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Dispersion-engineered AlGaAs-on-insulator waveguides for integrated nonlinear quantum optics

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Abstract

We demonstrate the capability of nanoscopic AlGaAs-on-insulator integrated structures to drastically enhance $\chi^{(2)}$ & $\chi^{(3)}$-nonlinearities. Simulations of simple, rectangular waveguides, for example, already reveal record-high SPDC efficiencies of up to 10^{-5} pairs per pump photon. Similarly, pump-enhanced $\chi^{(3)}$-nonlinearities could make near-deterministic parametric interactions at single-photon-level seed powers feasible. All the while, we apply dispersion engineering to tune these nonlinear interactions to C-band wavelengths to yield optimum interfaceability.

We present AlGaAs-on-insulator waveguides as a promising platform for second- and third-order nonlinear optical interactions [1]. Such integrated structures have large practical advantages over bulk implementations of frequency converters and pair sources as, for example, their scalable fabrication, stability and robustness, and reduced setup complexity. More strikingly so, preliminary calculations suggest that they could make efficiency regimes accessible in which nonlinear processes become significant at single photon level seed powers [2]. Such devices would revolutionize quantum communication, for example, through their ability to transform coherent states into single photon Fock states or by enabling photonic implementations of logical gates. Our material of choice, the III-V compound semiconductor aluminum gallium arsenide, provides large second- and third-order nonlinear coefficients, a transparency tunable to C-band wavelengths and their corresponding range of second harmonic frequencies, and mature fabrication quality. Furthermore, when AlGaAs is nanoscopically structured and immersed in dielectric cladding to produce highly confining waveguides, effective nonlinearities can be increased by orders of magnitude. Our contribution shows the optimization of $\chi^{(2)}$-efficiencies through careful balancing of the mode confinement and the three-wave mixing overlap in these structures. The procedure yields downconversion probabilities of 10^{-5} pairs per pump photon for simple rectangular waveguides, which can be further enhanced in microring resonators.

[1] M. Pu *et al.*, Optica **3**, 823–826 (2016)

[2] N. K. Langford *et al.*, Nature **478**, 360–363 (2011)