



HAL
open science

Subwavelength engineering of silicon photonics for nonlinear and optomechanical applications

J. Zhang, P. Nuño Ruano, T. T. D. Dinh, D. González-Andrade, X. Le Roux, M. Montesinos, C. Lafforgue, D. Medina-Quiroz, D. Benedikovic, P. Cheben, et al.

► **To cite this version:**

J. Zhang, P. Nuño Ruano, T. T. D. Dinh, D. González-Andrade, X. Le Roux, et al.. Subwavelength engineering of silicon photonics for nonlinear and optomechanical applications. Photonics North 2023, Jun 2023, Montréal, Canada. hal-04493342

HAL Id: hal-04493342

<https://universite-paris-saclay.hal.science/hal-04493342v1>

Submitted on 7 Mar 2024

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Subwavelength engineering of silicon photonics for nonlinear and optomechanical applications

J. Zhang^{1,2}, P. Nuño Ruano¹, T. T. D. Dinh¹, D. González-Andrade¹, X. Le Roux¹, M. Montesinos¹, C. Lafforgue¹, D. Medina-Quiroz¹, D. Benedikovic³, P. Cheben^{2,4}, D. Marris-Morini¹, E. Cassan¹, L. Vivien¹, N. D. Lanzillotti-Kimura¹ and C. Alonso-Ramos¹

¹Université Paris-Saclay, CNRS, Centre de Nanosciences et de Nanotechnologies, 91120 Palaiseau, France

²National Research Council Canada, 1200 Montreal Road, Bldg. M50, Ottawa, Ontario K1A 0R6, Canada

³University of Žilina, Dept. Multimedia and Information-Communication Technologies, 01026 Žilina, Slovakia

³Center for Research in Photonics, University of Ottawa, Ottawa, Ontario K1N 6N5, Canada

*Corresponding author: carlos.ramos@c2n.upsaclay.fr

Abstract: Periodically patterning silicon with a subwavelength pitch opens new degrees of freedom to control nonlinear effects and optomechanical interactions in silicon photonic circuits with unprecedented flexibility. In this invited presentation, we will show our most recent results on the use of suspended silicon waveguides for nonlinear supercontinuum generation in the near-IR and mid-IR. We will also discuss our recent demonstrations of subwavelength engineering of photons and phonons in non-suspended silicon optomechanical cavities.

The wide transparency range of silicon (1.1-8 μm wavelength) and the negligible two-photon absorption for wavelengths above 2 μm , make this technology a very promising candidate for supercontinuum generation in the mid-IR [1]. However, the use of the silicon-on-insulator (SOI) technology in the mid-IR is limited by the absorption of the silica cladding for wavelengths above 3.5 μm . Suspended silicon waveguides overcome the silica absorption limitation, allowing the use of the full silicon transparency range [2-4]. On the other hand, Brillouin scattering, i.e. the nonlinear interaction between optical and mechanical fields inside a material, has generated great scientific interest for its numerous applications in communications, sensing and quantum technologies [5]. However, efficient Brillouin interactions require simultaneous confinement of optical and mechanical modes. Such optomechanical confinement is challenging in SOI waveguides due to a strong phonon leakage towards the silica cladding.

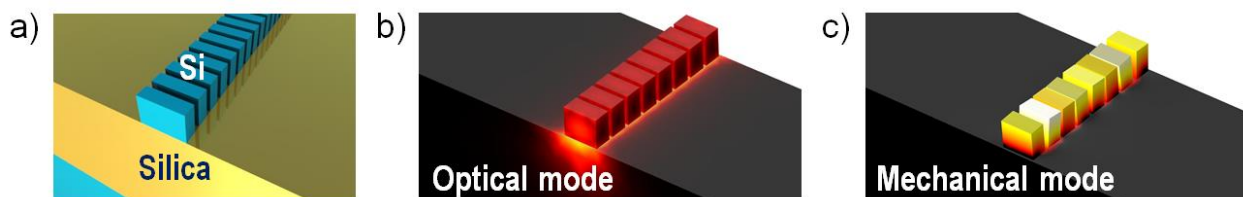


Fig. 1. (a) Schematic view of the proposed optomechanical silicon waveguide exploiting subwavelength periodic structuration. Calculated (b) optical and (c) mechanical modes of the subwavelength silicon waveguide.

Since their first demonstration in silicon photonics [6,7], subwavelength-grating metamaterials [8, 9] have been used as a powerful tool for overcoming performance limitations of conventional silicon photonic devices. Furthermore, periodically patterning silicon with a subwavelength pitch opens new degrees of freedom to control the propagation of light and sound in silicon photonic circuits with unprecedented flexibility. In this invited presentation, we will show our most recent results on the use suspended silicon waveguides for supercontinuum generation in the near-IR and mid-IR [10]. We will also discuss our recent demonstration of subwavelength engineering of photons and phonons in non-suspended silicon optomechanical cavities [11]. We use subwavelength structuration of silicon to tightly confine near-infrared photons and MHz phonons in non-suspended silicon waveguides, fully compatible with standard silicon photonics. Photons are confined by metamaterial index guiding, while phonons are confined by destructive interference of radiation to the cladding, while.

These results open exciting new perspectives to exploit nonlinear and

optomechanical effects with scalable silicon photonics technology, having great potential for applications in optical and wireless communications, radar, sensing, metrology and quantum technologies.

References

1. N. Singh, D. D. Hudson, Y. Yu, C. Grillet, S. D. Jackson, A. Casas-Bedoya, A. Read, P. Atanackovic, S. G. Duvall, S. Palomba, B. Luther-Davies, S. Madden, D. J. Moss, and B. J. Eggleton, “ Mid-infrared supercontinuum generation from 2 to 6 μm in a silicon nanowire” *Optica*, Vol. 2, No. 9, 797-802, 2015.
2. J. Soler Penadés, A. Sánchez-Postigo, M. Nedeljkovic, A. Ortega-Moñux, J. G. Wangüemert-Pérez, Y. Xu, R. Halir, Z. Qu, A. Z. Khokhar, A. Osman, W. Cao, C. G. Littlejohns, P. Cheben, I. Molina-Fernández, G. Z. Mashanovich, “ Suspended silicon waveguides for long-wave infrared wavelengths,” *Opt. Lett.*, Vol. 43, No. 4, 795-798, 2018.
3. W. Zhou, Z. Cheng, X. Wu, X. Sun, and H. K. Tsang, “ Fully suspended slot waveguide platform,” *J. Appl. Phys.*, Vol. 123, 063103, 2018.
4. W. Liu, Y. Ma, Y. Chang, B. Dong, J. Wei, Z. Ren, and C. Lee, “ Suspended silicon waveguide platform with subwavelength grating

- metamaterial cladding for long-wave infrared sensing applications,” *Nanophotonics*, Vol. 10, No. 7, 1861-1870, 2021.
5. B. J. Eggleton, C. G. Poulton, P. T. Rakich, M. J. Steel, and G. Bahl, “ Brillouin integrated photonics,” *Nat. Photon*, Vol. 13, 664-677, 2019.
 6. P. Cheben, D-X. Xu, S. Janz, and A. Densmore, “ Subwavelength waveguide grating for mode conversion and light coupling in integrated optics,” *Opt. Express*, Vol. 14, No. 11, 4695-4702, 2016.
 7. P. Cheben, P. J. Bock, J. H. Schmid, J. Lapointe, S. Janz, D.-X. Xu, A. Densmore, A. Delage, B. Lamontagne, and T. J. Hall, “ Refractive index engineering with subwavelength gratings for efficient microphotonic couplers and planar waveguide multiplexers,” *Opt. Lett.*, Vol. 35, No. 15, 2526-2528, 2010.
 8. P. Cheben, R. Halir, J. H. Schmid, H. A. Atwater, and D. R. Smith, “ Subwavelength integrated photonics,” *Nature*, Vol. 560, 565-572, 2018.
 9. R. Halir, A. Ortega-Moñ ux , D. Benedikovic, G. Z. Mashaovich, J. G. Wangu□emert-Pé rez, J. H. Schmid, I. Molina-Ferná ndez, and P. Cheben, “ Subwavelength-grating metamaterial structures for silicon photonic devices,” *Proc. IEEE*, Vol. 106, No. 12, 2144-2157, 2018.
 10. C. Lafforgue, M. Montesinos-Ballester, T.T.D. Dinh, X. Le Roux, E.

Cassan, D. Marris-Morini, C. Alonso-Ramos, L. Vivien, “ Supercontinuum generation in silicon photonics platforms,” *Photonics Res.*, Vol. 10, No. 3, A43-A56, 2022.

11. J. Zhang, P. Nunño Ruano, X. Le Roux, M. Montesinos-Ballester, D. Marris-Morini, E. Cassan, L. Vivien, N. D. Lanzillotti-Kimura, and C. Alonso Ramos, “ Subwavelength control of photons and phonons in release-free silicon optomechanical resonators,” *ACS Photonics*, Vol. 9, No. 12, 3855-3862, 2022.