Nuclear Instruments and Methods in Physics Research B 369 (2016) 66–67

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research B

journal homepage: www.elsevier.com/locate/nimb

Surface plasmons induced in Al spherical nanoparticles by Auger effect

J. García Gallardo [a,*], J.L. Gervasoni [b], L. Kövér [c]

[a] Laboratorio TANDAR, Centro Atómico Constituyentes (CNEA), Buenos Aires, Argentina
[b] Instituto Balseiro, Centro Atómico Bariloche (CNEA), Bariloche, Argentina
[c] Institute for Nuclear Research, HAS (MTA ATOMKI), Debrecen, Hungary

ARTICLE INFO

Article history:
Received 9 July 2015
Received in revised form 15 October 2015
Accepted 16 October 2015
Available online 19 November 2015

Keywords:
Plasmon
AES
Nano-sphere
Nano-particle

ABSTRACT

In this work we study the surface plasmon generation by electron–hole interaction in an aluminum spherical nano-particle due to the Auger electron–hole interaction by means of the Hamiltonian formalism.

1. Introduction

The study of surface plasmon production and decay is a very important topic for various research fields related to nano-structures, especially for the analysis using X-ray excited Auger Electron Spectroscopy (XAES) [1–4]. On the other hand, many of the synthesized nano-particles adopt spherical shape, or can be treated as if they were really spherical [5,6].

In previous works we studied extensively the surface plasmon production process due to electron–hole interaction applying both semi-classical and quantum mechanical models, and have found a three-term expression for the plasmon contribution [7–10].

In this work we study the surface plasmon production for spherical aluminum nano-structures generated during the Auger electron emission process.

2. Theoretical model

We follow the Hamiltonian formalism which considers the collective electron oscillations (plasmons) as generated by the interaction between the electron and the plasmon field [7,11].

The Hamiltonian describing the system is given by $H(t) = H_0 + H_I(t)$, where H_0 is the unperturbed harmonic oscillator Hamiltonian, and H_I is the *interaction* term, which refers to the interaction of the electron gas of the medium with the electron and the hole. For the case of an Auger interaction the hole charge is $2e$:

$$H(t) = -e\varphi^e\Theta(t-t_0) + 2e\varphi^h\Theta(t-t_0)$$

where φ^e is the electrostatic potential due to the electron, φ^h is the electrostatic potential due to the hole, Θ the *Heaviside* function, t_0 the time when the electron–hole pair is created.

The permitted oscillation modes ω_l are given by $\omega_l{}^2 = \omega_p{}^2 l/(2l+1)$, with $l = 1,2,3,\ldots$, and ω_p is the plasmon bulk frequency [12].

The results found for the XPS (X-ray Photoelectron Spectroscopy) photo-electron are still applicable for this case if we take into account that the hole charge is $2e$, instead of e [10].

The total contribution for plasmon production Q_A is:

$$Q_A = Q_A^e + Q_A^h + Q_A^{eh}$$

being, Q_A^e, Q_A^h and Q_A^{eh} the electron, hole and *interference* terms respectively for AES, and are related with the XPS terms Q^e, Q^h and Q^{eh}, by $Q_a^e = Q^e$, $Q_A^h = 4Q^h$ and $Q_a^{eh} = 2Q^{eh}$. Each of these contributions are at the same time contributed by the different terms l corresponding to the permitted oscillating modes:

$$Q_A^e = \sum_l Q_l^e$$

$$Q_A^h = \sum_l Q_l^h$$

$$Q_A^{eh} = \sum_l Q_l^{eh}$$

* Corresponding author.
E-mail address: gallardo@tandar.cnea.gov.ar (J. García Gallardo).

http://dx.doi.org/10.1016/j.nimb.2015.10.036
0168-583X/

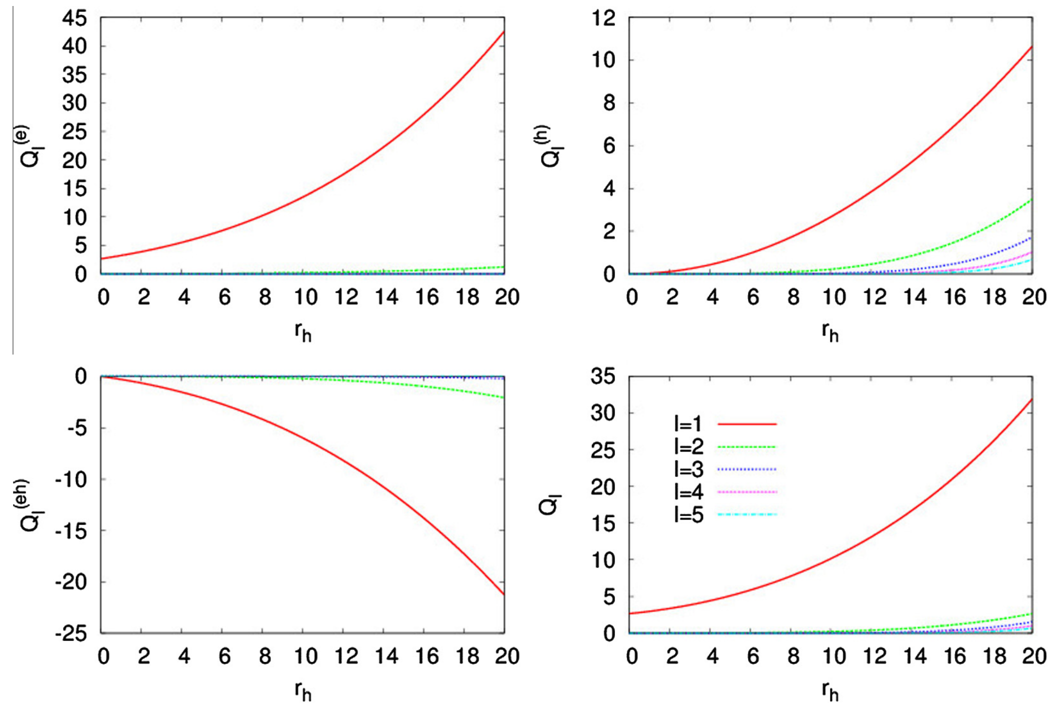

Fig. 1. Contributions to the average number of plasmons produced Q_l^e, Q_l^h and Q_l^{eh} respectively, excited by the Auger electron, the hole, the interference (electron–hole) and total, for the values $l = 1, 2, 3, 4$ and 5; as a function of r_h, the radial distance at which the electron–hole pair is created; for an Al sphere of radius $a = 20$ au ($\sim$1 nm) and an Auger electron escaping with $v = 4$ au ($\sim$108 eV).

3. Discussion and results

In the Fig. 1 we see the electron, hole and the interference contributions for the first five modes $l = 1,\ldots,5$ for an aluminum sphere of radius $a = 20$ au ($\sim$1 nm.) and an electron traveling with $v = 4$ au ($\sim$108 eV). All the qualitative results for the XPS interaction are still valid here: all contributions increase as the electron–hole pair creation distance from the surface approaches to zero. The contributions of Q_l decreases dramatically as l increases. Also, we cannot separate the contributions into *intrinsic* and *extrinsic*, even less than in the XPS case.

4. Concluding remarks

We used the very suitable Hamiltonian formalism for studying the plasmon production due to Auger electron emission from a spherical nano-particle of aluminum.

As shown above, the plasmon production in a spherical particle increases as the site of the electron–hole pair generation approaches the surface.

We see that the hole term in the expression describing the average number of plasmons produced is very comparable to the electron one and due to the interference term, the obtained average number of the surface plasmons produced shows us that in the case of aluminium nanospheres it is not possible to distinguish between the plasmon generation processes of intrinsic (hole) and extrinsic (electron) type. This behavior was advised before for the case of single-hole interaction (XPS), where the interference and hole terms were even smaller.

References

[1] G. de Abajo, Optical excitations in electron microscopy, Rev. Mod. Phys. 82 (2010).
[2] Y.F. Zhang, L.S. Liao, W.H. Chan, S.T. Lee, R. Sammynaiken, T.K. Sham, Phys. Rev. B 61 (2000) 8298.
[3] G. Compagnini, G. Patan, M. Sinatra, O. Puglisi, V. Nicolosi, D. Mihailovic, D. Vengust, J. Strle, J. Phys. Chem. Lett. 1 (2010) 393.
[4] G.G. Hembree, J.A. Vernables, Ultramicroscopy 47 (1992) 109.
[5] T. Ogura, Y. Saito, T. Higashihara, M. Ueda, Polym. Chem. 3 (2012) 2165.
[6] A.K. Patra, M. Sasidharan, A. Bhaumik, B. Saha, J. Mater. Chem. 21 (2011) 3925.
[7] J.L. Gervasoni, N.R. Arista, Phys. Rev. B 68 (2003) 235302.
[8] J.A. García Gallardo, J.L. Gervasoni, L. Kövér, Vacuum 84 (2010) 258.
[9] J.A. García Gallardo, J.L. Gervasoni, L. Kövér, J. Nanosci. Nanotechnol. 12 (2012) 9271.
[10] J.A. García Gallardo, J.L. Gervasoni, L. Kövér, Vacuum 107 (2014) 316.
[11] J.A. García Gallardo, J.L. Gervasoni, Plasmonics 10 (2015), http://dx.doi.org/10.1007/s11468-015-9883-8.
[12] J.L. Gervasoni, Nucl. Instr. Meth. Phys. B 267 (2009) 235.