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Different quantum optical response in fluorescence of gold and silver nanoparticles

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Abstract

Electrical permittivity and fluorescence emission behavior of gold and silver nanoparticles with radii range from 1 to 10 nm are studied in quantum mechanical regime and compared with classical results. It is observed that electrical permittivity of gold and silver nanoparticles is significantly modified considering quantum mechanical effects. Furthermore, it varies by wavelength while the size of nanoparticles decreases. The results indicate clear blue shift for silver and red shift for gold and also weakening of fluorescence peaks for both types of nanospheres. These quantum plasmonics particles which can pass through walls of living cells due to their small size can also serve as a fluorescent probe and delivery system for imaging and targeted delivery of bio-systems.

Keywords: Quantum plasmonics particles; Fluorescence; Quantum optics

1. Introduction

Nanometer-size metallic structures, namely nanoparticles, have received great attention in recent years due to their special physical and optical properties, such as strongly enhanced optical near-field around the particle, followed by larger absorption efficiency and stronger fluorescence signal [1–6]. Nanoparticles, such as biophotonics fluorescent labels, are widely used tools in diagnostics for common diseases such as diabetes [7] and cancer [8].

Optical properties of nanoparticles larger than 10 nm have already been widely studied in the literature using classical methods, but, these properties are strongly size dependent. On the other hand, studies show that nanoparticles with size of smaller than 10 nm, called Quantum Plasmonics Particles (QPP) are more efficient than larger nanoparticles in specific applications where some of those applications are reported in the review presented by Tame et. al. [9].

In spite of their interesting applications, QPPs have received less attention mainly due to their lack of microscopic structural details. *Ab initio* density functional theory (DFT) approaches are used to predict complete understanding of nanoparticles properties, but are currently limited to particles smaller than 1–2 nm, due to their high computational demands [10–12]. Experimental realization of QPPs properties, which is beneficial to compare their permittivity deviation from their corresponding in bulk, is difficult. Following the example of Genzel [13] and Kraus [14], in 2012, Scholl et al. [15], used an analytical quantum model to modify the classical

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Drude model and explained the behavior of QPPs which, beside its remarkably good agreement with DFT methods, is not limited by the particle's size. A few months later Osa et al. used this analytical model to compare absorption spectrum of gold and silver QPPs with those obtained classically by other groups [16–19].

Contrary to the absorption and scattering spectra of metal nanoparticles, their fluorescence behaviors have received less attention, even in classical regime. Compared to absorption spectrum, studying fluorescence behavior of nanoparticles is important according to different aspects: fluorescence spectroscopy is generally more accurate, it varies linearly for a large range of concentrations, and it has much higher signal to noise ratio. The last aspect is more significant for nanoparticles because for smaller sizes, i.e. for larger surface to volume ratio, the quantum efficiency of fluorescence intensity surprisingly increases over a million times higher than that of the bulk [20]. Experimentally observed fluorescence from copper and gold metals, with quantum efficiency on the order of 10^{-10}, was first reported by Mooradian [21]. After 15 years, Boyd et al. [22] experimentally studied this phenomenon using the single-photon induced luminescence technique. They also implemented a simplified model to explain the relation between the spectral peaks and the interband recombination at selected symmetry points in the Brillouin zone for gold, silver, and copper [23]. In 2000, Mohamed et al. [20] applied the same model to study emission from nanorods and then compared them with experimental data. Their results confirmed the validity of the Boyd model for nanoparticles fluorescence, but that

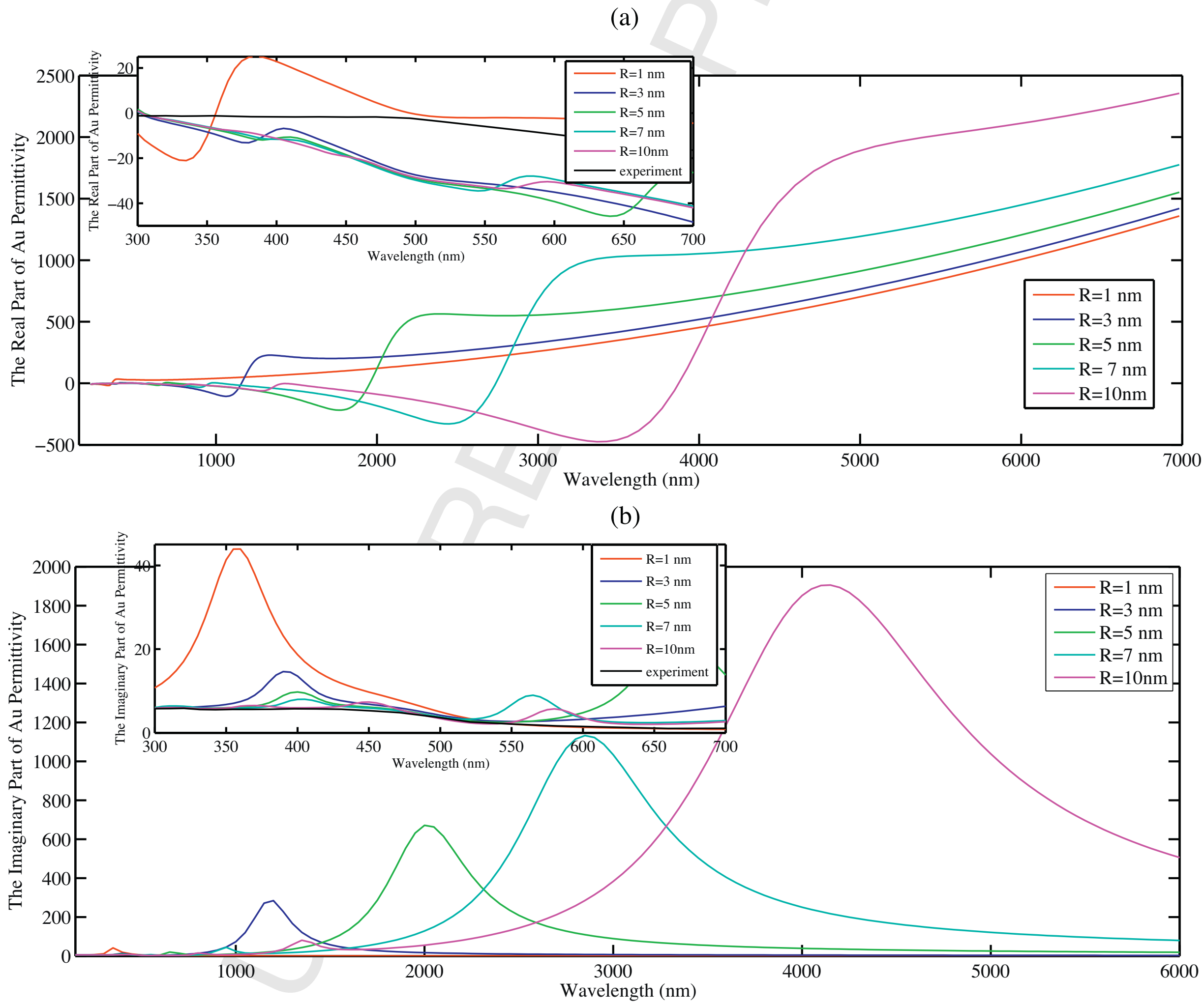

Fig. 1. Variation of (a) the real and (b) the imaginary parts of electrical permittivity for gold QPPs with different radii, calculated by using modified Drude models. The insets illustrate such variation in the visible region and experimental data for better comparison.