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Demonstration of SiC-on-insulator substrate with Smart Cut™ technology for photonic applications

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Silicon carbide (SiC) is a promising material for the realization of quantum and nonlinear photonic circuits. Indeed, it combines many interesting optical properties: a wide transparency window (UV to mid-IR), high second and third order optical nonlinearity coefficients ($\chi(2)$, $\chi(3)$), a high refractive index and no two-photon absorption (TPA) at near infrared wavelengths. SiC also exhibits point defects (colored centers) which are promising for Qbit realization due to their long spin coherence time and room temperature operation.

SiC photonics has been explored for some years, with very recent landmark demonstrations such as low-loss waveguides, high quality factor resonators, efficient on-chip frequency conversion via $\chi(2)$ and integration of single spin Qbits with nanophotonic cavities. This brings SiC at the forefront of efforts towards a monolithic platform combining quantum and nonlinear photonics [1]. However, these developments are hampered by the lack of commercial SiC-on-insulator (SiCOI) wafers. In fact, the aforementioned demonstrations rely on extremely expensive and experimental SiCOI dies obtained by the bonding and thinning method [1-2].

Leveraging on both the experience and mastery of the Smart Cut™ process for the fabrication of substrates for power components [3-5] and for optical devices [1, 6-9], this work aims to demonstrate the realisation of cost effective and high quality SiCOI wafers with a thin film of single-crystal SiC (thicknesses from 300 to 800 nm) on an insulating layer (SiO₂).

We have produced 150 mm SiCOI wafers with a 500nm-thick monoSiC layer transferred onto a monoSiC receiver substrate using a direct SiO₂/SiO₂ bonding process. These substrates are visually of very good quality (Fig. 1).

The final substrates show:

- very few bonding defects (see Fig. 1)
- a 500 nm monoSiC transferred film
- a very good post-CMP surface finish (low roughness value, rms < 1 nm)
- a low final substrate curvature (< 30 μ m). An innovative method, allowing to control the curvature of the substrate during the process has been implemented and will be detailed.
- a thin edge exclusion (< 3 mm)

Using e-beam lithography and a standard etching process, waveguides were patterned and structured on SiCOI substrates as illustrated on Fig. 2.

The optical indices of the SiC were measured from the visible to the infrared by ellipsometry. An advanced model has been used in order to take into account the strong birefringence of the silicon carbide film. As shown on Fig. 3(a), the extracted ordinary and extra-ordinary refractive indices are in good agreement with previously reported values from the literature [10]. Using these data, the conception of some photonic devices can be performed. For example, the modal behaviour of the SiC waveguides have been simulated as shown on Fig. 3(b). Moreover, microring resonators have been theoretically studied (Fig. 3(c)). By tuning the optical power coupled to the resonator from a feeding waveguide, an extremely high power density can be reached, which is key to trigger nonlinear optical effects such as Kerr frequency combs.

This work presents the SiCOI substrates fabricated using the Smart Cut™ technology. A 500 nm monoSiC layer was successfully transferred on a thick (> 1 μ m) SiO₂ layer. Obtaining the optical indices by spectroscopic ellipsometry allowed us to carry out simulations of the optical structures realized on SiCOI wafers. The waveguide realizations on these transferred substrates are in progress to demonstrate

their properties. Other characterisations of the transferred layer will be carried out to highlight the single-crystalline quality of SiC film.

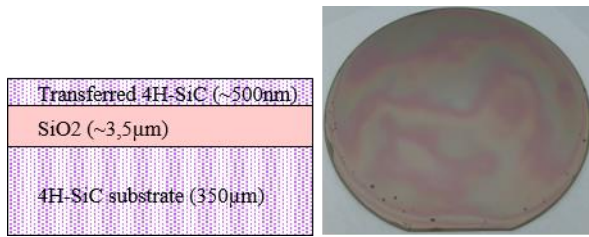


Fig 1: Picture and cross-sectional scheme of a 6'' SiC-on-insulator substrate.

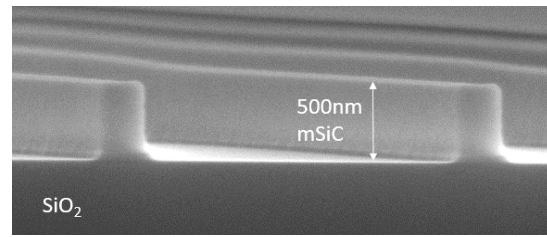


Fig. 2: Cross-section SEM image of a SiC guide array on insulator.

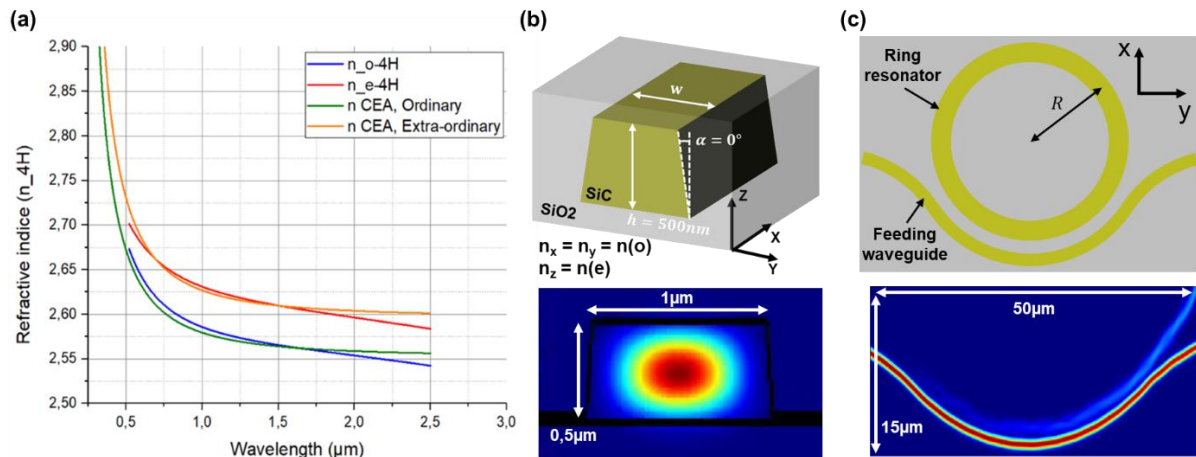


Fig. 3: (a) Dispersion of ordinary and extraordinary refractive indexes of undoped monoSiC. (b) SiC waveguide geometry and the associated modal simulation (electrical field magnitude). (c) Microring resonator and the simulation of the feeding waveguide-ring power coupling.

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