# Quantum nonlinear optics using χ2 nonlinearity

**Kejie Fang**

*Department of Electrical & Computer Engineering, University of Illinois, Urbana, IL*

Photon-photon interaction is a crucial element in the development of quantum information science and engineering, playing a vital role in a range of applications from nonlinear optical quantum computing to repeater-enabled quantum networks. However, to date, photon-photon interactions have only been achieved in an indirect way as mediated by individual or ensembles of quantum emitters with resonant photon-atom interactions. Such indirect photon-photon interaction via quantum emitters faces significant limitations in terms of excess thermal fluctuations, local-environment caused inhomogeneity, and the available photon wavelengths and bandwidth. These challenges can be overcome by employing direct photon-photon interactions via bulk optical nonlinearities, such as $\chi^{(2)}$ and $\chi^{(3)}$, which nevertheless has remained elusive.

We developed an InGaP quantum photonic platform with an extreme $\chi^{(2)}$ nonlinearity combined with low optical losses in the near infrared wavelength range. We demonstrated the highest nonlinearity with single-photon nonlinear coupling exceeding 10 MHz and highest nonlinearity-to-loss ratio about 1.5% among all integrated photonic platforms. Based on the InGaP quantum photonic platform, we realized, for the first time, direct photon-photon interactions via bulk optical nonlinearity, leading to exotic quantum correlations between photons, such as photon repulsion, attraction, and tunneling. In addition, we apply the InGaP photonic devices for nonlinearity-enabled quantum networking. Quantum teleportation and entanglement swapping usually rely on linear-optical Bell-state measurement of identical photons. This approach is incompatible with inhomogeneous emitters and suffers from the infidelity caused by the multi-photon emission of parametric down-conversion sources. To overcome these limitations, we use the efficient sum-frequency generation process in InGaP microresonators to realize nonlinear-optical Bell-state measurement and quantum teleportation of photons with different wavelengths. Our work opens up exciting possibilities for nonlinear quantum information processing in integrated photonic platforms.