Optical anisotropy of self-aligned Ag nanoparticles and nanowires on pre-rippled Si surfaces

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Nobel metal nanoparticles exhibit special optical properties due to their localized Surface-Plasmon-Resonance (SPR). The SPR frequency and strength depend on particle size, shape, surrounding medium, and alignment of the particles. In recent years many studies have been conducted in which metal nanoparticles were grown in a controlled and ordered way on pre-structured substrates. In this way the optical properties could be tuned and a strong optical anisotropy was achieved [1-4]. One way to make the pre-patterned substrates and to align particles is to use lithography. However, in order to reach patterns with dimensions similar to the particle size e-beam lithography has to be used which is not economic for large area patterning.

In the present study ion beam sputtering has been used for pre-structuring of the substrate followed by e-beam evaporation for deposition of the metal. First a low energy ion beam (Ar^+, 500 eV) is incident on the substrate surface (Si in our case) at an angle of 67^o to the surface normal to produce well ordered (20-50 nm) ripple patterns [5]. An atomic force microscopy image of such a patterned Si surface is shown in Fig. 1a. Then physically vaporized Ag atoms are deposited at grazing angle of 70° to the surface normal and perpendicular to the ripples direction. Varying different deposition parameters, i.e. ripple periodicity, substrate temperature and atomic flux, we were able to produce well ordered Ag nanoparticles and nanowires. A very high degree of alignment not reported so far using the present technique has been achieved. Fig. 1b and 1c show the aligned Ag particles and nanowires, respectively, self-aligned on pre-patterned Si.

The effect of temperature was also investigated for three cases: 1) deposition on a heated substrate; 2) post annealing in vacuum after deposition; and 3) post annealing after deposition and exposing to atmosphere. In all three cases the temperature has different influence on the alignment of the particles.

The aligned Ag nanoparticles and nanowires were characterized using ellipsometric spectroscopy in the photon energy range of 1.2-3.3 eV. Angle dependent change in the ellipsometric parameters Ψ and Δ show a strong anisotropic behavior (Fig. 2a), which is not observed on a bare Si rippled surface or for non-aligned Ag particles on a flat Si substrate. Dielectric functions extracted from the ellipsometric measurements using Lorentz oscillator model also confirm a strong angle dependency. Fig. 2b shows the real and imaginary part of the dielectric function for three different ripples orientation of 0°, 45°, and 90° with respect to the incoming light. We will report how this optical anisotropy depends on the shape, size, and alignment of the Ag nanoparticles and nanowires, respectively.

References:

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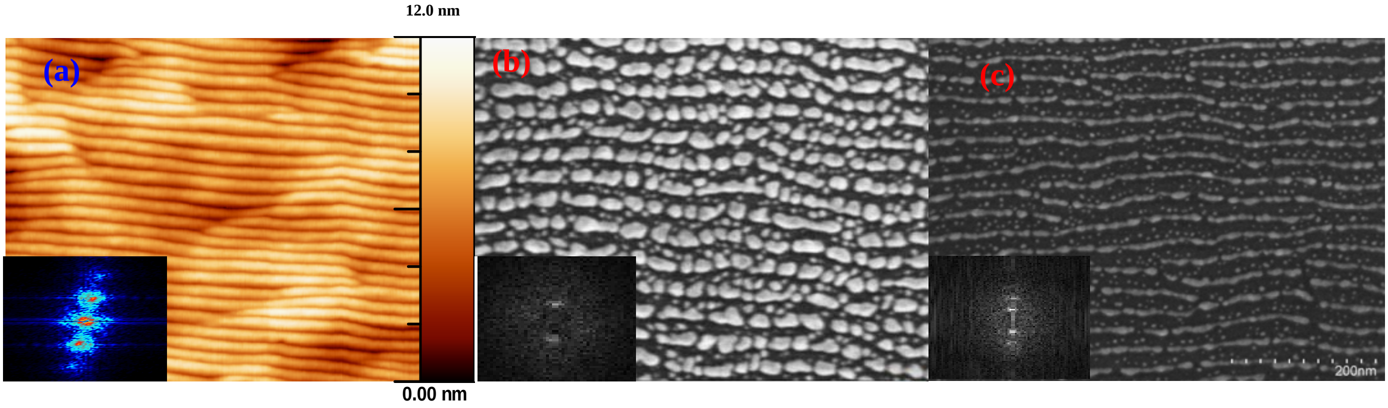

Figure 1: (a) Atomic force microscopy image of pre-rippled Si substrate, (b) Scanning electron microscopy image of aligned Ag nanoparticles and (c) of nanowires on pre-patterned Si templates with a periodicity of 32 nm. Insets show the Fourier transforms of the images.

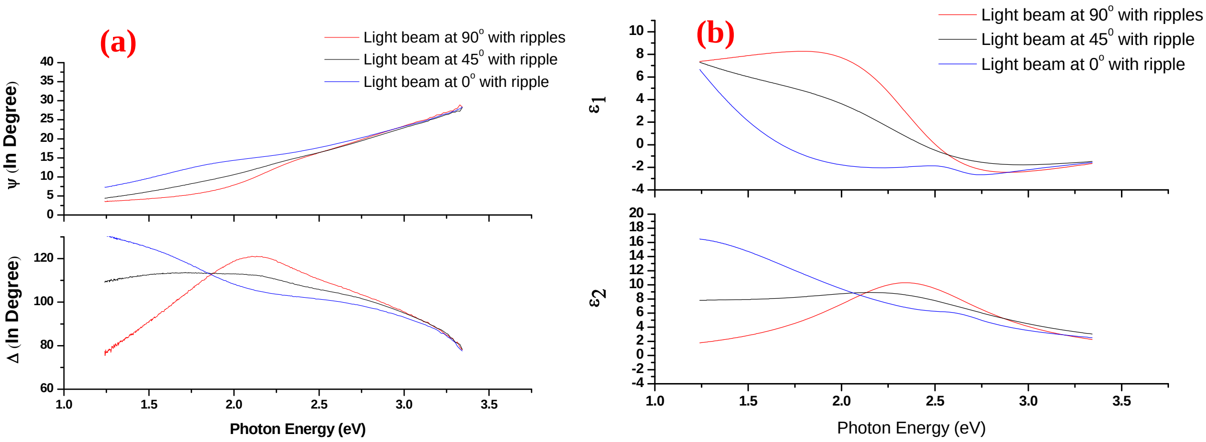

Figure 2: (a) (Ψ,Δ) capture using ellipsometry . The light beam is incident at three different angles of 0^o, 45^o and 90^o with respect to the ripples orientation. (b) Dielectric function (ε_1,ε_2) extracted using Lorentz oscillator model.