Sum-Frequency Generation and Photon-Pair Creation in AlGaAs Nano-Disks

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All-dielectric and semiconductor nonlinear nanophotonics is an emerging field enabling efficient optical interactions between magnetic and electric resonances at sub-wavelength scales, thereby achieving high directionality and high figures of merit due to very low losses [1,2]. It was shown that AlGaAs nanodisks with quadratic nonlinear susceptibility can provide second harmonic generation (SHG) with record-high efficiency of 10^{-4} [3], opening to a wide range of possible applications, including nonlinear microscopy and holography. In this work, we show experimentally that the strong quadratic nonlinearity in AlGaAs nano-disks allows efficient sum-frequency generation (SFG) with nontrivial polarization dependencies. By using the established classical-quantum analogy [4], we predict that these nano-resonators can facilitate efficient generation of quantum entangled photon pairs with higher than kHz biphoton rate and strong angular correlations.

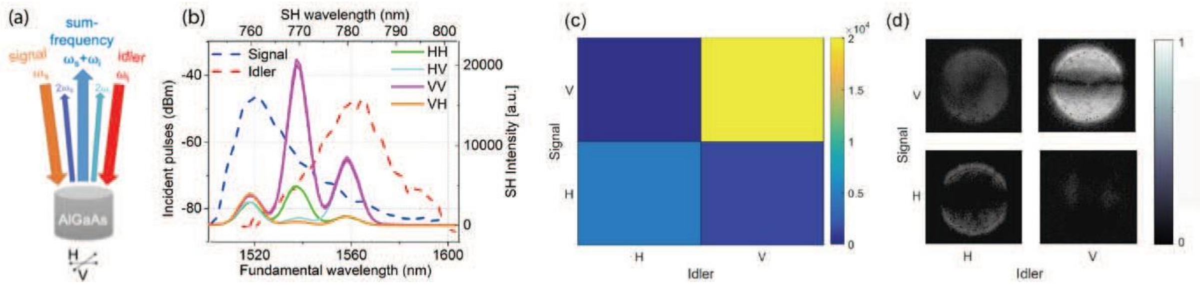

Fig. 1. Experimental observation of SFG. (a) Scheme of SFG with signal and idler beams in an [100] AlGaAs nano-resonator. The horizontal (H) and vertical (V) polarization axes lie in the wafer plane and are parallel to the crystalline axes of the AlGaAs lattice. (b) AlGaAs nano-resonator SFG reflection spectra at 770 nm and signal / idler SHG spectra at 760 / 780 nm; the plot shows four combinations of H and V polarizations of signal and idler beams, respectively. (c) Color map of H-polarized SFG at 770 nm for the polarization combinations shown in (b). (d) SFG directionality diagrams for the polarization combinations shown in (b).

SFG is measured from an [100] AlGaAs-on-oxide monolithic nano-resonator [5], as shown in Fig. 1 (a). A complete set of the experimental pulses are plotted in Fig. 1 (b). Dashed lines report the incident pulses, namely the signal and the idler with central wavelength of 1520 and 1560 nm, respectively, while solid lines report the three nonlinear parametric wave-mixing pulses, namely SFG at 770 nm, and signal and idler SHG at 760 nm and 780 nm, respectively. With the use of half-wave plates, we control the polarizations of the two incident pulses onto single AlGaAs nano-disk resonator. The resulting SFG signal counts at 770 nm are shown in Fig. 1(c) for different polarization sets of the two incident pulses, and the corresponding SFG radiation patterns measured via a camera and a Fourier imaging system are depicted in Fig. 1(d). The SFG radiation patterns strongly depend on signal/idler polarization combinations, with the highest measured SFG conversion efficiency being over 10^{-6}. We observe good agreement between the experimental results and our COMSOL finite-element simulations. Next, we analyze the integrated generation of entangled photon pairs through spontaneous parametric down-conversion (SPDC) [6], via the established proportionality to the SFG amplitude of classical signal and idler waves, propagating in the opposite direction [4]. We predict that a sub-wavelength AlGaAs nano-resonator can generate 10^4 photon pairs per second, which is comparable with some established bulk photon pair sources and demonstrates that nonlinearity on the nanoscale can be potentially employed for quantum state generation.

References

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