Tuning and Enhancement of the Magneto-Dielectric Behavior of Semiconductor Nanoparticles

B. García-Cámara*, J.F. Algorri, V. Urruchi, J.M. Sánchez-Pena and R. Vergaz
Displays and Photonic Applications Group, Electronic Technology Department,
Carlos III University of Madrid, Spain
*corresponding author: braulio.garcia@uc3m.es

Abstract. Magneto-dielectric response of semiconductor nanoparticles has been recently shown as a useful phenomenon for several applications, e.g. sensors. The enhancement and spectral tuning of this behavior is a keynote aspect for some of these approaches. In this work, we show that the Mie resonances of nanoparticles composed of $Al_xGa_{1-x}As$ can be enhanced and tuning in a fine way by controlling the relation between the particle size and the concentration of *Al* atoms (*x*).

Recently, it has been shown that high-refractive-index particles (e.g. Silicon, Germanium) with a size of few hundreds of nanometers present Mie resonances, both electric and magnetic [1, 2]. The appearance of these effects has been a revulsive in the field of Metamaterials because interesting phenomena, like the directional scattering proposed by Kerker et al. [3], have been experimentally demonstrated [4, 5]. Thus, the idea of a control over the light is closer. In addition, the similarity of the resonances with plasmon ones in metallic nanoparticles encourages the idea to reproduce some plasmonic applications, such as biosensors [6], with semiconductor nanoparticles, without the drawback of the thermal heating and the advantage of the CMOS compatibility. However, the potential relevance of these phenomena and their application in futuristic devices goes through the possibility to control them.

In this work, we have theoretically studied Mie resonances in small spherical particles made of a quite interesting composite, $Al_xGa_{1-x}As$. This material is obtained by replacing *Ga* atoms for *Al* atoms in the zincblende structure of *GaAs*. With optical properties between *GaAs* and *AlAs* [7], this composite offers a new freedom parameter to control its scattering response: the concentration of *Al*. Figure 1 shows both the spectral position (Figure 1a) and the maximum extinction efficiency (Figure 1b) of the first four Mie resonances of a sphere of a $Al_xGa_{1-x}As$ with a radius of 100 nm, as a function of the concentration parameter *x*. As can be seen, the spectral position of every resonance changes in a quasi-linear way with *x*. This effect is more remarkable in the dipolar magnetic resonance because a previous work [6] shows the invariability of the spectral position of the magnetic resonance with the particle size. However, here we show that this resonance could be tuned along a wide range ($\Delta\lambda$~100 nm) in a fine way by changing the *Al* concentration.

On the other hand, the variation of the maximum extinction efficiency (Q_{ext}) with *x* presents a non-linear relation. In fact, a maximum extinction can be achieved at a certain concentration in the dipolar resonances. This fact is crucial, because the application of these phenomena on futuristic application will involve the maximization of the signal-to-noise ratio and then light scattering. We have already studied that the *Al* concentration at which a maximum extinction is obtained can be also modified by a correct election of the

particle size. In such a way, that a certain relation between the particle size and the *Al* concentration could optimize the scattering response of the nanoparticle. Once again, we have paid attention on the dipolar magnetic resonance, because the maximum is more remarkable. In addition, the observance of phenomena like minimum-forward scattering or zero-backward scattering [4-5] or the design of the biosensor based on these resonances requires large values of the extinction efficiency at this resonance.

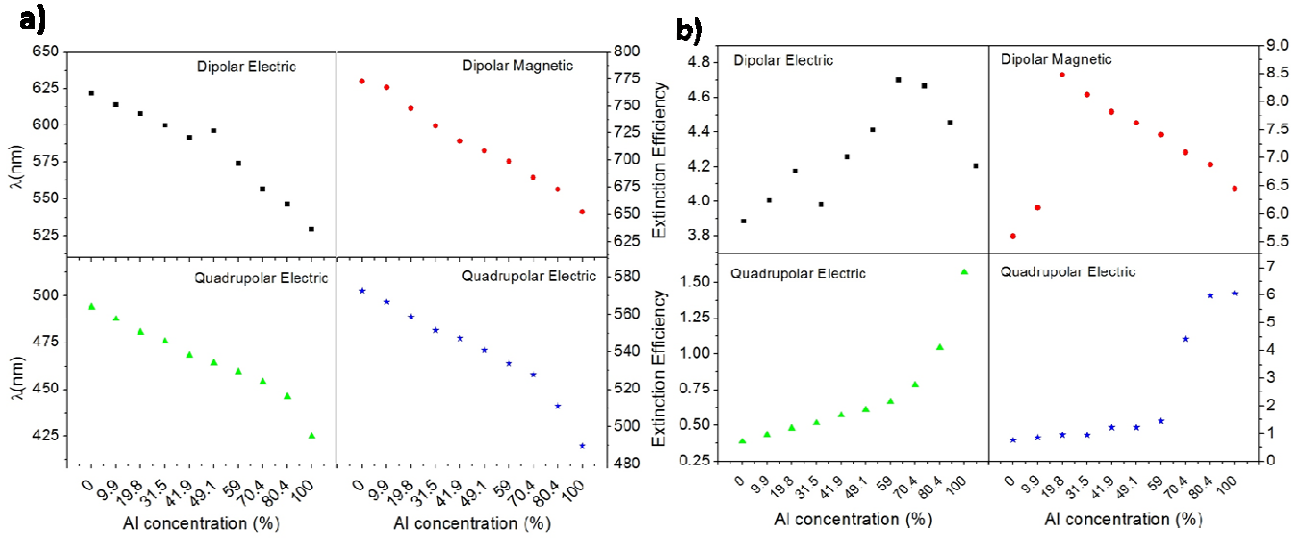

Figure 1. Spectral position (a) and maximum extinction efficiency (b) at the first four Mie resonances, both electric and magnetic, dipolar and quadrupolar; of a spherical particle of $Al_xGa_{1-x}As$ with a radius of *100nm* as a function of the Aluminium concentration (*x*).

Acknowledgements. This work has been supported by *Ministerio de Economía y Competitividad* of Spain under project *TEC2013-50138-EXP*.

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