Investigating the color change in annealed gold nano particle arrays.

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For small metal nano particles (MNP), the wavelength of the incident light is larger than the particle itself. The electric field is then relatively constant over the whole particle at any given time, displacing the conduction electron with respect to the ion cores. When the frequency of the incident light wave matches the Eigen frequency of the particle, a resonance condition is achieved. This is known as Localized Surface Plasmon Resonance (LSPR), and is the main mechanism for the absorption and scattering properties found for MNP. The size and shape of a given MNP, and permittivity of the surrounding medium of the particles are what determine which frequency the resonance occurs at [1].

Here we investigate the optical properties of large 2D arrays of ordered gold MNP's and how they are affected by annealing. The MNP arrays are fabricated using Electron Beam Lithography (EBL) and uniform Au deposition is achieved by using Electron Beam Evaporator (EBE). All fabricated samples are square arrays of MNP's designed to have a particle diameter of 53 nm and a inter particle distance of 160 nm. The arrays are annealed for 5 minutes at specific temperatures. The geometrical shape of the particles is investigated using scanning electron microscopy (SEM) and atomic force microscope (AFM), while the LSPR is determined from extinction measurements using a spectrometer setup (Filmetrics F-10).

Spectral analysis presented in Figure 1 show that the LSPR peak blue shifts for increasing annealing temperatures. Macroscopically, this is observed by a blue to red color change of the particle array due to the blue wavelengths being absorbed or scattered rather than reflected, see Figure 2. The resonance occurs at 600 ± 2 nm for the un-annealed sample, and decreases to approximately 540 nm when the sample is annealed at 450^{o}C. Surprisingly, SEM and AFM images show minimal changes in the geometry of the particles, though SEM images show a smoother particle surface for the annealed particles. We can also see the resonance peak becomes narrower as our annealed arrays have smoother edges which otherwise would give rise to loss.

The results enable us to fine tune the LSPR trough annealing, dictating what wavelength the array will absorb. This can prove useful when MNP arrays are used in applications such as photon detectors, photovoltaics, or biosensors [2].

References:

[1] *S. A. Maier, Plasmonics: fundamentals and applications (Springer, 2007).*

[2] *M. M. Greve, T. O. Håvardstun, and B. Holst, Journal of Vacuum Science and Technology B 31, 06F410 (2013).*

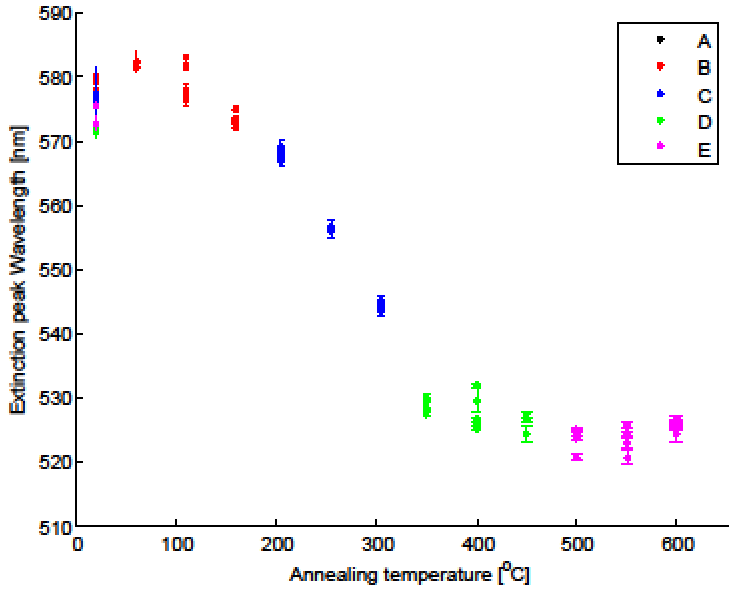

Figure 1: Peak position of LSPR vs annealing temperature. 5 measurements have been made for each temperature. Sample A is not annealed, B is annealed at 150ºC, C at 300ºC, D at 450ºC, and E at 600ºC.

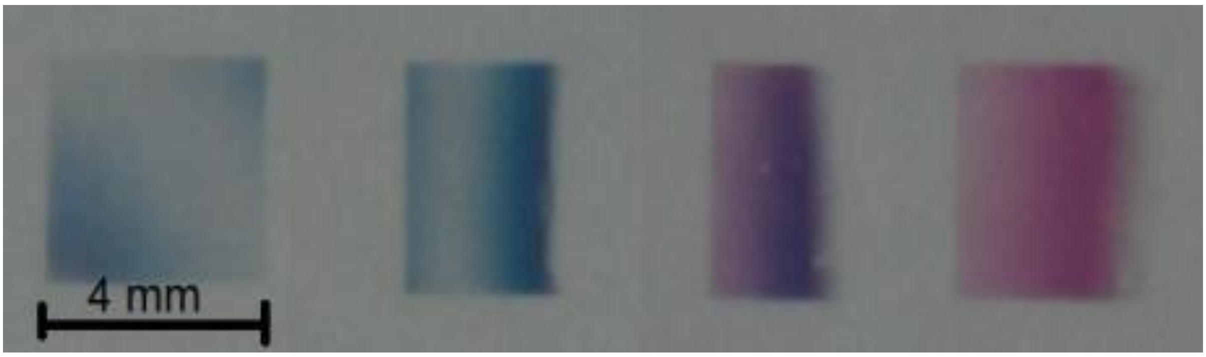

Figure 2: Optical image of MNP array showing the color change as observed by the naked eye. From left to right: Sample A; not annealed, B annealed at 150ºC, C at 300ºC, and D at 450ºC.