DOI: 10.1017/S1431927603441408
Microsc Microanal 9(Suppl 2), 2003

Combined HREM and Quantitative Electron Diffraction Characterization of Individual Pd_2Si Nanostructures on Si(111) Surfaces

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An important challenge in nanostructure characterization is how to characterize the structure of individual nanostructures. For this, electron beam had the potential advantages from the strong interaction with matter, ability to form images and small probe. To realize this potential, we combine HREM with quantitative electron diffraction to characterize the morphology and individual nanostructures. Here we report an application to study silicide formation.

Reactive growth is a major area of research in epitaxial growth. An important question is how surface chemistry affects the growth. 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, due in large part to the weak interaction between Ag and H [1,2]. In contrast to Ag, Pd interacts strongly with H and reacts readily with Si upon contact. Therefore, it would be very interesting to compare the initial growth behavior Pd on H-terminated and on clean Si(111) surfaces and investigate the nanoscale structural evolution. Related issues include whether the passivated H on the Si surfaces block Pd-Si reactions, how does the H affect the reaction path and the orientation relationship between the nanostructures and the Si substrate, and among others. We have addressed these issues by combining high resolution transmission electron microscopy imaging and quantitative electron diffraction techniques.

The Pd growth was carried out in a modified ultrahigh vacuum transmission electron microscope [3]. Si(111) substrates were pre-thinned to electron transparency. After H-termination [4], the samples were then immediately transferred to the UHV TEM for deposition and *in situ* characterization. Ag was deposited using the electron-beam evaporation. The growth rate was 0.003 ML/s. Ex-situ high resolution TEM observation was made immediately after the removal from the UHV TEM. These observations were carried using a JEOL 2010F electron microscope. All images were recorded digitally using slow-scan charge-coupled-device cameras and image plates to facilitate quantitative analysis.

The results show that Pd_2Si is formed even at room temperature on the H-terminated Si(111) surfaces, which means that H does not block the reaction between Pd and Si. However, there are marked differences in growth behavior. At RT, Pd_2Si on H-Si(111) has no preferred orientation, but tends to be 2-D growth; while Pd_2Si forms epitaxial islands on the clean Si(111) surfaces with Pd_2Si (0001)//Si(111) and Pd_2Si [10-10]//Si[0-11]. When depositing at 400˚C, instead of continuous layers, better aligned Pd_2Si islands with irregular shapes are formed on the H-Si(111) surfaces; while rectangular islands are grown on the clean Si(111) surfaces with the long edge and the c-axis of Pd_2Si aligned along one of the three {110} orientations. Detailed results will be presented.

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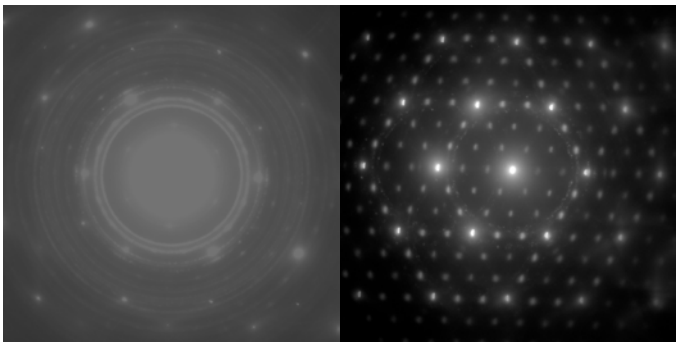

Figure 1. Transmission electron diffraction patterns for 4.8 ML Pd deposited on H-Si(111) (left) and clean Si(111) (right) at RT. Pd_2Si on H-Si(111) has no preferred orientation; while Pd_2Si forms epitaxial islands on the clean Si(111) surfaces with Pd_2Si (0001)//Si(111) and Pd_2Si [10-10]//Si[0-11].

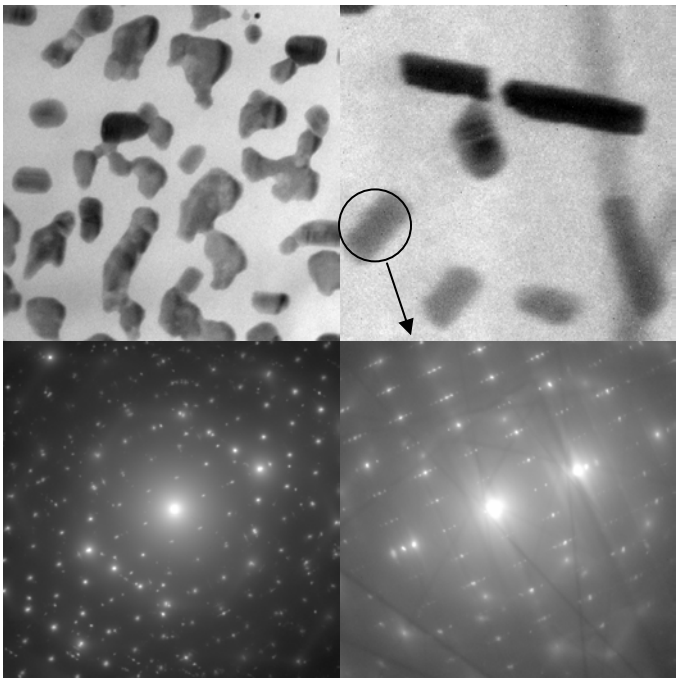

Figure 2. BF images and transmission electron diffraction patterns for 4.8 ML Pd deposited on H-Si(111) (left column) and clean Si(111) (right column) at 400˚C. The epitaxy is improved on H-Si(111). But the c-axis of Pd_2Si changed from perpendicular to the Si(111) to parallel to it.

https://doi.org/10.1017/S1431927603441408 Published online by Cambridge University Press