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Ag Nanostructure Evolution on H-terminated Si(111) Surfaces

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Here we report an in-situ growth and ex-situ electron microscopy characterization of nanometer-sized Ag dots grown on hydrogen-terminated Si(111) surfaces. The study was carried out with two objectives: 1) to understand self growth o clusters on crystalline surfaces and 2) to demonstrate the ability of electron characterization for nanostructure determination.

Hydrogen termination of the dangling bonds on Si (111) surfaces reduces the surface energy, leading to the modification of Ag growth mode from the Stranski-Krastanov to Volmer-Weber growth, thus, the formation of metallic nanoclusters on Si surfaces. Controlling the shape, size and spatial distributions, as well as the epitaxial relationship of these nanoclusters, are extremely important because these factors determine the properties of the nanocluster ensemble. For this reason, we use the cluster growth of Ag on H-terminated Si (111) surfaces as the model system to study.

The Ag nanostructure growth and initial characterization were carried out in a modified ultrahigh vacuum transmission electron microscope [1]. Si(111) substrates were pre-thinned to electron transparency. After H-termination [2], the samples were then immediately transferred to the UHV TEM for deposition and in-situ characterization. Ag was deposited using the electron-beam evaporation at room temperature. The growth rate was 0.008 ML/s. Ex-situ high resolution TEM observation was made immediately after the removal from the UHV TEM. These observations were carried using Phillips CM12 TEM and JEOL 2010F electron microscopes. All images were recorded digitally using slow-scan charge-coupled-device cameras, and image plates to facilitate quantitative analysis.

The results show that epitaxial Ag clusters of controlled sizes from ~1 to 10 nm can be grown on H -terminated Si(111) surfaces. The nanostructure of these clusters evolves in stages showing 1) irregular angled shapes at low coverage (≤ 1 ML), 2) mostly single crystal with faceted -hut-like shapes from 2 to 5 ML, 3) mound -like islands at higher coverage that are increasingly defective, and 4) the islands become irregular again at even higher coverage due to coalescence (see Figs. 1 and 2). We found that the rapid coalescence of small clusters drives the nanostructure transition and leads to a step -like growth of nanoclusters. Meanwhile, the azimuthal alignment of the Ag nanoclusters is significantly improved with the increasing coverage [3].

Reference

[1] M.T. Marshall, M.L. McDonald, X. Tong, M. Yeadon, J.M. Gibson, Rev. Sci. Instru. 69, 440 (1998).
[2] G.S. Higashi, R.S. Becker, Y.J. Chabal, and A.J. Becker, Appl. Phys. Lett. 58, 1656 (1991).
[3] This work is supported by DOE and the electron microscopy characterization was carried out at the center for microanalysis of materials, UIUC. We thank Dr. R. Twe sten and Mr. M. Marshall for asistance.

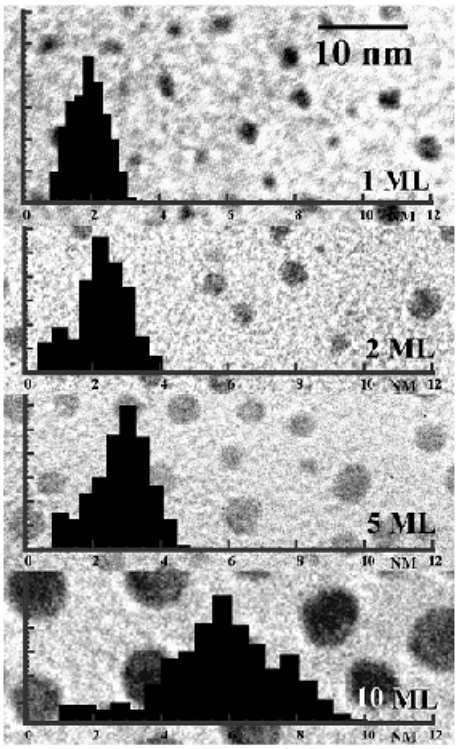

Fig. 1 Electron images and the size distributions of Ag clusters recorded and measured 1, 2, 5 and 10 equivalent monolayer (ML) coverage. Ag appears dark from the strong scattering and a slightly under focus. The size measured is the diameter of clusters (nm) in projection using image processing of digitally recorded images. At 1 ML, Ag clusters have the irregular and angled shapes. Between 2 to 10 ML, Ag clusters are round faceted with the appearance of a droplet. The spatial distribution of clusters are random, each cluster is separated by an exclusion zone.

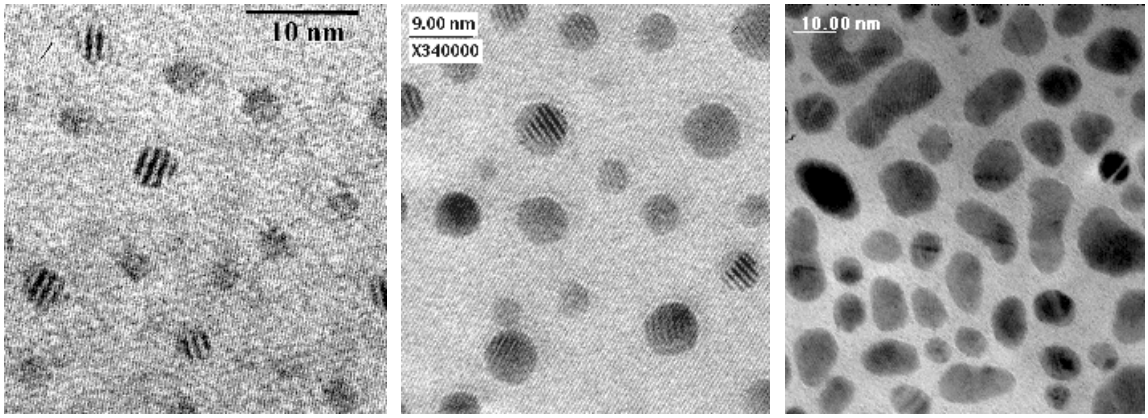

Fig. 2 Electron Moire fringes of Ag on Si showing the misorientation and the internal structure of the nanoclusters. The spacing and orientation of Moire fringes give the strain an d orientation of each cluster. Using this technique we found that small Ag clusters of 2-3 nm in diameter are mostly single crystal and large clusters are twinned with defects. Clusters in the orientation (110)Ag|| (110) Si has a strain of 0.3%.

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