Robust Quantum Entanglement and Enhanced Resonance Energy Transfer by Epsilon-near-zero Plasmonic Waveguides

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Efficient entanglement and strong resonance energy transfer between optical dipole emitters randomly distributed in a photonic system over extended time periods and long distances remain a key challenge. The main reasons of this problem are the extremely weak dipole-dipole interactions, decoherence, and dephasing between the emitters mainly caused by radiative and nonradiative losses. In our presentation, we will demonstrate that we tackle these problems by proposing an efficient way to nanoengineer both the temporal (entanglement [1]) and spatial (resonance energy transfer [1] and superradiance [2]) coherent emission dynamics by an ensemble of emitters. A practical plasmonic waveguide system is used, that exhibits an effective epsilon-near-zero (ENZ) response [3] and can simultaneously achieve entanglement and strong resonance energy transfer in elongated distances, long time scales, and, even more importantly, independent of the emitters' nanoscale positions.

Since it is very difficult to control the position of emitters in nanoscale regions, the reported ENZ plasmonic waveguide is advantageous for the experimental verification of the presented strongly entangled states compared to alternative plasmonic waveguide systems (wedge or rod), where the emitters need to be accurately placed in predefined positions to achieve maximum entanglement [4]. This distinct feature makes the ENZ waveguide an ideal platform for multi-qubit entanglement operation. More specifically, we calculate the concurrence and the resonance energy transfer rate for a passive or active ENZ plasmonic waveguide and compare the results to similar metrics for two other commonly used plasmonic waveguide systems, i.e., V-shaped groove milled in a flat metallic surface and cylindrical metallic nanorod. It is clearly proven that the ENZ waveguide drastically outperforms the other two waveguide types when it comes to improving the entanglement and the resonant energy transfer performance. More importantly, the efficiency of the entanglement between the emitters does not depend on their position within the ENZ waveguide, as the ENZ plasmonic mode has an ideally infinite phase velocity combined with strong and homogeneous electric field enhancement, which are important features that can lead to multi-qubit entanglement or resonance energy transfer. Moreover, we demonstrate that efficient steady-state entanglement can be achieved by using coherent external pumping and report a practical way to detect this interesting quantum optical operation by computing the second-order correlation function. The presented findings stress the importance of plasmonic ENZ waveguides in the design of the envisioned on-chip quantum communication and information processing plasmonic nanodevices.

References

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