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POLARIZATION ANALYSIS OF THE SCATTERED RADIATION BY SILICON NANOPARTICLES IN THE INFRARED

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ABSTRACT. In this work we have studied the spectral dependence of the linear polarization degree at a right-angle scattering configuration (RASC) for silicon nanoparticles ($R \sim 200nm$) in the IR ($1 - 2\mu m$). For isolated and isotropic particles smaller than the incident wavelength, this parameter is complementary to the conventional spectral analysis for showing deviations from the pure electric dipole-like response due to either magnetic dipole-like or higher-order contributions.

1. Introduction

It is well-known that polarimetric characteristics of the light scattered by isolated particles or particles systems contain information about the scatterer: size, shape and optical properties [1]. In particular, in a previous research [2], we showed that the spectral evolution of the linear polarization degree measured at a scattering angle of 90° ($P_L(90°)$) is sensitive to deviations from a pure dipolar behavior (size, anisotropy, multiple scattering). Concerning isolated and isotropic particles, this means that if the size parameter $x = 2\pi R/\lambda$ is smaller than 1 and multipolar effects are absent, $P_L(90°)$ remains equal to 1. If particle size grows and/or multipolar contributions become important, significant changes are detected in $P_L(90°)$.

In a later work [3], we evidenced that this particular parameter can also identify magnetic response in light scattering by small particles. This is because $P_L(90°)$ can get negative values when the magnetic character of the particle dominates. In this case, to simulate a scatterer with both electric and magnetic character in a given range of wavelengths, we used analytical expressions for the optical constants (ϵ and μ) following Ruppin's work [4].

In a very recent research, it has been shown that nanoparticles made of silicon and with radius of several hundreds of nanometers ($R \sim 200$ nm) present both electric- and magnetic-like behaviors in the infrared [5, 6]. Taking into account that this is a realistic scattering system, the objective of this work is to apply our knowledge developed in [3] for an ideal system, to analyze polarimetric properties of scattered radiation by silicon nanoparticles in the IR. In particular, we will present a spectral analysis of the linear polarization degree at right-angle scattering configuration (RASC).

2. Linear polarization degree (P_L) at Right-Angle Configuration

The linear polarization degree ($P_L(\theta_{sca})$) of the intensity scattered by a particle is defined by [7]

$$P_L(\theta_{sca}) = \frac{I_\perp(\theta_{sca}) - I_\parallel(\theta_{sca})}{I_\perp(\theta_{sca}) + I_\parallel(\theta_{sca})} \tag{1}$$

where $I_\perp$ and $I_\parallel$ are the components of the scattered intensity linearly polarized perpendicular and parallel to the scattering plane, respectively, and measured at the scattering angle θ_{sca}. For $\theta_{sca} = 90°$ and for particle sizes such that the only contributions to the scattered field come from the first two Mie coefficients (a_1 and b_1) ,

$$P_L(90°) = \frac{|a_1|^2 - |b_1|^2}{|a_1|^2 + |b_1|^2} \tag{2}$$

In this case, $P_L(90°)$ is positive when the dipolar electric contribution (coefficient a_1) dominates, while it is negative if the dipolar magnetic contribution (coefficient b_1) is the dominant term [3]. If quadrupolar terms (associated to Mie coefficients a_2 and b_2) become significant (for instance, due to particles size), P_L is given by

$$P_L(90°) = \frac{\frac{9}{4}|a_1|^2 + \frac{25}{4}|b_2|^2 + \frac{15}{2}b_1 \cdot a_2^* - \frac{9}{4}|b_1|^2 - \frac{25}{4}|a_2|^2 - \frac{15}{2}a_1 \cdot b_2^*}{\frac{9}{4}|a_1|^2 + \frac{25}{4}|b_2|^2 + \frac{15}{2}b_1 \cdot a_2^* + \frac{9}{4}|b_1|^2 + \frac{25}{4}|a_2|^2 + \frac{15}{2}a_1 \cdot b_2^*} \tag{3}$$

3. Results

We have applied the previous analysis to silicon nanoparticles in the IR ($1 - 2\mu m$) which present a complex behavior with the emergence of magnetic resonances [6]. The refractive index of silicon is obtained from reference [8] and it is reproduced in Figure 1. In the spectral region of interest (blue square), the real part of the refractive index is mainly constant and equal to 3.5, approximately, while the imaginary part is negligible.

In Figure 2 we show the spectral evolution of ($P_L(90°)$) for silicon particles with $R =$ 230 nm in the interval ($1 - 2\mu$m). In this range, only the coefficients a_1 (electric dipolar), b_1 (magnetic dipolar) and b_2 (magnetic quadrupolar) have a non-negligible contribution. From this figure, we can identify three regions. When the electric dipolar character (a_1) dominates (1.2μm$< \lambda < 1.4\mu$m), P_L is clearly positive and tends to the ideal value of 1. As the magnetic dipolar conduct (b_1) becomes more important, P_L tends to decrease and it is negative when the magnetic dipolar resonance is excited (1.6μm$< \lambda < 1.8\mu$m). This is consistent with previous results [2, 3]. In contrast, a more complex evolution appears for shorter wavelengths ($\lambda < 1.2\mu$m) where a sharp magnetic quadrupolar mode (b_2) is excited. This mode induces an abrupt change in the value of P_L. On the left of the mode ($\lambda \sim 1.15\mu$m) the magnetic character of this resonance dominates and P_L is negative. At the center of the resonance ($\lambda \sim 1.17\mu$m), the strong values of b_2 involves that P_L is close to 1 (see equation (3)). After the resonance, the value of P_L decreases but remains positive due to the influence of the electric dipolar contribution.

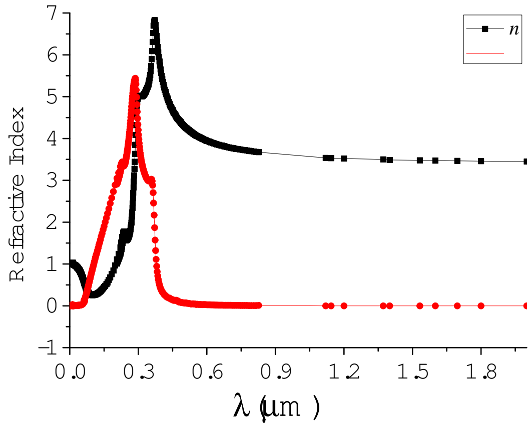

Figure 1. Real (n) and imaginary (k) values of the refractive index of silicon as given by [8]. The blue square identifies the considered range in the infrared part of the spectrum.

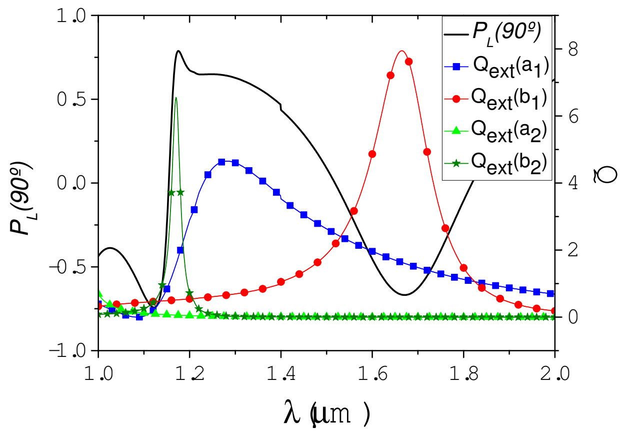

Figure 2. Spectral evolution of $P_L(90^\circ)$ of a silicon particle ($R = 230$ nm). The first four contributions of the Mie expansion to the extinction efficiency are also shown.

4. Conclusions

In summary, in this research we have analyzed the spectral evolution of the linear polarization degree at right angle scattering configuration, $P_L(90^\circ)$, of silicon particles ($R/\lambda < 1$) in the IR. We can conclude that its measurement can be a complementary tool to the conventional analysis of either the scattering or extinction spectra. $P_L(90°)$ can reveal and distinguish electric and magnetic responses of the scattering system.

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References

[1] M.I. Mishchenko and L.D. Travis, *In Light Scattering from Microstructures*, pp. 159-175, F. Moreno and F. González, Eds. (Springer-Verlag, 2000).
[2] B. Setién, P. Albella, J.M. Saiz, F. González and F. Moreno, "Spectral behaviour of the linear polarization degree at right-angle scattering configuration for nanoparticle systems", New J. Phys. **12,** 103031 (2010).
[3] B. García-Cámara, F. González and F. Moreno, "Linear polarization degree for detecting magnetic properties of small particles", Opt. Lett. **35,** 4084-4086 (2010).
[4] R. Ruppin, "Extinction properties of a sphere with negative permittivity and permeability", Solid State Commun. **116,** 411-415 (2000).
[5] R. Fenollosa, F. Meseguer and M. Tymczenko, "Silicon colloids: From microcavities to photonic sponges", Adv. Mater. **20,** 95-98 (2008).
[6] A. García-Etxarri, R. Gómez-Medina, L.S. Froufe-Pérez, C.López, L. Chantada, F. Scheffold, J. Aizpurua, M. Nieto-Vesperinas and J.J. Sáenz, "Strong magnetic response of submicron Silicon particles in the infrared", Opt. Express **19,** 4815-4826 (2011).
[7] C.F. Bohren and D.R. Huffman, *Absorption and Scattering Light by Small Particles*, (Wiley&Sons, 1983).
[8] E.D. Palik, *Handbook of Optical Constants of Solids*, (Academic Press, 1985).

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