Numerial analysis of local density of states of plasmons in Si-SiO_2-silver nanocavity system

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Introduction

It has been a long time since Ritchie explained energy loss by surface plasmons from thin metallic films [1]. Attention to the field of plasmonics has been increased dramatically because of its capabilities and applications such as Surface-Enhanced Raman Spectroscopy (SERS) [2]–[5]. Simultaneously, many theoretical studies regarding a quantum approach of explaining the Purcell effect inside micro- and nano-metallic cavities have been done using plasmonics [6]. Recently, Agarwal et al. observed a great enhancement in photon emission in silicon inside silver nanocavity [7]. In this abstract, we used the finite-difference time-domain (FDTD) method to study electromagnetic enhancement inside the nanocavity and how plasmons interact with atoms — silicon and silicon dioxide in Agarwal structure— in quantum electrodynamical approach.

Local Density of States

To better understand this collective electron motion, plasmons, in the structure given in Figure 1, we introduce the concept of the local density of states (LDOS). Herein, we adopt the conventional definition [8] of the LDOS as measure of how much overlap that is between the dipole source and the harmonic modes of a system. In the structure of our interest, LDOS is the density of states of plasmons in the nanocavity from a Gaussian source. Furthermore, the electromagnetic enhancement in a nano- and microcavity is direct proportional to the LDOS [9].

Method

Computation of LDOS with FDTD method is described in detail in the reference given previously [8]. Herein, we use an open source FDTD simulator, MEEP [11]. Static dielectric constants are used to specify silicon and silicon dioxide layer, and the Drude-Lorentz model for metal is used to describe the polarizability of silver. LDOS of the given sturcture with two polarizations of the dipole source (Gaussian pulse with 140 fs pulse width and central frequency of $6.55 * 10^2$ THz), TM and TE, are used. Comparison between LDOS of the structure given and a modified structure with no SiO_2 layer is made to observe how the presence of SiO_2 layer makes difference to the LDOS signiture.

Discussion

We found that the intensity of LDOS is generally greater with TMz mode than those with TEz mode (see Figures 2 and 3). We expect the polarization of the plasmon and these results provide tools for determining the most suitable laser polarization to maximize the ponderomotive force. Since an electron moves in a circle that is in perpendicular plain to the magnetic field (the field with TEz mode is pointing y axis: in the cylindrical geometry, the electron motion is in the direction of the axis). In addition an electron would move in the same direction as the electric field, so in the cylindrical geometry, it would move in the direction that is perpendicular to the axis. Figure 4 illustrates the motions. FDTD simulation also shows that the location of dominant peaks in LDOS spectra for the structure with SiO_2 interlayer in Figure 5 are separated by an average of 150 meV, whereas those for the structure without SiO_2 interlayer are separated by an average of 100 meV. This indicates that the SiO_2 interlayer affects the resonant mode inside the cavity. Moreover, the 150-meV separation of the modes may open the way to exploiting combined plamon and phonon modes in device applications since SiO_2 has a strong polar mode at 153 meV.

Acknowledgement

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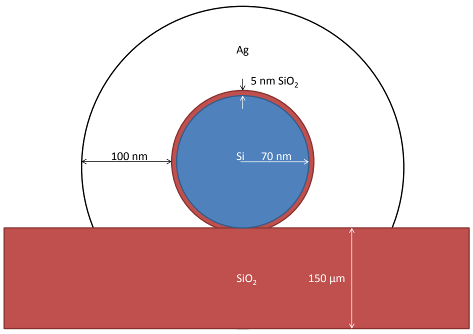

Fig. 1. Si-SiO_2-silver nanocavity system

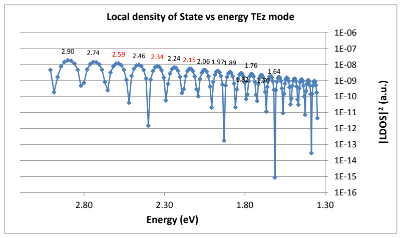

Fig. 2. LDOS versus energy with TEz mode

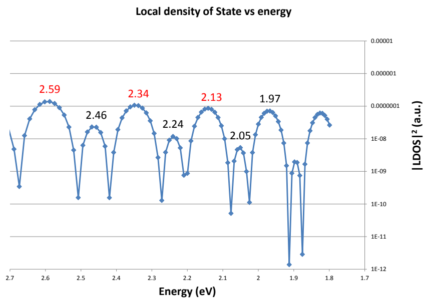

Fig. 3. LDOS versus energy with TMz mode

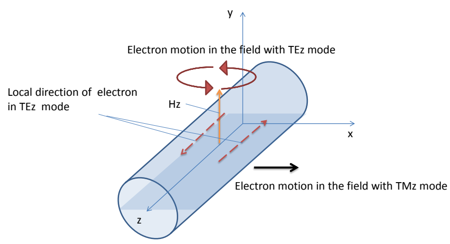

Fig. 4. Electron motion in TEz and TMz mode

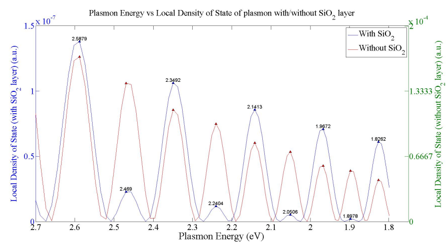

Fig. 5. LDOS versus energy with TMZ mode; comparison with the LDOS of the structure without SiO_2 interlayer