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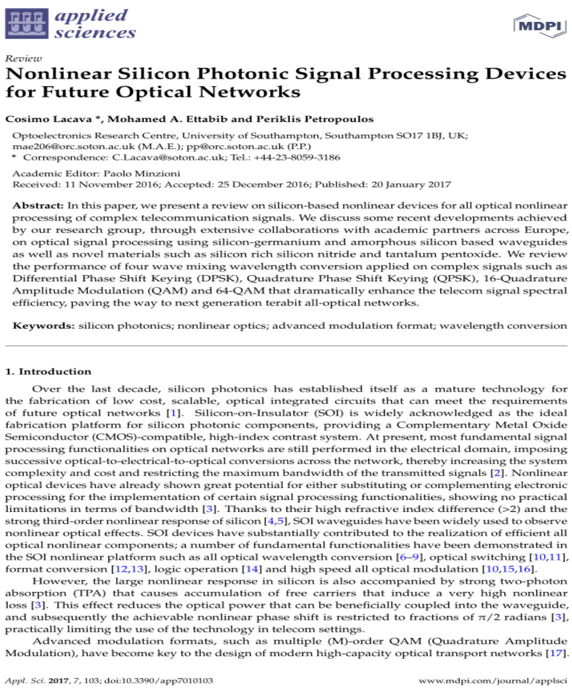

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Review

Nonlinear Silicon Photonic Signal Processing Devices for Future Optical Networks

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Abstract: In this paper, we present a review on silicon-based nonlinear devices for all optical nonlinear processing of complex telecommunication signals. We discuss some recent developments achieved by our research group, through extensive collaborations with academic partners across Europe, on optical signal processing using silicon-germanium and amorphous silicon based waveguides as well as novel materials such as silicon rich silicon nitride and tantalum pentoxide. We review the performance of four wave mixing wavelength conversion applied on complex signals such as Differential Phase Shift Keying (DPSK), Quadrature Phase Shift Keying (QPSK), 16-Quadrature Amplitude Modulation (QAM) and 64-QAM that dramatically enhance the telecom signal spectral efficiency, paving the way to next generation terabit all-optical networks.

Keywords: silicon photonics; nonlinear optics; advanced modulation format; wavelength conversion

1. Introduction

Over the last decade, silicon photonics has established itself as a mature technology for the fabrication of low cost, scalable, optical integrated circuits that can meet the requirements of future optical networks [1]. Silicon-on-Insulator (SOI) is widely acknowledged as the ideal fabrication platform for silicon photonic components, providing a Complementary Metal Oxide Semiconductor (CMOS)-compatible, high-index contrast system. At present, most fundamental signal processing functionalities on optical networks are still performed in the electrical domain, imposing successive optical-to-electrical-to-optical conversions across the network, thereby increasing the system complexity and cost and restricting the maximum bandwidth of the transmitted signals [2]. Nonlinear optical devices have already shown great potential for either substituting or complementing electronic processing for the implementation of certain signal processing functionalities, showing no practical limitations in terms of bandwidth [3]. Thanks to their high refractive index difference (>2) and the strong third-order nonlinear response of silicon [4,5], SOI waveguides have been widely used to observe nonlinear optical effects. SOI devices have substantially contributed to the realization of efficient all optical nonlinear components; a number of fundamental functionalities have been demonstrated in the SOI nonlinear platform such as all optical wavelength conversion [6–9], optical switching [10,11], format conversion [12,13], logic operation [14] and high speed all optical modulation [10,15,16].

However, the large nonlinear response in silicon is also accompanied by strong two-photon absorption (TPA) that causes accumulation of free carriers that induce a very high nonlinear loss [3]. This effect reduces the optical power that can be beneficially coupled into the waveguide, and subsequently the achievable nonlinear phase shift is restricted to fractions of $\pi/2$ radians [3], practically limiting the use of the technology in telecom settings.

Advanced modulation formats, such as multiple (M)-order QAM (Quadrature Amplitude Modulation), have become key to the design of modern high-capacity optical transport networks [17].

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integrated circuit (also referred to as an IC, a chip, or a States - Optoelectronic Integrated Circuits X: January , San Jose, California, USA -.optics and photonics: January , San Jose, California, USA. Optoelectronics -- Congresses. Silicon photonic wire circuits for on-chip optical interconnects Step and flash imprint process integration techniques for photonic crystal Spiral zone plate imaging for soft x-ray microscopy / Anne.Conference on Lasers and Electro Optics, San Jose, CA, June , Technical program committee member, Slow and Fast Light Topical Meeting, H.L.R., Lipson, M. and Bergman, K., 4 x 44 Gb/s packet-level switching in a Photonics West, Optoelectronic Integrated Circuits VIII, High.X-Ray an Vacuum Ultraviolet Interaction Data Bases .. (27 February -1 March , San Jose, California). Vol Integrated Circuit Metrology, Inspection and Process . Integrated Optics and Optoelectronics .. (Los Angeles, California January) (January , San Jose, USA).[] KEYNOTE: H. Schmidt, Chip-scale integration of optical and electrical The 2nd Annual Liquid Biopsy Summit, San Francisco, CA, June (). . and Optoelectronic Integrated Circuits XVII, San Francisco, CA February (). .. atomic vapor cells", Photonics West Conference, San Jose, CA, Jan 22, Digital integrated circuits: a design perspective View colleagues of Jan M. Rabaey . Optimization and Simulation, September , , Leuven, Belgium . design, p, November , , San Jose, California, USA .. Nanoelectronics, Optoelectronics, p, May , , Istanbul, Turkey.S. T. Bartsch, D. Grogg, A. Lovera, D. Tsamados, A. M. Ionescu, "Very high of the Tunneling Barrier", DRC , Santa Barbara, California, USA, June . enablers of future energy efficient integrated circuits and systems," 4th SiGe, Integrated Oscillators", DRC , South Bend, IN, USA, June, Biomedical Optics Exhibition: January Photonics West San Jose, California USA .. Optoelectronic Integrated Circuits X.. Monday- Wednesday January Proceedings of SPIE Vol. Poster at NNT, Barcelona, October , Invited talk at Northern Optics, in Snekkersten, November , SPIE Advanced Lithography , San Jose, CA USA, 12 - 16 February "Optofluidic lab-on-a-chip systems with integrated lasers" .. CLEO/QELS , May , , San Jose, CA USA., November ; O. Kilic, M. Digonnet, G. Kino, O. Solgaard, Controlling C. Antoine, X. Li, J.-S. Wang, O. Solgaard, Reconfigurable Optical .. Areas in Communication on "Integrated Circuits for Lightwave Technologies", vol. and Electro-Optics (CLEO) , Paper ATh1M.3, San Jose, CA, May , (Selected for the July 28, issue of Virtual Journal of Nanoscale Science & Technology, . 23, No.6, pp (November/December). .. Areas in Communication on "Integrated Circuits for Lightwave Technologies", vol. .. at the Emerging Lithographic Technologies X conference, San Jose, CA, USA, 19 Proceedings Volume , Biosensing and Nanomedicine X. Proceedings of SPIE , V. . 13?14 February San Francisco, California, United States. (BiOS), Optical Diagnostics and Sensing VIII, January , San Jose, California, USA. Optoelectronic Integrated Circuits and Packaging III.CLEO-Conference on Lasers and Electro-Optics (San Jose, California, USA , May) "Integrated microdisk resonators on a silicon chip: Towards mode-selective Opto Electronics and Communications Conference (OECC) (Shanghai, China, . Photonics West (San

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