Numerical Analysis of Electric Field Enhancement in ZnO film with Plasmonic Au quantum dots

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INTRODUCTION

ZnO nanostructures have attracted interests for broad ranges of fields of study due to their unique optical and electrical properties [1-3]. Especially, the spontaneous polarization in the nanostructure would produce the permanent strong static electric field that can be applied to many studies. Also, their strong polarizability also make them a suitable candidate for many applications such as ion channel modulation, photodetector and LEDs in UV range. In this abstract, the plasmonic enhancement of the induced electric field produced from ZnO nanostructures is studied by numerical analysis. ZnO nanostructure of interest is exhibited in Fig 1.

MODEL

Finite Element Method (FEM) is used for all numerical calculations done in this abstract, using a modified version of open-source FEM code, JFEM2D [4]. The details on FEM code is described in a code author's article [5]. For ZnO dielectric functions, Loudon's model of uniaxial crystals gives[6]:

$$\epsilon^{\perp}(\omega) = \epsilon_{\infty}^{\perp} \frac{\omega^2 - \omega_{LO^{\perp}}^2}{\omega^2 - \omega_{TO^{\perp}}^2} \quad (1)$$

where $\epsilon_{\infty}^{\perp}$ is the high frequency dielectric constant in the direction along the c-axis, $\omega_{LO^{\perp}}$ and $\omega_{TO^{\perp}}$ are the LO and TO phonon frequencies. The parameters used in the calculation are summarized in Table 1. The Lorentz-Drude model of dielectric functions is used for Au quantum dots, which is given by

$$\epsilon(\omega) = 1 - f_1 \frac{\omega_p^2}{\omega^2 + i\Gamma_1 \omega} + \sum_{j=2}^{n} \frac{f_j \omega_p^2}{\omega_{0,j}^2 - \omega^2 - i\Gamma_j \omega} \quad (2)$$

where f_j are oscillator strength of jth oscillator, ω_p is plasma frequency, Γ_j are damping constants of jth oscillator, $\omega_{0,j}$ are resonant frequencies of jth oscillator. The parameters of Au are summarized in reference [8]. Two dimensional approximation is used, and the nanostructures will be treated as infinitely long cylinders in z direction, where z=0 plane is the domain of calculations.

RESULTS AND DISCUSSION

Fig 2 and Fig 3 show the meshgrid of ZnO film with and without two Au quantum dots in air, respectively. The comparison between maximum electric field amplitude of ZnO film with Au quantum dots and without Au quantum dots versus photon wavelength (TM mode of incident field) is shown in Fig 4. In general, the electric field is enhanced throughout the entire range. A high peak in UV range indicates that the Au quantum dots can significantly enhance the UV radiation from ZnO.

ACKNOWLEDGMENT

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REFERENCES

[1] Gogurla, N. et al. *Multifunctional Au-ZnO Plasmonic Nanostructures for Enhanced UV Photodetector and Room Temperature NO Sensing Devices*, Scientific Reports 4, 6483 (2014).

[2] Bai, S. et al. *High-Performance Integrated ZnO Nanowire UV Sensors on Rigid and Flexible Substrates*. Adv. Funct. Mater. 21, 4464–4469 (2011).

[3] Soci, C. et al. *ZnO Nanowire UV Photodetectors with High Internal Gain*. Nano Lett. 7, 1003–1009 (2007).

[4] J. M. McMahon, JFEM2D, Available from: <http://www.thecomputationalphysicist.com> (2015).

[5] McMahon, J. et al, *Gold nanoparticle dimer plasmonics: finite element method calculations of the electromagnetic enhancement to surface-enhanced Raman spectroscopy*, Anal. Bioanal. Chem. 394:1819-1825 (2009).

[6] Stroscio, M. A., Dutta, M., *Phonons in Nanostructures*, Cambridge: Cambridge UP, 2001. Print.

[7] Hanada, T., *Basic Properties of ZnO, GaN, and Related Materials*, Advances in Materials Research, Volume 12, 1-19 (2009)

[8] Zeman, E. J., Schatz, G. C., *An accurate electromagnetic theory study of surface enhancement factors for silver, gold, copper, lithium, sodium, aluminum, gallium, indium, zinc, and cadmium*, J. Phys. Chem., 91 (3), pp 634–643 (1987)

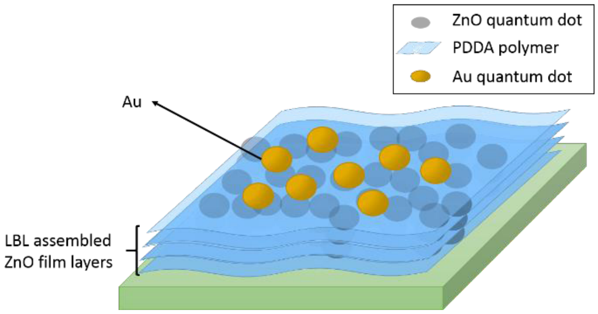

Fig. 1. Schematic diagram of ZnO thin film assembled by layer-by-layer technique with PDDA polymer with Au quantum dots.

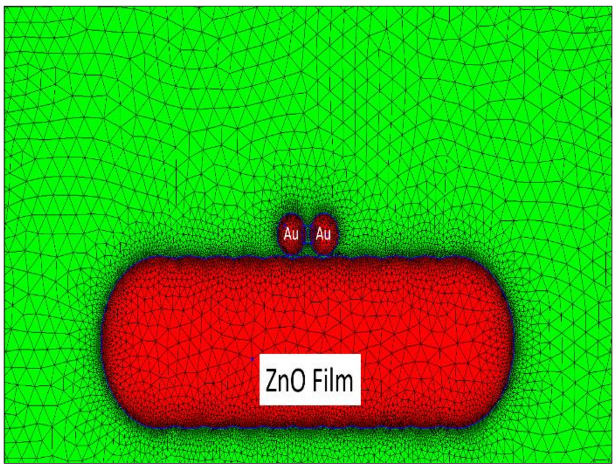

Fig. 2. Meshgrid of ZnO film with two Au quantum dots in air. Red with a "ZnO Film" label indicates ZnO film, Red with "Au" labels are gold quantum dots, and green presents the air.

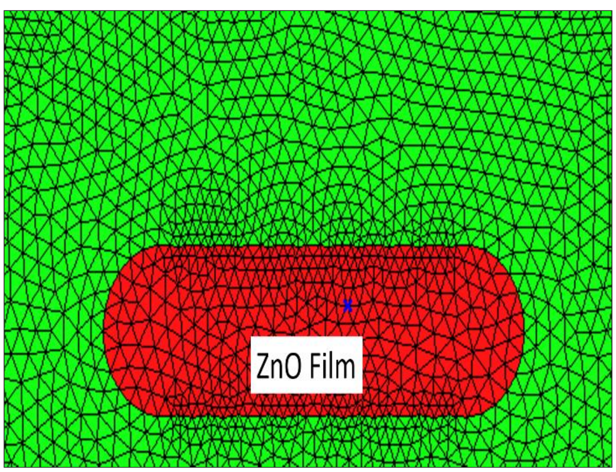

Fig. 3. Meshgrid of ZnO film in air. Red indicates ZnO film and green presents the air

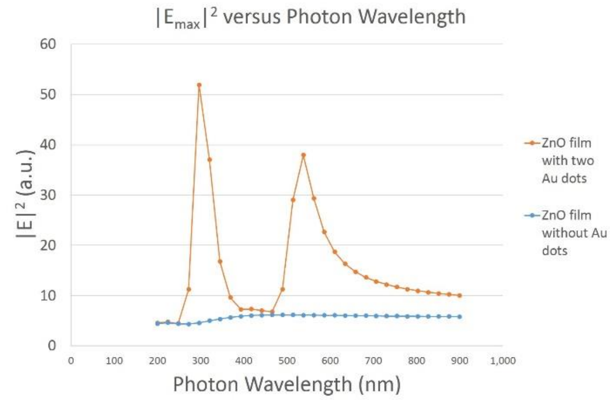

Fig. 4. Maximum electric field amplitude of ZnO film with Au quantum dots and without Au quantum dots

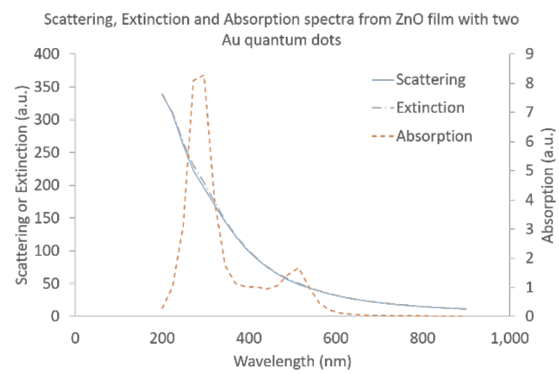

Fig. 5. Scattering, absorption, and extinction spectra of ZnO film with Au quantum dots

	$\epsilon^{\perp}(0)$	$\epsilon^{\perp}(\infty)$	ω_{LO}	ω_{TO}
ZnO	8.49	7.40	$72.8/\hbar$	$51.0/\hbar$

Table 1. Dielectric function parameters for ZnO