An experimental study of light absorbance of gold metal nanoparticles in the size range 45 to 200 nm fabricated using e-beam lithography.

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The localized surface plasmon resonance (LSPR) effect in metal nanoparticles, is important for many applications ranging from detectors and sensors to photovoltaic devices.[1,2] The LSPR frequency is very sensitive to the specific shape, size and surrounding environment of the nanoparticles. Seemingly minute differences in shape and surface structure can have a big effect. [3,4] Therefore it is important to compare the properties of nanoparticles of nominally similar sizes but fabricated with different techniques.

Here we present a systematic study of the optical properties of large, regular arrays (3 mm x 3 mm) of cylindrical, gold nanoparticles on glass in the size range: 45 to 200 nm in diameter and a height of 25 nm (see Fig. 1) The nanoparticle arrays were fabricated using e-beam lithography combined with electron beam evaporation. Gold was chosen because it is widely used in the literature as a model system. For the smallest particle sizes (less than 80 nm) a bi-layer resist scheme was used to facilitate the lift-off process. The distance between the particles was kept at two nanoparticle diameters for all samples to avoid optical coupling between the particles.[5] Gold is known to adhere poorly to glass and therefore an adhesion layer is often used. As an additional thin film would potentially distort our optical measurements, it was desirable to avoid this. After some testing, it was found that gold nanoparticles stick quite well to glass coverslips of borosilicate (Thermo Scientific).

The advantage of using e-beam to fabricate the nanoparticles is, among others, that the size and spacing can be well controlled. The disadvantage is that it takes a long time to prepare large samples. For these reason earlier studies of e-beam fabricated nanoparticles have mostly been carried out on small particle ensembles. The optical properties have mainly been investigated using optical microscopes in combination with a spectrophotometer, allowing the nanoparticle light extinction to be investigated. See for example [5]. As the extinction is a measure of the light absorption and scattering by the nanoparticles it works well for small particle sizes, mainly absorbing light. However for larger particles, scattering becomes increasingly important, and the two interactions needs to be measured independently. With our large sample arrays it was possible to test the optical properties using an integrating sphere setup, allowing simultaneous measurement of transmitted, forward scattered and reflected light over large solid angles. With this information the sample absorbance can be calculated directly (Fig. 2).The extinction spectrum is also obtained. For some particle sizes previous measurements of extinction spectra on small ensembles of e-beam fabricated nanoparticles exist in the literature. We compare our results with these and find a good agreement, which confirms the reproducibility of the e-beam production method.

As the main result we compare our absorbance measurements with previous absorbance measurements of large array of gold nanoparticles prepared on glass using hole-mask colloidal lithography technique[6]. We also make a comparison with simulations using a commercial finite difference time domain software package (Lumerical inc.) We discuss the differences and similarities we find. This work highlights the influence of the production method on the nanoparticle properties.

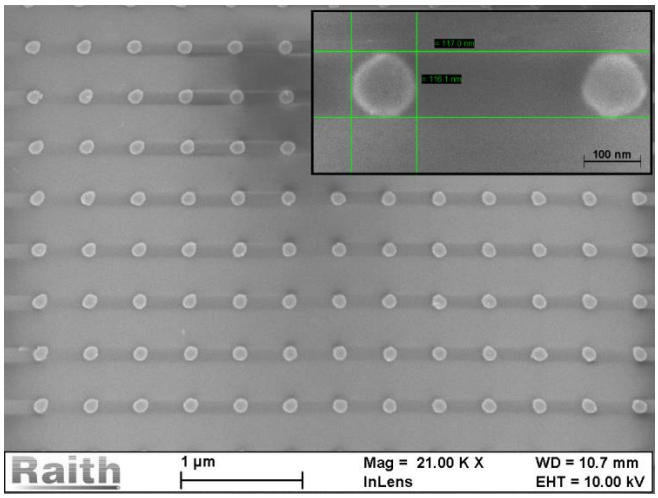

Figure 1: SEM micrograph showing a small area of one of gold nanoparticle arrays investigated. The nanoparticles have a diameter of about 60 nm.

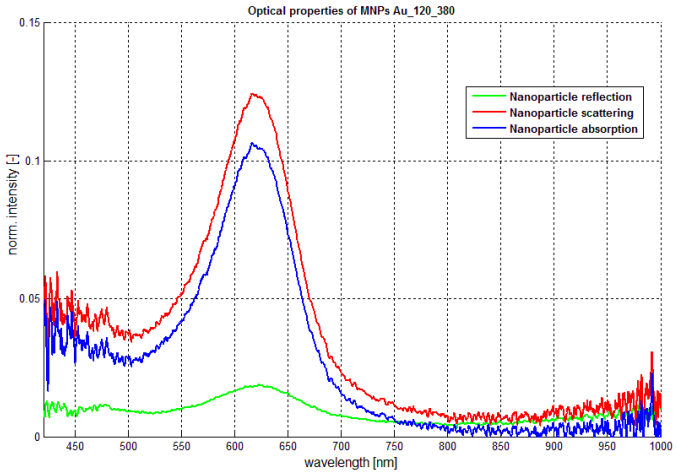

Figure 2: Integrating sphere measurement of one of the gold nanoparticle arrays, here presenting nanoparticles with diameter of 120 nm and inter-particle distance of 380 nm. The normalized scattered and reflected intensity is measured and the calculated absorbance is shown in blue curve.

References:

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