Charge Dynamics in a Core-shell Nanoparticle with Dielectric Core Enclaved by a Semiconducting Shell

Yanlin Li[1], Zi Wang[1], Tao Shen[2], and Thomas Wong[1]*

1 Department of Electrical and Computer Engineering, Illinois Institute of Technology, Chicago, IL 60616, USA
2 College of Information Engineering and Automation, Kunming University of Science and Technology, Yunnan, China
Email: twong@ece.iit.edu

A dielectric core enclaved by a semiconducting shell form a core-shell structure that exhibits polarization properties in the terahertz frequency range possessing unique features along with those of the homogeneous semiconducting nanoparticle (T. Shen, M. Yan and T. Wong, IEEE Trans-AP, v. 61, p. 4229-4238, 2013.) Previous work has shown that an insulating outer shell on a semiconducting core led to enhancement of the local field while the surface plasmon resonance exhibited a red shift (Y. Li, Z. Hu and T. Wong, IEEE APS-URSI Symp. 2017.) The subject of this investigation can be considered as the dual of the previously studied core-shell nanoparticle.

In the low frequency range and up to the plasma resonance frequency, the shielding effects of the mobile carriers in the shell confine the electric field to the region close to the outer semiconductor surface so that the structure has a dipole moment close in value to that of a solid semiconducting nanoparticle when excited by a dynamic electric field. Provided the thickness of the semiconducting shell reaches several Debye lengths, the presence of the dielectric core has little influence on the total polarization of the structure in this frequency range, since the electric field is shielded from the core region by the mobile charges in the shell. Beyond the surface plasmon resonance, the inertia effect of the charge carrier subdues its ability to respond fast enough to the polarizing electric field, rendering the shielding effect gradually subsides as the frequency is increased. In the high frequency region, the polarization of the core-shell structure is determined by the core dielectric and the shell's lattice polarization. In this high frequency range it can be considered as a core and a shell made of dielectric with different permittivities, provided that the photon energy of the exciting field is less than the energy bandgap of the semiconducting shell. Of particular interest is the large negative contribution to the real part of the dipole moment above plasmon resonance frequency before it settles to the high frequency limit. The magnitude for the case of a thin shell is substantially larger than that exhibited by a solid nanoparticle. The presence of the dielectric core forces the current to go around the semiconductor shell instead of passing through the center of the structure. This circular path gives rise to delay in the polarization so that the dipole moment can attain a substantial negative value even in a moderately doped outer shell. This out-of-phase polarization can be impetus to inductive reactance for circuitry applications in the terahertz frequency range.