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Two-qubit correlations via a periodic plasmonic nanostructure

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ABSTRACT

We theoretically investigate the generation of quantum correlations by using two distant qubits in free space or mediated by a plasmonic nanostructure. We report both entanglement of formation as well as quantum discord and classical correlations. We have found that for proper initial state of the two-qubit system and distance between the two qubits we can produce quantum correlations taking significant value for a relatively large time interval so that it can be useful in quantum information and computation processes.

1. Introduction

In the field of quantum information and quantum computing [1], quantum correlations play an essential role. More specifically, entanglement is the most widespread type of quantum correlations and the most thoroughly studied. For this purpose many measures of entanglement have been introduced over the past years, and among them the most familiar is the entanglement of formation (EoF) [2]. However, entanglement of formation cannot measure other types of quantum correlations. For this purpose, quantum discord (QD) [3,4] as a measure of all quantum correlations, was introduced about a decade ago. As QD is defined as the difference between the total and classical correlations, one can easily compute the classical correlations (CC) of a system additionally to quantum correlations.

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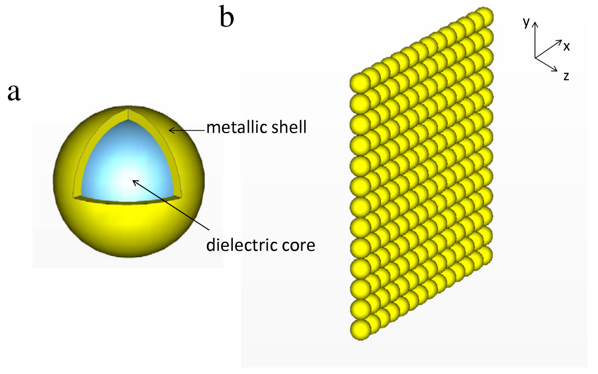

Fig. 1. Schematic diagram of the plasmonic nanostructure of our system. (a) A metal-coated dielectric nanosphere and (b) a square lattice (monolayer) of metal-coated dielectric nanospheres.

Recently, it has been shown that qubits, namely single molecules or quantum dots, can be strongly coupled by interacting with surface plasmons of plasmonic nanostructures [5–34]. This is an area of active current research in nanophotonics and falls within quantum plasmonics [35]. Entanglement of two qubits, mediated by a one-dimensional plasmonic waveguide has recently been studied [11,12,17], and quantified via the concurrence [2]. However, since concurrence is only a variable in the definition of EoF, it is more appropriate to use EoF rather than concurrence in order to properly quantify the entanglement [18]. Additionally to entanglement, the behavior of QD in two qubits coupled by an one-dimensional plasmonic waveguide has also been recently studied [18,23,26]. Besides one-dimensional plasmonic waveguides, entanglement of two qubits separated by a metal or metamaterial slab [13], a metallic nanoparticle [16], a hybrid photonic–plasmonic resonant structure which consists of two metal nanoparticles and a high-Q whispering-gallery-mode microcavity [24], an array of metal nanoparticles [25], and three-dimensional infinite- and finite-length plasmonic waveguides [33] has also been discussed. Moreover, a scheme has been quite recently proposed to generate a maximally entangled state between two qubits by means of a dissipation-driven process by coupling the qubits by a plasmonic nanoantenna [31].

A particular plasmonic nanostructure which has been proposed and studied in detail by our group is a two-dimensional lattice of metal-coated dielectric nanoparticles (see Fig. 1). The presence of this nanostructure leads to enhanced dipole–dipole interaction between two quantum systems [10]. In addition, the same plasmonic nanostructure leads to strongly modified (suppressed in certain cases) spontaneous emission rates of individual quantum systems that in turn can be used for simulating quantum interference in spontaneous emission [5,8], for the modification of the spontaneous emission spectrum of quantum systems [9], for creating optical transparency and slow light [14], for enhanced nonlinear optical rectification [15] and phase-dependent absorption/dispersion [22], as well as for transient gain without inversion [27], enhanced Kerr nonlinearity [28], and enhanced quadrupole transitions [34].

The combination of strong dipole–dipole interaction between two quantum systems [10] and the reduced spontaneous emission rates of an individual quantum system [5,8,14,15] could lead to strong quantum correlations between the two qubits. Therefore, in this work we study the interaction of two qubits, e.g. atoms, molecules or quantum dots, with a two-dimensional lattice of metal-coated dielectric nanoparticles. We calculate both EoF and QD associated with this system, for several initial states of the two-qubit system, in order to indicate the difference between entanglement, which is measured by the EoF, and the total quantum correlations, which are measured by the QD. We compare the results for two qubits in free space and for two qubits mediated by a plasmonic nanostructure. We find that QD for some initial states presents a sudden change during its time evolution. As recently studied [23], this sudden transition in the time evolution of QD shows a similar transition between classical and quantum decoherence [36,37].

In the next section we present the basic theory of problem under study. Specifically, we use the master equation for the quantum system, that contains terms which are influenced by the coupling