Available online at www.sciencedirect.com
ScienceDirect
Procedia Materials Science 11 (2015) 434 – 437
Procedia Materials Science
www.elsevier.com/locate/procedia

5th International Biennial Conference on Ultrafine Grained and Nanostructured Materials, UFGNSM15

The Effects of Surface Oxidation and Interparticle Coupling on Surface Plasmon Resonance Properties of Aluminum Nanoparticles as a UV Plasmonic Material

A. Ziashahabi[a], R. Poursalehi[a,*]

[a]*Nanomaterials Group, Department of Materials Engineering, Tarbiat Modares University, P.O.Box: 14115-111, Tehran, Iran*

Abstract

Aluminum as a new plasmonic material is of great significance and can be used in array-based chemical and biological sensors instead of silver and gold with lower cost and more amenable manufacturing. It is vital to prevent oxidation and material degradation, in order to improve the performance and sensitivity of aluminum based surface plasmon resonance (SPR) devices. Aluminum nanoparticles passivate by forming the surrounding oxide layer. In this research, SPR properties of aluminum nanoparticles in different dielectric environments were investigated. Using boundary element method and MNPBEM simulation package the sensitivity of aluminum plasmon resonance to the presence of surrounding oxide layer, two nanoparticle coupling and different dielectric mediums were studied. Results show that in core-shell nanoparticles SPR peak position shifts from 170 nm to 206 nm by increasing shell thickness from 1 to 5 nm. In coupled Al nanoparticles by decreasing the gap distance between the particles from 20 to 0 nm the SPR longitudinal peak wavelength redshifted from 137 nm to 167 nm. Finally we study the effect of different embedding medium refractive indexes. Increasing dielectric matrix refractive index from 1 to 2 leads to redshift in SPR peak wavelength from 154 nm to 202 nm. Furthermore, enhancement of SPR peak position by refractive index is linear. In conclusion, the results show that aluminum can be used as a suitable substitution of conventional plasmonic materials especially for UV-plasmonic applications.

Peer-review under responsibility of the organizing committee of UFGNSM15
Keywords: Aluminum; UV-plasmonic; surface oxidation; interparticle coupling.

* Corresponding author. Tel.: +98-021-82883997; fax: +98-021-82884390.
E-mail address: poursalehi@modares.ac.ir

Peer-review under responsibility of the organizing committee of UFGNSM15
doi:10.1016/j.mspro.2015.11.030

1. Introduction

Plasmonics is the science of confining the incident light to sub-wavelength dimensions which creates intense and localized electromagnetic fields in metallic nanostructures. Gold and silver are well-known plasmonic materials that have been intensively used in biosensors, Canalejas-Tejero et al. (2013), nanoantennas and electronic devices, Castro-Lopez et al. (2011), light harvesting and energy storage systems, Ramadurgam et al. (2014), Villesen et al. (2013). Aluminum as a new UV plasmonic material has attracted attentions recently, knight et al. (2014). Aluminum is a low cost, easy manufacturing and mass producible material which can be considered as an alternative to silver and gold in some applications. In order to prevent material degradation and access high quality aluminum nanostructures surface treatment and passivation is needed. The plasmonic response of Al nanostructures depend sensitively on presence of a surface oxide layer, particle size, shape and surrounding material. To design a plasmonic device, these parameters should be considered and precisely calculated how they effect on surface plasmon resonance (SPR) peak shape and position. Simulations are indispensable to fundamental understanding and track the effective factors on plasmon properties of nanoparticles and finally to design a plasmonic device. Simulation of nanostructures plasmons is nothing but solving the Maxwell's equations for nanoparticles with favorite size, geometry and dielectric function. Recently boundary element method (BEM) have been used for the simulation of optical properties of plasmonic particles, Trügler et al. (2011), Trügler et al. (2008), surface enhanced spectroscopy, Koller et al. (2010), sensoric, Jacab et al. (2011), and electron energy loss spectroscopy (EELS), Hohenester et al. (2009). In this research, first boundary element method which has been used to study electromagnetic properties of Al nanoparticles briefly introduced. Then, effect of oxide surface on plasmon properties of Al nanoparticles was investigated. Finally the effects of interparticle coupling was also discussed.

2. Simulation

BEM is a numerical computational method that have been used to solve Maxwell's equations for simulation of plasmonic nanoparticles, Hohenester et al. (2012). In this method dielectric functions assumed to be homogenous and separated with sharp interfaces. For numerical calculations of electromagnetic equations discretization is done on interfaces rather on the whole volume. Therefore, computations are less time consuming than methods rely on volume discretization. In BEM a particle surface discretized to elements which has a value of surface charge. Surface elements connect with Green's function and a solution of electromagnetic equations is provided through electrostatic Green function. In this research BEM approach was used to study Al plasmon properties through MNPBEM14 simulation package. Effects of Al_2O_3 oxide shell, two particle coupling and different dielectric mediums on Al nanospheres with 10 nm diameter was investigated. All calculations were done using Palik dielectric function, Palik (1998) for Al and Al_2O_3 and dielectric function of the environment was assumed to be constant. Each mentioned parameters may cause plasmon peak shifts or damps that are important in designing plasmonic devices.

3. Results and discussion

3.1. Effect of oxidation layer on Aluminum plasmon resonance

Noble metals such as gold and silver have been extensively used in SPR based biosensors, because of their very low resistivity and low optical losses in visible and near-infrared regions of the spectrum. However, the high cost of these metals limit large scale use of them. Aluminum is a low cost plasmonic material with broadly tunable SPR peak wavelength but, it has the disadvantage of oxidation and material degradation. In order to design an Aluminum based SPR device one have to overcome this issue. The passivation of aluminum is a well-known phenomenon that involves the oxidation of the exposed-to-air aluminum surface into a thin, insulating, water-insoluble and waterproof film that is able to resist reactions with water, oxygen, or diluted acids. Presence of oxide layer significantly effects on SPR peak wavelength of the Aluminum. Here, plasmon properties of aluminum nano-spheres with 10 nm diameter and different oxide layer thicknesses were studied. Fig. 1 shows that the SPR peak wavelength shifts from 170 nm to 206 nm with increasing shell thickness from 1 to 5 nm.

3.2. Coupled nanoparticles

In coupled nano-spheres dipoles may oscillate parallel or perpendicular to line connecting center of two spheres. Therefore there would be two oscillation modes and two peaks. Longitudinal mode is more intense and has higher wavelength because oscillator length is higher in that case. Fig. 2 depicts the effects of interparticle coupling in SPR resonance peak position and intensity. As two spheres close to each other from 20 nm spaced to completely contacted peak wavelength shifted from 137 nm to 167 nm. This redshift is not monotonous, in near spaces peaks are more separated and they shift two higher wavelengths. When the distance between two spheres is 15 nm further separation dose not effect on peak position significantly. In a case that there is no space between spheres more than two peaks is observed due to interface between two spheres.

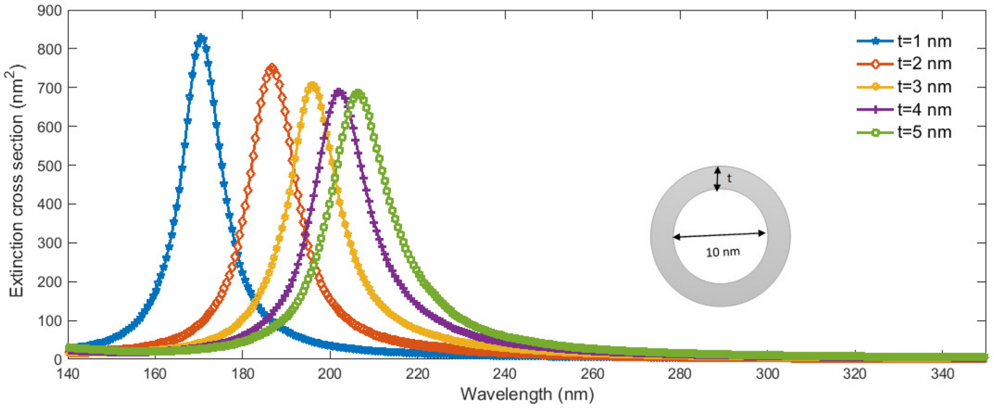

Fig. 1. Extinction cross section of Al nanospheres with different oxide shell thicknesses.

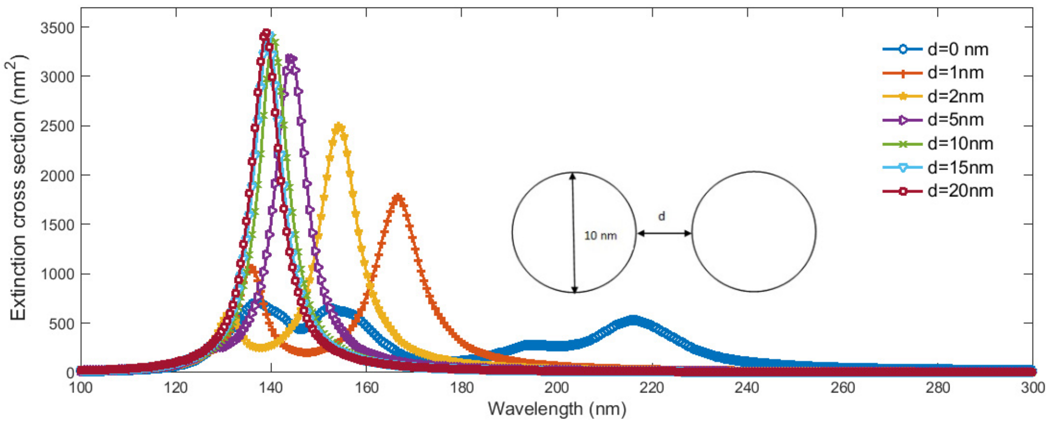

Fig. 2. Extinction cross section of Al coupled nanospheres.

Finally, we investigate the effect of refractive index on plasmon peak position of coupled nano-spheres. As illustrated in fig. 3 increasing refractive index from 1 to 2 cause peak wavelength increase monotonously from 154 nm to 202 nm.

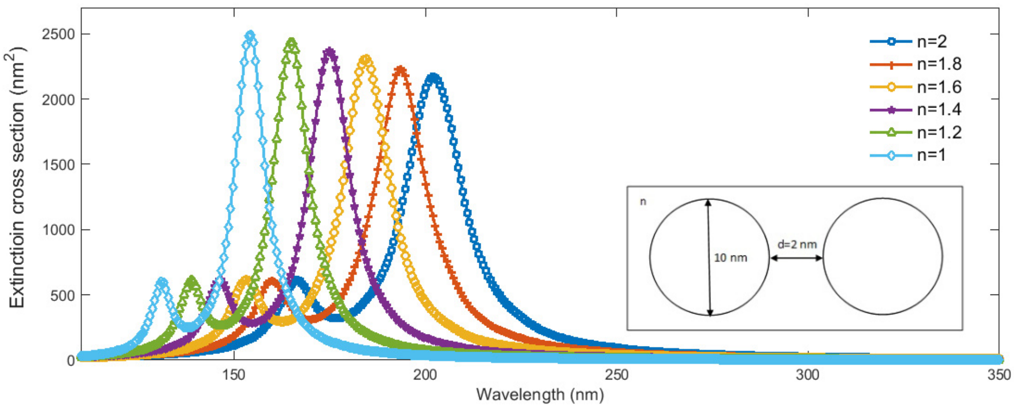

Fig. 3. Extinction cross section of Al coupled nanospheres in different dielectric media.

4. Conclusion

In this research plasmon resonance properties of different aluminum nanoparticles were investigated. Effects of inter-particle coupling, dielectric environment and oxide layer were studied. Increasing medium's refractive index or thickness of oxide layer result to increase in SPR peak wavelength. In coupled aluminum nano-spheres closing the spheres may cause to redshift of the SPR peak wavelength. Aluminum as a new plasmonic material has a broadly tunable SPR peak wavelength which enables many applications in SPR based sensor devices. This tunability, low cost and abundance of aluminum enables many commercial applications of aluminum nanostructures. As a new plasmonic material Aluminum is capable of being suitable replacement of silver and gold nanostructures.

References

Canalejas-Tejero, V., Herranz, S., Bellingham, A., Moreno-Bondi, M.C., Barrios, C.A., 2013. Passivated aluminum nanohole arrays for label-free biosensing applications. ACS applied materials & interfaces, 6(2), 1005-1010.

Castro-Lopez, M., Brinks, D., Sapienza, R., van Hulst, N.F., 2011. Aluminum for nonlinear plasmonics: resonance-driven polarized luminescence of Al, Ag, and Au nanoantennas. Nano letters, 11(11), 4674-4678.

Hohenester, U., Ditlbacher, H., Krenn, J.R., 2009. Electron-energy-loss spectra of plasmonic nanoparticles. Physical review letters, 103(10), 106801

Hohenester, U., Trügler, A., 2012. MNPBEM–A Matlab toolbox for the simulation of plasmonic nanoparticles. Computer Physics Communications, 183(2), 370-381.

Jakab, A., Rosman, C., Khalavka, Y., Becker, J., Trügler, A., Hohenester, U., Sönnichsen, C., 2011. Highly sensitive plasmonic silver nanorods. ACS nano, 5(9), 6880-6885.

Koller, D.M., Hohenester, U., Hohenau, A., Ditlbacher, H., Reil, F., Galler, N. Krenn, J.R., 2010. Superresolution Moiré mapping of particle plasmon modes. Physical review letters, 104(14), 143901.

Knight, M.W., King, N.S., Liu, L., Everitt, H.O., Nordlander, P., Halas, N.J., 2014. Aluminum for plasmonics. ACS nano, 8(1), 834-840.

Ramadurgam, S., Lin, T. G., & Yang, C., 2014, Aluminum plasmonics for enhanced visible light absorption and high efficiency water splitting in core–multishell nanowire photoelectrodes with ultrathin Hematite shells. Nano letters, 14(8), 4517-4522.

Trügler, A., Hohenester, U., 2008. Strong coupling between a metallic nanoparticle and a single molecule. Physical Review B, 77(11), 115403.

Trügler, A., Tinguely, J.C., Krenn, J.R., Hohenau, A., Hohenester, U., 2011. Influence of surface roughness on the optical properties of plasmonic nanoparticles. Physical Review B, 83(8), 081412.

Villesen, T.F., Uhrenfeldt, C., Johansen, B., Larsen, A.N., 2013. Self-assembled Al nanoparticles on Si and fused silica, and their application for Si solar cells. Nanotechnology, 24(27), 275606.