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Nano-engineering unlocks the potential of SiC for photonics

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Silicon carbide (SiC) is playing a very important role in power electronics due to its high electron breakdown field, high electron saturation velocity, wide bandgap, high melting point and high thermal conductivity compared to its silicon (Si) counterpart. If we have a close look of the optical properties of SiC, they are also outstanding. For example, it possesses both high second-order and third-order nonlinearity. Leveraging the mature material growth and processing technology, the advance of the nano-engineering is unlocking the potential of SiC for integrated photonics.

In the field of integrated photonics, there co-exist multiple material platforms, such as Si, SiN, InP, GaAs, AlN, etc. Due to different nature of the materials, none of them has ideal properties to demonstrate all the basic building blocks to realize the monolithically integrated sub-system so far. Among them, Si is mostly researched and implemented benefitting from the powerful complementary metal-oxide-semiconductor (CMOS) processing. III-V materials (InP, GaAs etc.) have the advantage of on-chip light sources, but they have never competed with Si in terms of cost and scalability. Among the wide bandgap materials, SiC is CMOS compatible and is emerging as a promising material platform for integrated nonlinear and quantum photonics because of the following super properties: 1) SiC has high refractive index and very tight optical confinement is achievable; 2) SiC has wide bandgap and is transparent in a broad wavelength range from near ultraviolet to mid-infrared; 3) SiC has good thermal conductivity which mitigates the thermal management effort when high power injection is needed; 4) SiC has many intrinsic defects which are optically addressable, thus it is a good candidate to provide an on-chip single photon source for quantum integrated circuits as well.

To unlock the superior optical properties of SiC, a big barrier is to transfer it from bulky wafers into thin films with controllable thickness and crystal quality. The so-called silicon carbide on insulator (SiCOI) stack is currently formed by 3 different ways: smart-cut to form 4H SiCOI, bonding and CMP to form 3C SiCOI, bonding and grinding to form 4H SiCOI.

When high-quality SiCOI stack is ready, dispersion and etch control become important. A good etch control to have smooth waveguide sidewall results in low loss of the waveguides, which is fundamental to demonstrate all the nonlinear and quantum optics experiments without extreme demands for experimental setups and real applications in future. Dispersion control is crucial for nonlinear process in the waveguides where phase matching is required, which in turn is achieved by controllable nanofabrication process.

In this talk, the state-of-the-art SiC photonics is reviewed with focus on nonlinear photonics. We will present our recent results on nano-engineering of this material including chemical mechanical polishing of this material to achieve atomic scale surface smoothness, precise nanofabrication processing to control the dispersion of the waveguides, as well as on the microring resonator enhanced four-wave mixing process and supercontinuum generation from SiCOI stacks made by the smart cut method. Both thermal-optical coefficient and polarization dependent nonlinear refractive index are derived for SiCOI platform. With a specific target to achieve optical frequency comb, the requirements on the loss of the waveguide are simulated. Prospects of SiCOI platform for both nonlinear and quantum photonics will be presented at the last part of this talk.

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[1] A. Yi, Y. Zheng, H. Huang, J. Lin, Y. Yan, T. You, K. Huang, S. Zhang, C. Shen, M. Zhou, W. Huang, J. Zhang, S. Zhou, H. Ou, X. Ou, Optical Materials, (2020),107, 109990.
[2] Y. Zheng, M. Pu, A. Yi, X. Ou, H. Ou, Optics Letters, (2019), 44, 5784-87.
[3] X. Shi, W. Fan, A. K. Hansen, M. Chi, A. Yi, X. Ou, K. Rottwitt, H. Ou, Submitted to Advanced Photonics Research.

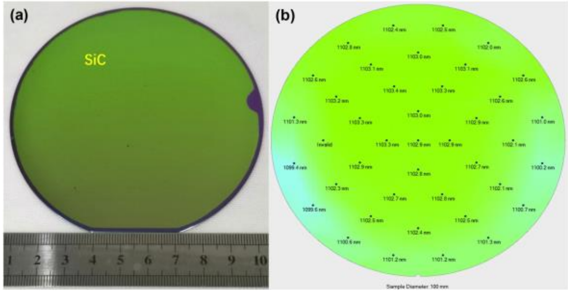

Figure 1. (a) Photograph of 4-inch wafer-scale 4H–SiCOI substrate fabricated using ion-cutting and layer transferring technique. (b) The thickness homogeneity of SiC film was measured by white light interferometer [1].

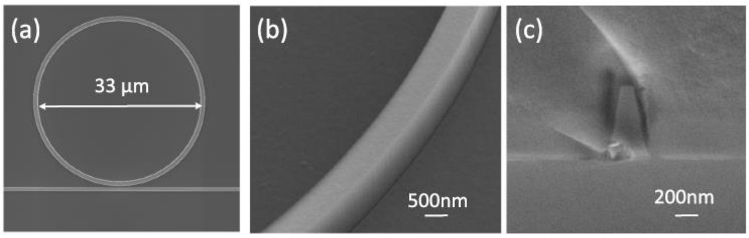

Figure 2. (a) Top-view SEM picture of a fabricated SiC microring resonator with 16.5 µm radius. (b) Zoom-in SEM picture of a fabricated microring resonator. (c) Cross-section of an inverse nanotaper at the cleaved facet [2].

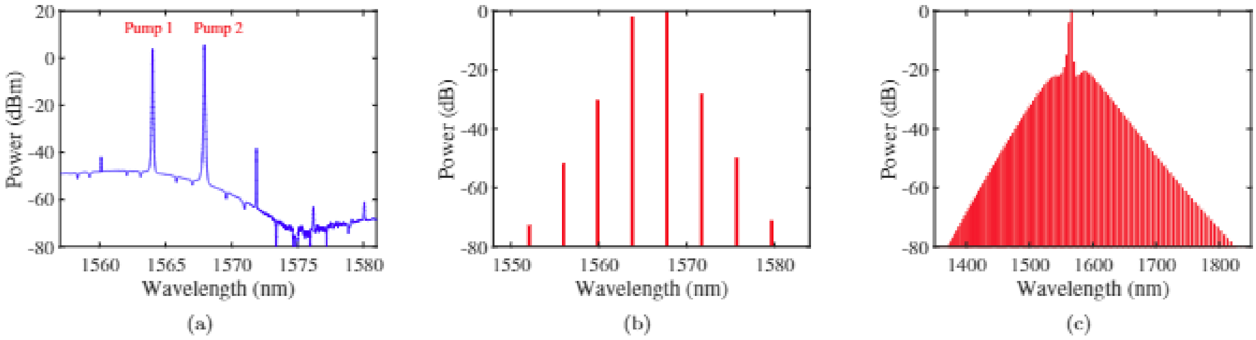

Figure 3. (a) The measured spectrum of the TE polarized dual-pump OPO in a 4H-SiC microring resonator. The adjacent frequency lines are separated by one FSR. (b) The simulated result of the TE polarized dual-pump OPO in a 4H-SiC microring resonator. (c) The simulated result of soliton frequency comb generation through thermal tuning [3].