**Plasmonics in the UV: Gallium and Aluminium nanoparticles. A comparison with Gold and Silver**

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During the last fifteen years, metallic nanoparticles have attracted the attention of many researchers due to the double possibility of localizing light in nanometric dimensions and getting high intensity local fields (excitation of Localized Plasmon Resonances, LPR's). Their use as plasmonic sensors has found many nanotechnology applications in biosensing [1], nanocircuitry [2], spectroscopy [3], photovoltaic devices [4] and microscopy [5]. Typical plasmonic sensor tools are made of Silver and Gold. Nanoparticles made of these metals show LPR's in the VIS-NIR range [6]. Because of the enormous impact of these tools in biosensing applications and also because many biological molecules and matter respond in the UV part of the spectrum [7], it is necessary to investigate and design plasmonic tools able to work at shorter wavelengths. Aluminium [8] and Gallium [9] have recently shown to be two possible candidates to cover this spectral range. The purpose of this contribution is to show a numerical comparison through the DDA method (Discrete Dipole Approximation) between these metals and the conventional Gold and Silver when nanoparticles made of these materials are located on dielectric substrates. The hemispherical particle shape will be taken as a basic geometrical model to develop this comparison, in part stimulated by the experiments performed in [9].

Figure 1 left shows the real part of dielectric constant of Aluminium, Gallium, Gold and Silver. The spectral response of spherical isolated nanoparticles (R=20nm) are plotted in Figure 1 right, where we show the normalized spectral absorption efficiency for each metal. As can be seen, Gold and Silver have a plasmonic resonance in the visible and near-ultraviolet zone, respectively; while Gallium presents a peak in 3.5 eV and the Plasmon resonance of Aluminium is outside the range represented (UV zone).

In Figure 2 we represent the spectral absorption efficiency of a hemispherical particle (R=20nm) on a sapphire substrate. Our model takes into account two factors: the incident polarization and the angle of incidence. We simulated two polarization states: S and P (perpendicular and parallel components to incidence plane, respectively). A comparison with the isolated particle case shows both the effect of the substrate and particle shape on the positions and structure of the spectra. Particularly notorious is the big shift undergone by the Al resonance due to the presence of the substrate. Concerning the resonant spectral position for each metal, Gold and Silver are in 2.1eV (590nm) and 2.6eV (476nm) respectively, i.e. in visible range. On the other hand, Aluminium has a LPR in 3.9eV(318nm) and Gallium presents two clear resonances, one in 2.5eV (496nm) associated to S polarization and other in 4.7eV (264nm) associated to P polarization. The choice of incidence angle is also important. At normal incidence S and P polarizations cannot be distinguished (both components are parallel to the substrate). However, for angles different to normal, P component (parallel to the incidence plane and perpendicular to the substrate) increases, leading to changes in her spectral response.

**References**

[1] Romain Quidant, Mark Kreuzer, Nature Nanotechnology, **5** (2010) 762.
[2] N. Engheta, Science, **317** (2007) 1698.
[3] R.G. Freeman, K.C. Grabar, K.J. Allison, R.M. Bright, J.A. Davis, A.P. Guthrie, M.B.Hommer, M.A. Jackson, P.C. Smith, D.G. Walter, and M.J. Natan, Science **267** (1995) 1629.
[4] H.A. Atwater, A. Polman, Nat. Materials **9** (2010), 205.
[5] T. Kalkbrenner, U. Hakanson, A. Schädle, S. Burger, C. Henkel, V. Sandoghdar, Phys. Rev. Lett. **95** (2005) 200801.

[6] K. Lance Kelly, Eduardo Coronado, Lin Lin Zhao, and George C. Schatz, Journal Of Physical Chemistry B **107** (2003) 668.
[7] Itai Lieberman, Gabriel Shemer, Tcipi Fried, Edward M. Kosower, and Gil Markovich, Angewandte Chemie **120** (2008) 4933.
[8] Mustafa H Chowdhury, Krishanu Ray, Stephen K Gray, James Pond, and Joseph R Lakowicz, Analytical Chemistry **81** (2009) 1397-403.
[9] P.C. Wu, T. Kim, A.S. Brown, M. Losurdo, G. Bruno and H.O. Everitt, Appl. Phys. Lett. **90** (2007) 103119.

## Figures

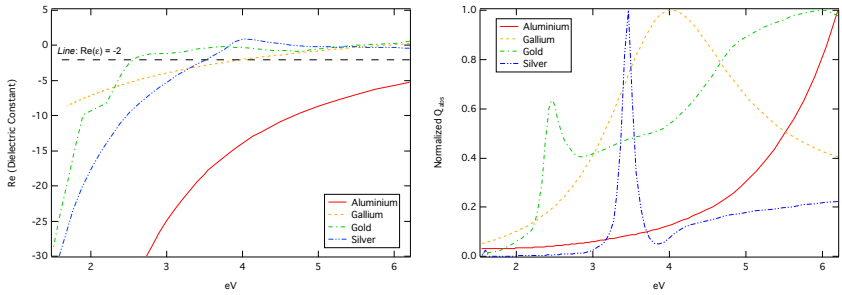


**Figure 1.** *Left*: Comparison of the real part of dielectric constant for Aluminium, Gallium, Gold and Silver. In addition, it includes a line-mark of Re(ε) = -2. *Right*: DDA calculations of the normalized absorption efficiency ($Q_{abs}$) of isolated spheres (R=20 nm) made of Aluminium, Gallium, Gold and Silver respectively.

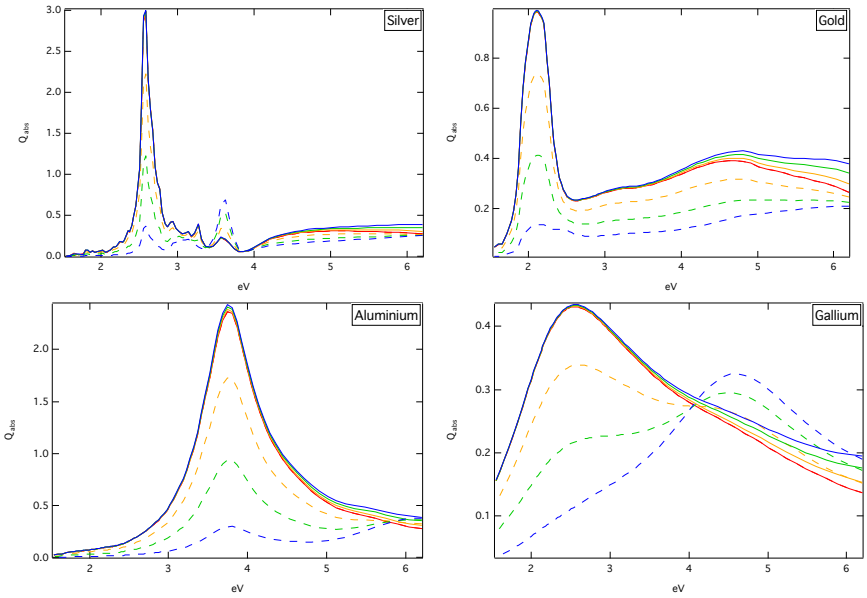


**Figure 2.** DDA calculations of the absorption efficiency ($Q_{abs}$) of Aluminium, Gallium, Gold and Silver hemispherical nanoparticles (radius 20nm) on Sapphire substrate. P (dashed lines) and S (solid lines) incident polarization are shown for different angles of incidence: 0º (red lines), 30º (orange lines), 50º (green lines) and 70º (blue lines). Silver and Gold have LPR's in the visible zone (1.50-3.10 eV), Aluminium and Gallium in UV zone (>3.10 eV).

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