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ABSTRACT

Hybrid integration of SiC has enormous potential for telecommunication applications, nonlinear photonics, sensing, and quantum photonics. Amorphous SiC (a-SiC) is particularly interesting as it has enormous potential to be deterministically integrated with most established photonic platforms. However, high-quality a-SiC photonics were missing, and compatibility with CMOS or III-V platforms requires low-temperature deposition. We have recently developed high-quality a-SiC photonics at low temperatures (<150°C) and demonstrated ring resonators with quality factors exceeding $5x10^5$ (waveguide propagation loss of 0.78 dB/cm). Low-temperature deposition allowed high-performance photonic circuits by liftoff. Moreover, process compatibility made the integration of a-SiC with lithium niobate (LN) and silicon nitride (SiN) possible. On a-SiC/LN platform, we achieved electro-optical tunability of 3.4 pm/V (3mm tuning length). Furthermore, on a-SiC/SiN platform we showcase coupling efficiencies (between a-SiC and SiN), exceeding 90%, making the combination of ultralow loss (SiN) and dense (a-SiC) photonics possible.

Keywords: Silicon Carbide, Hybrid photonics integration, Integrated photonics, Electro-optics material, High performance photonic materials.

1. INTRODUCTION

The proliferation of integrated photonic platforms has enhanced many applications in several fields such as satellite and ground optical communications, light-detection and ranging (LiDAR), spectroscopy, optical quantum computing and bio-sensing. Silicon nitride, silicon-on-insulator, lithium niobate or indium phosphide are some of the well-established platforms each with unique characteristics. For example, low waveguide propagation losses, high-refractive index contrast for dense integration, heat-free and fast electro-optical modulation or the ability to produce light on-chip. However, there is not an efficient route to integrate them all into a single photonic platform. Crystalline silicon carbide is another photonic platform with a high refractive index, very low propagation losses, high second-order nonlinearity, broad transparency window from the visible to the mid-infrared range and the presence of single photon sources. Nevertheless, integrating this material with other existing platforms involves transfer bonding, an expensive and time-consuming process that lacks precision in layer thickness, hence decreasing the integration flexibility. Even when this requirement is fulfilled, the processing temperatures involved and chemical interactions between materials reduce compatibility. Integrating silicon carbide with other materials in a single platform remains challenging.

2. HIGH-QUALITY AMORPHOUS SILICON CARBIDE

Amorphous silicon carbide is a promising platform for tackling integration challenges with photonic platforms. One of the most promising properties of a-SiC is the presence of a strong third-order non-linear coefficient, 10 times higher than that of SiN and crystalline SiC. Third-order non-linearities are an important requirement for four-wave mixing processes, indispensable for quantum photonic information processing and optical computing. Our group has demonstrated high-quality a-SiC photonics using a low-temperature deposition process (<150°C) and optical ring resonators with intrinsic quality factors exceeding $5x10^5$, representing waveguide propagation losses of 0.78 dB/cm **[1]**. Tuning the thermo-optic properties of photonic platforms has been a focal point in integrated photonics with wide-ranging applications. The thermal tunability of a platform usually depends on the waveguide material and devices exploit it with metal microheaters on top. We will show a simple approach to deterministically tune optical ring resonators on a-SiC by using silicon dioxide

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claddings achieving large negative, positive and athermal wavelengths shifts. Most importantly, we will show that it can be universally applied to any photonic platform **[2]**.

3. INTEGRATION WITH LITHIUM NIOBATE

Lithium niobate has shown highly efficient standard parametric down-conversion of light owing to the high second-order non-linear coefficient. We demonstrate the integration of amorphous silicon carbide with lithium niobate with the vision to exploit both second and third-order non-linearities on a single chip. This fulfills an important requirement for quantum photonic experiments and optical computing to generate entangled photon states efficiently. In this platform we fabricate optical ring resonators with electrodes in a push-pull configuration, showing loaded quality factors of $10x10^5$ and electro-optic tunability of 3.4 pm/V **[3]**.

4. INTEGRATION WITH THIN FILM SILICON NITRIDE

Silicon nitride photonics have been extensively studied due to the fabrication processes' low propagation losses and maturity. In recent years, 40 nm thin film silicon nitride has shown very low losses using standard fabrication processes. To demonstrate the flexibility of our technique and owing to the low deposition temperatures, we will show the integration of amorphous silicon carbide using a simple lift-off process with thin film silicon nitride. To achieve high coupling between platforms, we designed and fabricated a tapper providing experimental coupling efficiencies exceeding 95% at wavelengths around 1550 nm **[4]**. Most important and foreseeing the use of this platform together with single-photon sources based on nanowires, we will show the extension of this approach for high coupling efficiencies at a wavelength of 885 nm **[5]**.

5. CONCLUSION AND FUTURE OUTLOOK

We demonstrated the integration of amorphous silicon carbide with several well-established photonic platforms. Single photon sources are being thoroughly characterized in our lab and will be embedded in photonic circuits. In combination with state-of-the-art on-chip superconducting nanowire single-photon detectors, we plan to perform more ambitious quantum photonic experiments.

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