Induced second-order nonlinearities in Silicon Nitride integrated photonics

Marco Clementi

Photonic Systems Laboratory,
École Polytechnique Fédérale de Lausanne (EPFL)
1015 Lausanne, Switzerland

Silicon nitride (SiN) has become one of the primary candidates for the development of integrated nonlinear photonics owing to its direct CMOS workflow compatibility, as well as excellent linear and nonlinear optical properties, and its wide transparency from the visible to mid-infrared.

Within the last decade, we have been witnessing the significant progress made towards improving SiN waveguide devices and harnessing the available optical nonlinearities through a wide variety of nonlinear optical phenomena such as soliton formation [1], photon pair generation [2], and, recently, three-wave mixing [3].

While the latter is not directly accessible in SiN after fabrication due to its centrosymmetric (amorphous) nature, it can be achieved by optically inducing the second-order nonlinearity $\chi^{(2)}$ via coherent photogalvanic effect (CPE) [4]. Such *all-optical poling* technique allows for the inscription of a self-organized periodic space-charge grating and subsequent quasi-phase-matching (QPM) of optical fields participating in the three-wave mixing process, such as second-harmonic generation (SHG), sum-frequency generation (SFG) [4] and difference-frequency generation (DFG) [5].

Here, we will review the recent results of optical poling in SiN photonic structures. We will first discuss the underlying physical process, which allows the inscription of the QPM grating [6], and subsequently, illustrate a number of applications to integrated nonlinear photonics. These include the highly efficient second harmonic generation (SHG) achievable in waveguides and resonant structures [7]; the efficiency improvement associated with seeding of the process by injection of light at SH frequency [8]; the generation of energy-entangled photon pairs by spontaneous parametric down-conversion [9]; the generation of frequency comb at normal dispersion regime; the cascaded generation of higher-order harmonics [10].

[1] B. Shen, L. Chang, J. Liu, H. Wang, Q. F. Yang, C. Xiang, R. N. Wang, J. He, T. Liu, W. Xie, J. Guo, D. Kinghorn, L. Wu, Q. X. Ji, T. J. Kippenberg, K. Vahala, and J. E. Bowers, Nature **582**, 365 (2020).

[2] M. Kues, C. Reimer, J. M. Lukens, W. J. Munro, A. M. Weiner, D. J. Moss, and R. Morandotti, Nat. Photonics **13**, 170 (2019).

[3] A. Billat, D. Grassani, M. H. P. Pfeiffer, S. Kharitonov, T. J. Kippenberg, and C.-S. Brès, Nat. Commun. **8**, 1016 (2017).

[4] D. Grassani, M. H. P. Pfeiffer, T. J. Kippenberg, and C.-S. Brès, Opt. Lett. **44**, 106 (2019).

[5] E. Sahin, B. Zabelich, O. Yakar, E. Nitiss, J. Liu, R. N. Wang, T. J. Kippenberg, and C.-S. Brès, Nanophotonics **10**, 1923 (2021).

[6] E. Nitiss, T. Liu, D. Grassani, M. Pfeiffer, T. J. Kippenberg, and C.-S. Brès, ACS Photonics **7**, 147 (2020).

[7] E. Nitiss, J. Hu, A. Stroganov, and C.-S. Brès, Nat. Photonics **16**, 134 (2022).

[8] O. Yakar, E. Nitiss, J. Hu, and C.-S. Brès, arXiv 2203.06980 (2022).

[9] R. Dalidet, F. Mazeas, E. Nitiss, O. Yakar, A. Stroganov, S. Tanzilli, L. Labonté, and C.-S. Brès, Opt. Express **30**, 11298 (2022).

[10] J. Hu, E. Nitiss, J. He, J. Liu, O. Yakar, W. Weng, T. J. Kippenberg, and C.-S. Brès, 48 (2022).