ}C$ (figure 1c) and -50 pm/$^{\circ}C$ (figure 1d) were achieved. We attribute this unique behavior to the differences in thermal expansion coefficients of the core (a-SiC) and the cladding (SiO_2).[9] It has been demonstrated, using PECVD, that varying pressure, and temperature can modify the film stress.[10–12] By changing the temperature and pressure in our recipe, we can further improve the thermal properties of the devices without compromising the optical quality. Most importantly, our technique can be applied to other photonic platforms such as Silicon Nitride and Silicon-On-Insulator.

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