Raman and Kerr frequency comb in a 4H-silicon-carbide on insulator based microresonator

Afridi, Adnan Ali; Lu, Yaoqin; Shi, Xiaodong; Wang, R. ; Li, J.; Li, Q.; Ou, Haiyan

Publication date:
2023

Document Version
Publisher's PDF, also known as Version of record

Raman and Kerr frequency comb in a 4H-silicon-carbide on insulator based microresonator

A. A. Afridi[1)], Y. Lu[1)], X. Shi[1)], R. Wang[2)], J. Li[2)], Q. Li[2)], and H. Ou[1)*]
[1)] DTU Electro, Technical University of Denmark, DK-2800 KGS. Lyngby, Denmark
[2)] Department of Electrical and Computer Engineering, Carnegie Mellon University, Pittsburgh, Pennsylvania 15213, USA
E-mail: haou@dtu.dk

We experimentally demonstrated a mixed Kerr and Raman frequency comb in a 4H-silicon carbide (SiC) microresonator. The achieved frequency comb spectrum is in the range from ~1440 to 1960 nm at an on-chip power of ~350 mW. The Raman generation in SiC helps to extend the comb bandwidth over the longer wavelength region.

The development in frequency comb technology has significantly attracted research interests for its potential in out-of-lab commercial applications [1]. To date, frequency combs have been vital key elements for applications including communication [2], LiDAR [3], frequency synthesizer [4] and dual-comb spectroscopy [5], etc. Moreover, broadband frequency combs with low power consumption and low noise are the fundamental requirements for the photonics integration and led to the development of a variety of material platforms, including Silica [6], Si [7], Si_3N_4 [8], AlN [9], $LiNbO_3$ [10], AlGaAs [11], and SiC [12].

The SiC material has recently emerged as a promising material platform for photonics and nonlinear optics due to its excellent optical and nonlinear properties. SiC has a wide bandgap (2.2 eV to 3.4 eV) and low two photon absorption (TPA), high thermal conductivity, wide transparency window (visible to mid-infrared) regions and high refractive index of 2.6 at telecom wavelength, enabling strong light confinement [13]. In addition, SiC has not only strong third-order (χ^3) but also possess second-order (χ^2) non-linearities making it significant platform for meteorology applications.

In this work, we employ a 4H-SiC microresonator with a radius of 36 μm and cross-section of 1.0×0.63 μm^2 (width×thickness), shown in the schematic of Fig. 1(a). The device was made of Cree 4H-SiC and fabricated using a similar process as discussed in Ref. [13]. Inverse tapers were successfully implemented by polishing the two facets of SiC, achieving a total insertion loss <10 dB. As shown in Fig. 1(b), the simulated integrated dispersion (D_{int}) is calculated using Comsol, considering a sidewall angle (θ) of 80° and center pump wavelength near 1566 nm. Figure 1(c) shows the normalized resonance of fundamental transverse electric mode (TE_{00}) near 1566 nm. The free spectral range (FSR) is around 473 GHz and the extracted intrinsic quality factor (Q_{int}) is 0.3 million (the lower Q compared to the results in Ref. [13] was mainly due to smaller ring widths). The inset of Fig. 1(c) is a microscopic image of one of the devices.

The Santec TSL-510 laser light is amplified using an erbium-doped amplifier (EDFA) and launched into the 4H-SiC microresonator using the lensed fibers to excite the frequency comb and spectrum is recorded using optical spectrum analyzer (OSA). Here we set the amplifier's output power to ~900 mW i.e., 350 mW in waveguide and tune the laser wavelength from blue to red position on the pump wavelength (~1566 nm). As shown in the Fig. 1(d), we observe the stokes at the Raman shift of 775.8 cm^{-1} which corresponds to the phonon E_2(TO) [14] and by further tuning the laser wavelength Raman and four wave mixing (FWM) Kerr comb is achieved in the wavelength range of ~1440 to 1960 nm, respectively. The results are of interest in the further study of on-chip Raman laser in the 4H-SiC platform and for applications such as biological and spectroscopy.

This work was funded by the European Union's Horizon 2020 FET Open (SiComb, No. 899679) and VILLUM FONDEN (VIL50293).

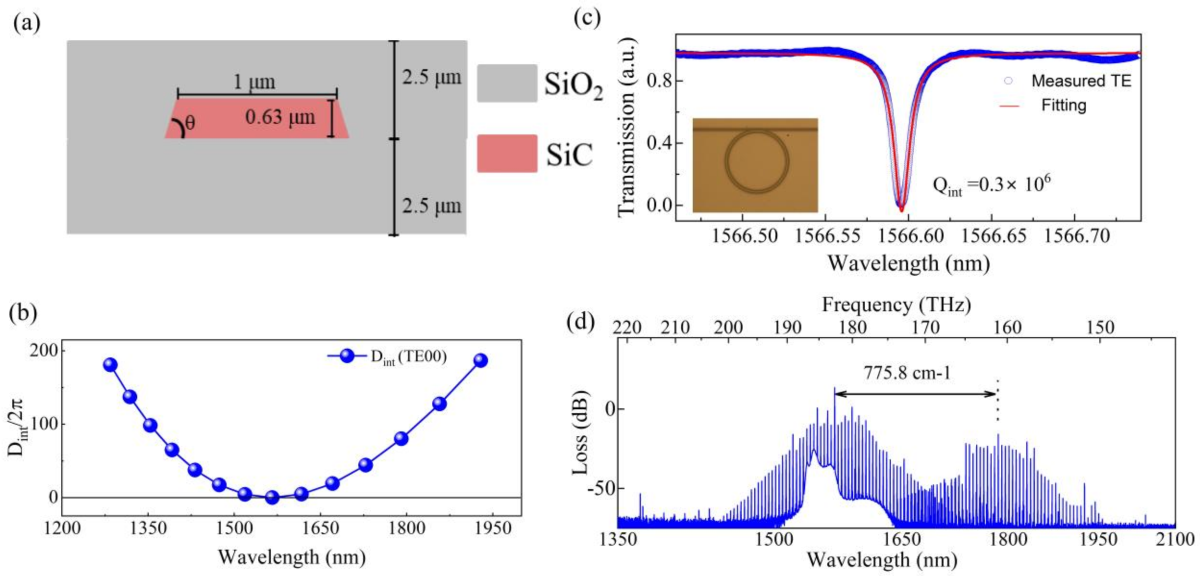

Fig. 1. (a) Schematic of the 2D cross-section of 4H-SiC microresonator waveguide embedded in SiO_2. (b) Using COMSOL multiphysics, integrated dispersion (D_{int}) is calculated of TE_{00} mode using microresonator waveguide width of 1 µm and radius of 36 µm. (c) Zoomed-in view of the fitted (red) TE_{00} resonance mode. Inset is the microscopic image of one of the devices. (d) Recorded Raman and Kerr comb spectrum at in-waveguide power of 350 mW.

[1] T. Fortier and E. Baumann, Commun. Phys. 2, 153 (2019).
[2] A. A. Jørgensen, D. Kong, M. R. Henriksen, F. Klejs, Z. Ye, Ò. B. Helgason, H. E. Hansen, H. Hu, M. Yankov, S. Forchhammer, P. Andrekson, A. Larsson, M. Karlsson, J. Schröder, Y. Sasaki, K. Aikawa, J. W. Thomsen, T. Morioka, M. Galili, V. Torres-Company and L. K. Oxenløwe, Nat. Photon. 16, 798–802 (2022).
[3] J. Riemensberger, A. Lukashchuk, M. Kaprov, W. Weng, E. Lucas, J. Liu, and T. J. Kippenberg, Nature 581, 164–170 (2020).
[4] D. T. Spencer, T. Drake, T. C. Briles, J. Stone, L. C. Sinclair, C. Fredrick, Q. Li, D. Westly, B. R. llic, A. Bluestone, N. Volet, T. komljenovic, L. Chang, S. Lee, D. Y. Oh, M. G. Suh, K. Y. Yang, M. H. P. Pfeiffer, T. J. Kippenberg, E. Norberg, L. Theogarajan, K. Vahala, N. R. Newbury, K. Srinivasan, J. E. Bowers, S. A. Diddams, and S. B. Papp, Nature 557, 81–85 (2018).
[5] M. G. Suh, Q. F. Yang, X. Yi, K. J. Vahala, Science 354, 600-603 (2016).
[6] P. Del'Haye, A. Schliesser, O. Arcizet, T. Wilken, R. Holzwarth and T. J. Kippenberg, Nature 450, 1214–1217 (2007).
[7] A. G. Griffith, R. K.W. Lau, J. Cardenas, Y. Okawachi, A. Mohanty, R. Fain, Y. H. D. Lee, M. Yu, C. T. Phare, C. B. Poitras, A. L. Gaeta and M. Lipson, Nat Commun 6, 6299 (2015).
[8] J. S. Levy, A. Gondarenko, M. A. Foster, A. C. Turner-Foster, A. L. Gaeta & M. Lipson, Nature Photon 4, 37–40 (2010).
[9] H. Jung, C. Xiong, K. Y. Fong, X. Zhang, and H. X. Tang, Optics letters 38, no. 15 (2013).
[10] H. Yang, Q. F. Yang, J. Ling, R. Luo, H. Liang, M. Li, B. Shen, H. Wang, K. Vahala, and Q. Li, Optica 6, no. 9 (2019).
[11] P. Minhao, L. Ottaviano, E. Semenova, and K. Yvind, Optica 3, no. 8 (2016).
[12] Guidry, A. Melissa, K. Y. Yang, D. M. Lukin, A. Markosyan, J. Yang, M. M. Fejer, and J. Vučković, Optica 7, no. 9 (2020).
[13] C. Lutong, J. Li, R. Wang, and Q. Li, Photonics Research 10, no. 4 (2022).

[14] C. Wang, Z. Fang, A. Yi, B. Yang, Z. Wang, L. Zhou, C. Shen, Y. Zhu, Y. Zhou, R. Bao, Z. Li, Y. Chen, K. Haung, J. Zhang, Y. Cheng and X. Ou, Light Sci Appl 10, 139 (2021).