Generation of entangled photon pairs from high quality factor silicon microring resonator at near-zero anomalous dispersion

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Introduction

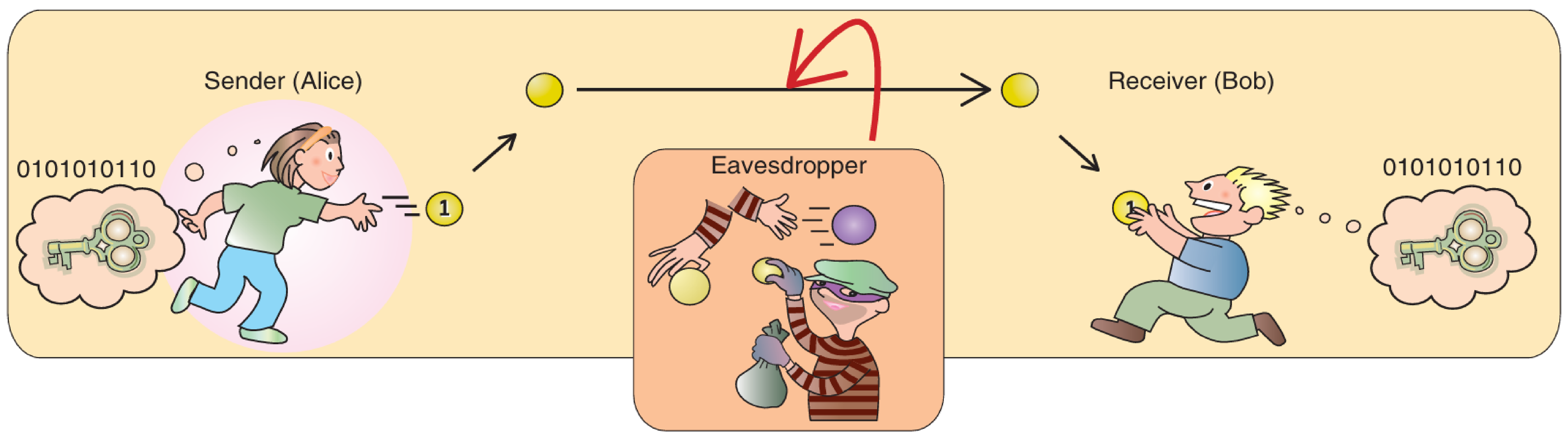


Fig 1) A quantum signal source in the form of single photons is an inherent requirement to the principle of Quantum Key Distribution [1].

- Compact, efficient, high-quality and scalable non-classical photon sources are one of the most critical building blocks for quantum information processing and communications.
- Microrings with non-linear properties can be integrated with other devices on photonic integrated platforms to produce single photons via spontaneous four wave mixing (SFWM). This is possible in the technologies like SOI [2], InP [3] and Si_3N_4 [4].

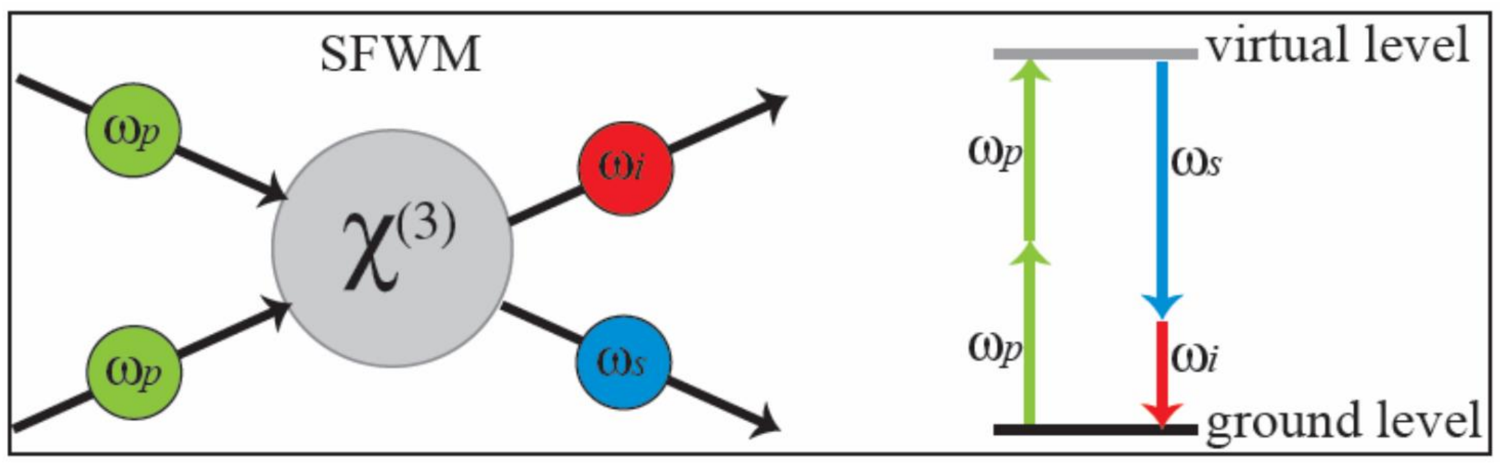
Theory & Methods

- The evolution of a pulse through a near zero dispersion and nonlinear medium considering phase matching is given by nonlinear Schrödinger equation (NLSE) given as [5]

$$i\frac{\partial E(z,t)}{\partial x} - \frac{\beta_2}{2}\frac{\partial^2 E(z,t)}{\partial t^2} + i\frac{\alpha}{2} + \gamma|E(z,t)|^2E = 0$$

where E is the complex envelope of the electric field, $\gamma = 2\pi n/\lambda_p A_{eff}$ is the nonlinear coefficient with n as kerr index of the waveguide material, A_{eff} is the mode interaction overlap area, λ_p is the pump wavelength, β_2 is the group velocity dispersion (GVD) and α represents linear losses.

Considering photon pair generation:



- Degenerate SFWM occurs when a nonlinear material, described by a third-order susceptibility $\chi^{(3)}$ is pumped with two photons at energies ω_p [6]. These photons are then annihilated, and a photon pair is created at ω_s and ω_i, called signal and idler respectively satisfying phase matching and energy conservation.

References

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Results

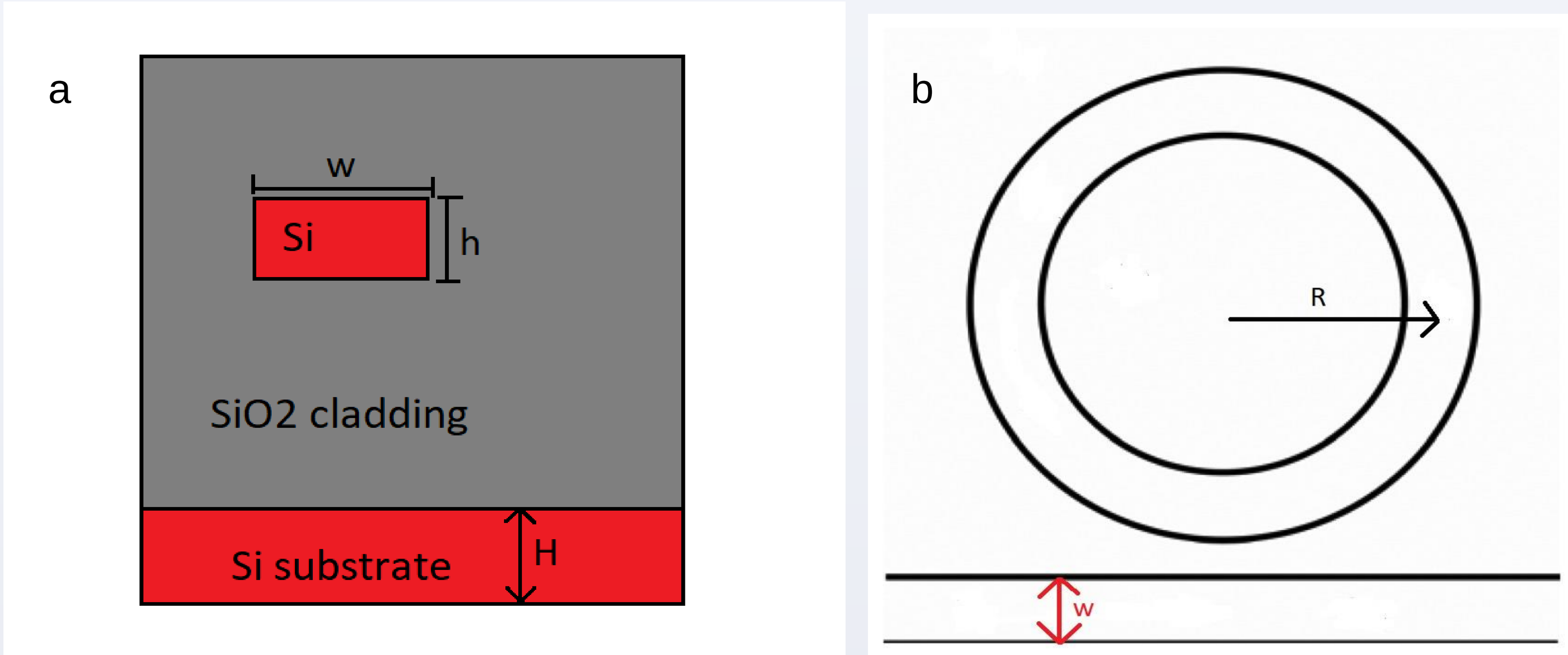

Fig 2) a. Si ring and bus percolated inside SiO_2 cladding, b. Top view of the layer where Si ring and the bus are percolated. Dimensions: H= 0.5 micron, h= 220 nm, R= 6 micron.

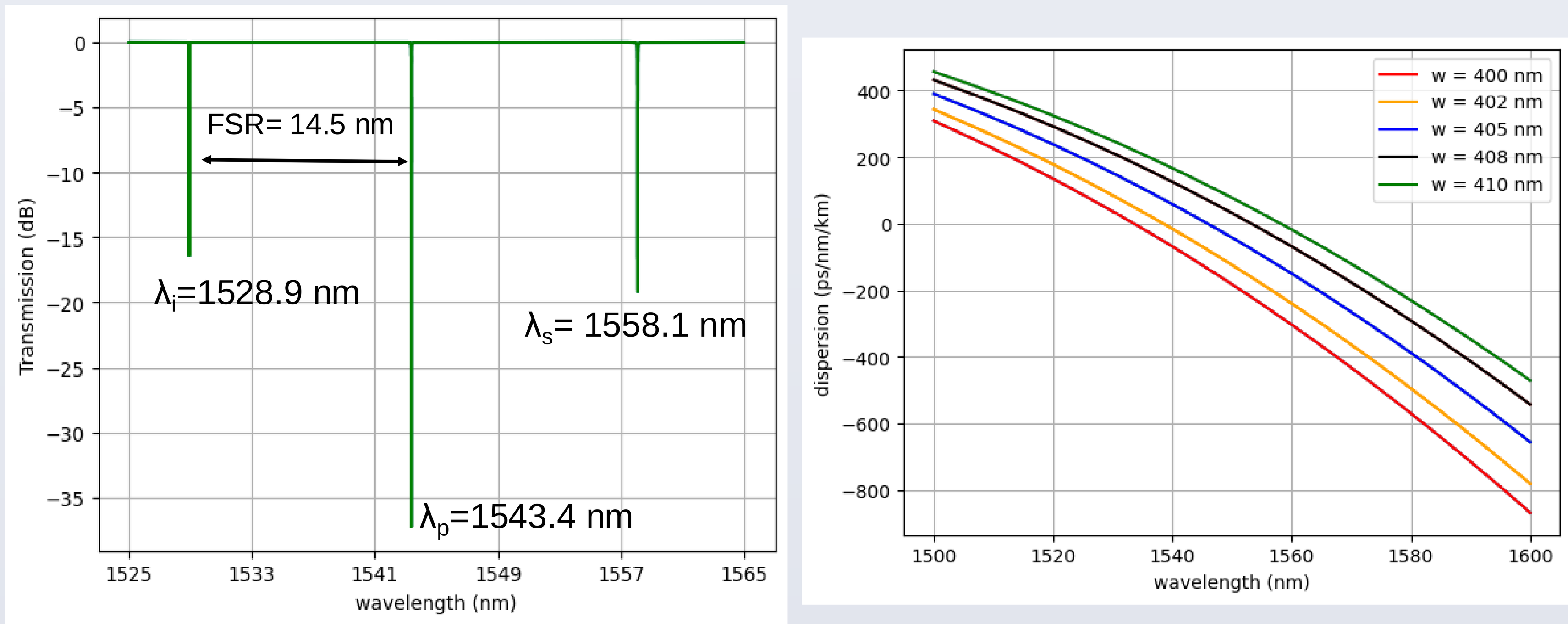

Fig 3) Transmission characteristics with w=405 nm and gap= 270 nm and variation of dispersion for ring cross-section with different waveguide widths.

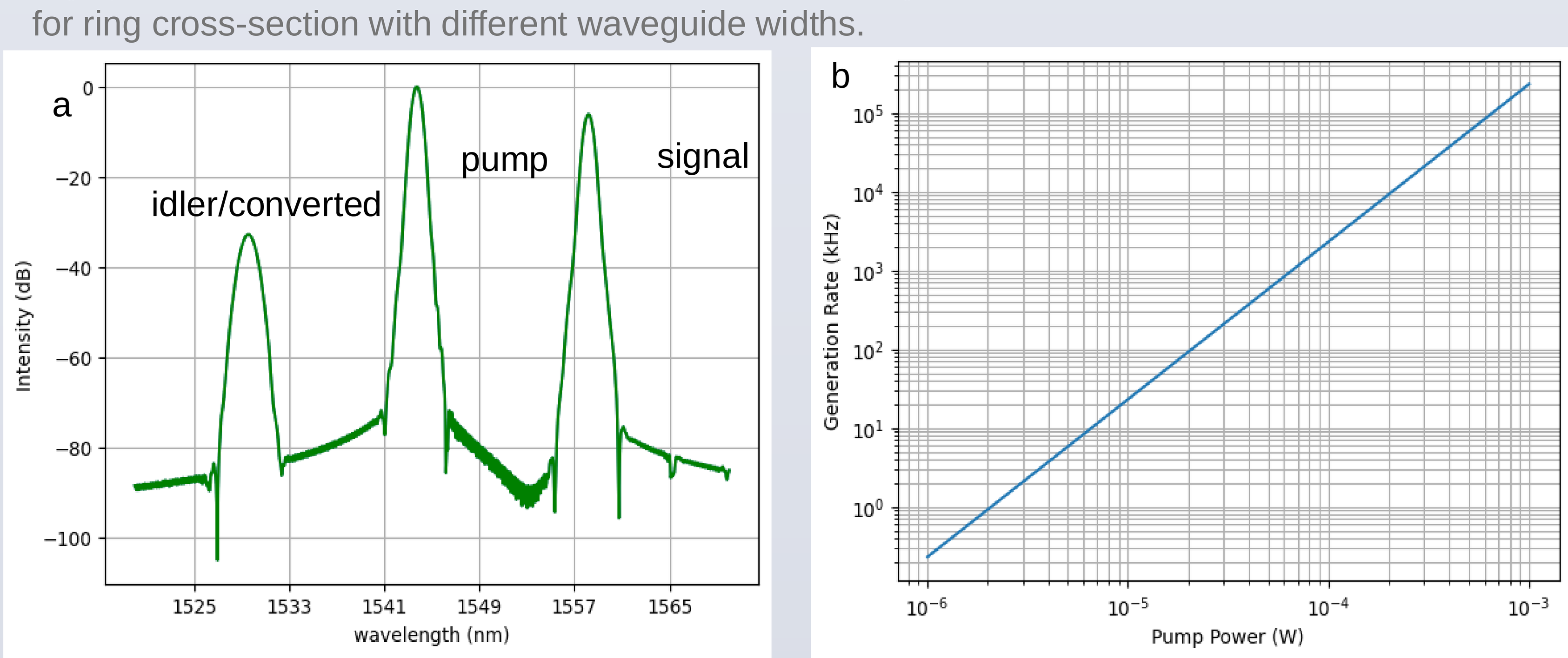

Fig 4) Classical FWM and Photon generation rate (PGR) for the width of 405 nm, a. Normalized power spectrum for a maximum pump electric field of 6.0e7 (V/m) and signal electric field of 3.0e6 (V/m) obtained from the 2.5-D FDTD analysis including both linear dispersion and non-linear refractive index, b. Variation of PGR with pump power.

Discussion and Conclusions

- We studied smallest ring for the photon pair generation with quality factor as high as 10^5.
- The width of the waveguides is chosen such that the phase matching condition is satisfied allowing the propagation of fundamental modes only. The value of α for TE_0 mode being 0.00039 dB/cm.
- The dispersion parameter of 23 (ps/nm/km) at our chosen dimensions compares to the GVD of -0.0122 (ps^2/m) which is lowest ever reported in the literature to the best of our knowledge in silicon rings used for photon generation, thus reducing the phase mismatch drastically.
- From the Finite Difference Eigen-mode simulations the fundamental mode propagates with interaction overlap area of 0.19μm^2 and considering Kerr index of 4.1×10^{-18} m^2/W [7], we expect our configuration to generate photon pairs with higher PGR at lower power regimes [8].

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