A frequency network through parallel processing of frequency-bin entangled photons from a 21 GHz SOI micro-resonator

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Harnessing the frequency degree of freedom of photons offers interesting perspectives for quantum information processing (QIP), allowing dense coding in a single spatial mode, hyperentanglement, multiplexing, parallelization and large distance traveling without stabilization or drift compensation. State-of-the-art integrated schemes to generate frequency-entangled states for frequency QIP through spontaneous four-wave-mixing (FWM) are limited by trade-offs in size, number of frequency modes and spectral separation. We have developed a bright and low footprint (<0.05 mm^2) photon pair sources emitting at telecom wavelength and generate efficiently **frequency-entangled photon pairs from a Silicon On Insulator (SOI) micro-resonator with a free spectral range (FSR) 21 GHz (Fig 1a-b), harnessing 83 signal-idler pairs** (S_n-I_n) over a >1.5 THz bandwidth (Fig 1d) to encode qubits or even qudits (cf. Fig 1b).
The low 21 GHz FSR is designed for optimal use of off-the-shelf fibered electro-optic phase modulators (EOM) and programmable filters (PF) in an EOM-PF-EOM configuration [1] to **manipulate in parallel several frequency-entangled qubits.** We thus perform quantum state tomography (Fig 1c) applying two parallel quantum gates to two qubits encoded in adjacent modes. We demonstrate such quantum state tomography independently on 17 frequency entangled qubits (coloured modes in Fig 1d) achieving fidelities above 85%. We report [2] for the first time the use of frequency entangled pairs, frequency demultiplexing and parallelized frequency quantum gates on those states to create **in the frequency domain a 5-user-fully-connected network without trusted node (Fig 2).**

References

[1] H-H. Lu et al., Phys. Rev. Letters, 2020.
[2] A. Henry et al., arXiv:2305.03457 (2023)

Figures

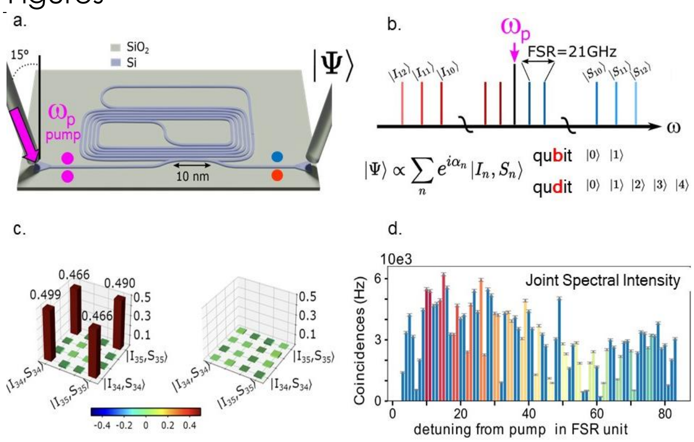

Figure 1: a. FWM photon pair generation in a 21 GHz SOI resonator [shape optimized using Bezier curves to minimize losses, modal phase matching condition setting the silicon waveguide width to achieve abnormal dispersion] pumped by ω_p ~1540 nm cw laser tuned in resonance (b.) c. Real and Imaginary part of the reconstructed density matrix of a 4-frequency-entangled state (fidelity of 0.96% to a maximally entangled state). The generated frequency entangled state |ψ> can be used to encode qubits or qudits for QIP across 166 frequencies (d.)

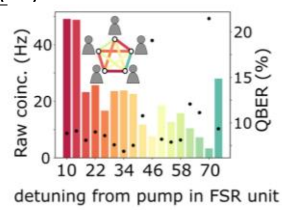

Figure 2: Raw key rate and QBER (qubit error rate) for a frequency fully connected network without trusted node. Reliable (QBER>11%) pairs are exchanged in a frequency fully-connected network following the colour code of Figure 1d.