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Enhancement of surface plasmon resonances on nonlinear optical properties in spherical dome semiconductor nanoshells

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ABSTRACT

The interaction between a metallic nanopartical(MNP) and dome semiconductor nanoshells hybrid system on the nonlinear optical properties has been discussed. By means of the effective mass approximation and the compact-density-matrix methods, we have studied the enhancement of surface plasmon resonances(SPRs) on the second-harmonic generation(SHG) and nonlinear optical rectification. The results reveal that SHG and optical rectification are affected obviously by the SPRs of MNP, and the influence is related to the inner and external radius of the spherical dome semiconductor nanoshells.

1. Introduction

In the past few decades, with the development of nanofabrication technology, a growing number of people begin to pay attention to nonlinear optics, since nonlinear effect produced a lot of new phenomena, such as, SHG, third-harmonic generation(THG), optical rectification, absorption coefficient and refractive index *etc.* in different low-dimensional nano-materials. In addition, there are optical parametric oscillation, self-focusing, optical bistable and stimulated Raman scattering [1], and *so on*. At present, attention has been devoted to the study of the nanohybrid system, in which the most concerned about is local surface plasmon resonance(LSPRs). And the quantum dot(QD) of the metallic spherical dome shells is also widely concerned. Because of its unique optical properties, for example, highly enhanced local electric field near the rims and increased absorption at longer wavelengths compared with their shells or sphere counterparts [2–6], it has been used in many field, like, solar energy harvesting [7–9], space design [10,11], biological and chemical detection [12], data storage [13–15] *etc.*. In Ref. [16], incident intensity and phase of guided wave not only strengthen the surface plasmon polariton (SPP), but also achieve this modulation by optical parametric amplification. The results can be used in nonlinear optical integration and modulation.

Due to distinctive optical properties and broad field of application of the LSPRs, a lot of researches have been studying it. In 1975, Genzel et al. studied that the plasmon resonance showed a blue shift in a glassembedded silver nanosphere, when the sizes rang from $10nm$ to $2nm$ [17]. In 2013, SH et al. found that the scattering spectra of such hetero-NRs show longitudinal resonance wavelengths that are nearly insensitive to the relative composition of Ag and Au. Instead, the resonance is mostly governed by the overall length of the nanorod. This shows that the plasmons oscillate along the entire length of the NR without the significant perturbation at the Ag-

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Au interfaces [18]. In 2013, the fabrication of arrays of Al/Al_2O_3 core/shell nanoparticles with a metallic-core diameter between 12 and 25 nm display sharp plasmonic resonances at very high energies, up to 5.8 eV (down to $\lambda = 215nm$), which has been studied by Maidecchi et al. [19]. Liang et al. found that one can control the properties of nonlinear optical absorption and nonlinear optical rectification of a nanoring by tuning the outer and inner radius. Moreover, they found also that the nonlinear optical properties of a nanoring can be modulated by the magnetic flux through the nanoring [20]. Jiang et al. surveyed the interaction between MNP and semiconductor quantum dot(SQD), and found that the center-to-center distance and the radius ratio between MNP and SQD decide on the enhancement [21]. Liu et al. found that through the modulation of the inner and external radius, the resonant peak of optical rectification can be tuned effectively [22]. From above studies, they did a lot of work. However, we find that the interaction between MNP and the spherical dome semiconductor nanoshells has never been considered in the calculation about nonlinear optical properties.

In this paper, we mainly study the SHG and nonlinear optical rectification in spherical dome semiconductor nanoshells. The paper is arranged according to the following structure. In Section 2, we give the model and calculation in detail. In Section 3, we mainly give the numerical results and discussions. A brief conclusion will be showed in last section.

2. Theory

2.1. The quantum corrected dielectric function

It's a fact that the dielectric function included the interband electron transitions and intraband electron transitions. So the express of the dielectric function is as follow.

$$\varepsilon(\omega) = \varepsilon_{inter}(\omega) + \varepsilon_{intra}(\omega). \tag{1}$$

The intraband contribution satisfies the Drude model.

$$\varepsilon_{intra}(\omega) = 1 - \frac{\omega_p^2}{\omega^2 + j\omega\gamma}, \tag{2}$$

where ω_p denotes plasma frequency and $\gamma = \gamma_{bulk} + \frac{A\nu_f}{Rm}$ is the corrected collision frequency for bulk metal and quantum-size effect has consideration in bulk metal. A represents the factors of the interface and shape of the material. ν_f is the classical Fermi velocity [21]. When we consider the quantum-size effect, the quantum corrected dielectric function described in this way [23].

$$\varepsilon(\omega) = \varepsilon_{inter}(\omega) + 1 + \omega_p^2 \sum_i \sum_j \frac{S_{if}}{\omega_{if} - \omega^2 - j\omega\gamma}, \tag{3}$$

where S_{if} is a function of transition frequency ω_{if},

$$S_{if} = \frac{2M\omega_{if}}{\hbar N} \left| < f \middle| z \middle| i > \right|^2, \tag{4}$$

where S_{if} denotes the oscillator strength, N is the total electron number in conduction band and M presents the electron mass, respertively.

2.2. The MNP-SQD interaction

In this section, we mainly discuss the interaction between MNP and SQD. A spherical MNP with the radius R_m and a spherical dome with the inner radius R_1 and the external radius R_2 placed in vacuum consist of hybrid nanosystem. The sketch of the structure is shown in Fig. 1. The center-to-center distance and surface-to-surface distance are defined as Δ and d, respertively. A laser irradiates the hybrid nanosystem, equivalent to the interaction between the hybrid nanosystem and the oscillating electric field

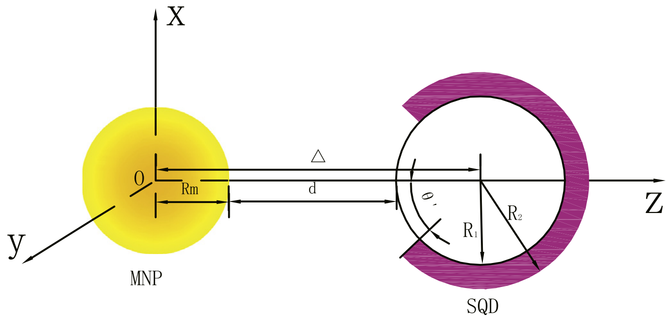

Fig. 1. The model of the hybrid nanosystem which consisted of gold nanosphere and dome nanoshell. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)