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Survival of quantum entanglement in transmission without plasmonic resonance

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Abstract

We report a study of the influence of a thin gold film on the transmission of polarization-entangled photon pairs using quantum tomography to compare the state of the system with and without metallic film. Measurement is done with either a plasmonic nanostructures or a continuous, planar gold film. We find that plasmonic resonances are not responsible of the robustness of entanglement. At normal incidence, quantum entanglement is preserved also with the continuous metallic film, in consequence of the equality between transmission coefficients for polarizations s and p. This result reduces the need of plasmonic nanostructures when intensity of transmitted signal is sufficient.

As shown in the literature, a periodic array of subwavelength nanostructures on a metallic film enables coupling of light with localized surface plasmons: the latter allow greatly enhanced transmission at resonance [2-4] with preservation of entanglement [5,6]. We studied entanglement preservation after the interaction of polarization-entangled photons with such materials using quantum tomography. The near-infrared (818 nm) polarization-entangled photons pairs are produced by parametric downconversion using two identical type-I BBO-crystals with orthogonal optical planes. The sample is placed through one of the two optical paths of the degenerate photon pairs. In each photon path, quarter and half waveplates placed in front of a polarizing beamsplitter select the basis of the polarization measurement. Photons are finally detected with four single-photon counting modules and coincidences are recorded using a field-programmable gate array coincidence counter. The quantum state of the pairs before and after their interaction with the sample is determined by quantum tomography using the code developed by Paul Kwiat's quantum information group [1]. With this estimation of the quantum state, we evaluated different quantum features of the system, like the experimental state fidelity with respect to the maximally entangled Bell state theoretically produced $F(\phi_+, \sigma_i)$, and with respect to the state before the sample $F(\rho_0, \sigma_i)$, and the entanglement of formation $E_f(\sigma_i)$. These properties quantify the influence of the film on the entanglement and polarization state of the photon pairs.

Similarly, we investigated the need of plasmonic resonances by studying the survival quantum entanglement after transmission through a continuous, planar gold film, in function of the angle of incidence. Our experimental and theoretical results show that, at normal incidence, the sample does not affect the polarization of transmitted photons. Consequently, entanglement is preserved even though the total number of detected correlations decreases. When increasing the angle of incidence, the different transmission coefficients for s and p polarizations decrease entanglement, as the sample starts to behave as a partially polarizing device. In comparison to nanostructured samples, our results on the flat, thin film of gold indicate that the interaction with surface plasmons at resonance enhances transmission. However, it does not play a role on the robustness of the quantum entanglement for the photon pairs that are transmitted.

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