Sensing with HRI nanoparticles by means of the linear polarization degree

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Abstract

The spectral evolution of the linear polarization degree ($P_L$) at right-angle scattering configuration ($\theta=90^\circ$) is numerically studied for high refractive index (HRI) dielectric nanoparticles. The goal of this research is oriented to sensing purposes. This analysis is performed as a function of the refractive index of the surrounding medium, and it is compared with the more conventional extinction efficiency ($Q_{ext}$) parameter. We focus on the spectral region where quadrupolar magnetic, dipolar electric and dipolar magnetic resonances are located for various semiconductor materials.

Introduction and Methods

Nanotechnology has revolutionized science during the last years by generating important theoretical and practical developments. Particularly, interaction of light with metallic nanoparticles (NP’s) has been a very active field in optics with impact in many areas, including sensing applications [1]. When incident light illuminates a metallic NP, free electrons start to oscillate. This generates localized surface plasmons (LSP’s). These coherent oscillations of the electronic plasma, which depends on the material properties, the particle size, shape, and also on the wavelength of the incoming radiation, are able to produce some particular surface charge distributions [2]. For certain frequencies, resonances can be observed and strong enhancements of the electric field in the surroundings of the NP’s may occur. Although most studies on metallic NP’s take advantage of the good response of the plasma in the visible range, their metallic nature is also the cause of their main disadvantage, i.e. the ohmic losses.

High refractive index (HRI) dielectric NP’s have been proposed as a solution for this problem because light can travel through these materials without being absorbed [3]. Furthermore, depending on their size and shape, they can show clear resonances in well-defined spectral ranges [4], being whispering gallery-like modes responsible for these resonances. Another important feature is the appearance of a magnetic response that these non-magnetic materials are able to exhibit. During the last years this magneto-dielectric behavior has been vastly explored for some elements, such as Silicon or Germanium [5], while the study of other semiconductor compounds has begun only recently [6,7].

In this research, spherical NP’s of Silicon (Si), Germanium (Ge), Aluminum Arsenide (AlAs), Aluminum Antimonide (AlSb) and Gallium Phosphide (GaP) are theoretically analyzed for a set of refractive indices of the surrounding media ($m_{ext}$) from 1 to 2. The spectral evolution of the linear polarization degree of the scattered light at right-angle detection, $P_L(90^\circ)$ [8], is established as a polarimetric parameter for sensing purposes. Although the study is performed for five materials, general results are shown for Silicon, as representative of their behavior. The most important common feature of these materials is their low absorption. In fact, in a range that varies from VIS to IR their absorption can be considered null in most cases [9].

Results and Discussion

Fig. 1 shows the spectral evolution of $P_L(90^\circ)$ for a Silicon NP (R=200nm) as a function of $m_{ext}$. As can be seen, the location and magnitude of all resonances evolve with $m_{ext}$. In fact, an estimate of $m_{ext}$ can be obtained from $P_L(90^\circ)$, by observing the wavelengths where resonances occur. Although Si has no absorption in the studied wavelength range, there are some materials, such as Ge, that have absorption traces in the NIR region [9]. The right choice of materials and sizes for each sensing application will lead to better results in sensing devices. Nevertheless, even in the worst case, electric resonances are less sensitive with absorption than magnetic ones [10], so that their fingerprint in $P_L(90^\circ)$ can still be followed in sensing.

$$\frac{\partial P_L(90^\circ)}{\partial m_{ext}}$$

(1)
Fig. 2 shows the sensitivity of $P_L(90^\circ)$ to changes in $m_{ext}$ (Eq. 1) at the wavelengths where resonances take place for isolated NP’s of Si, Ge, AlAs, AlSb and GaP (always at $R=200$ nm). It is clear that Ge shows low sensitivity at short wavelengths (where the magnetic quadrupolar resonance appears). Such phenomenon lies in the absorption shown by Ge in this spectral range [9]. Furthermore, the main result is the high sensitivity values obtained for all these materials, regardless of the analyzed resonance. As a consequence, $P_L(90^\circ)$ can be considered as an experimentally feasible indicator for sensing purposes.

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References

Figures

1- Fig. 1: Spectral evolution of $P_L(90^\circ)$ for a Silicon nanoparticle ($R=200$ nm) as a function of $m_{ext}$. Indicators $a_1$, $b_1$, and $b_2$ show the resonances location in the analyzed spectrum [11] (dipolar electric and magnetic, and quadrupolar electric, respectively).

2- Fig. 2: Sensitivity of $P_L(90^\circ)$ with $m_{ext}$ at the wavelengths where resonances take place for isolated nanoparticles of Si, Ge, AlAs, AlSb and GaP ($R=200$ nm). Sensitivity expressed in $RIU^1$ ($RIU$ stands for Refractive Index Units).