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Growth and morphology of ultra-thin Ni films on Pd(1 0 0)

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Abstract

A series of Ni films with thickness from 0.2 monolayers (ML) to 12.5 ML were epitaxially grown on a Pd(1 0 0) substrate at room temperature. Growth and morphology were investigated by scanning tunneling microscopy (STM), reflection-high-energy-electron diffraction (RHEED) and Auger electron spectroscopy (AES). We found that the strain relief mechanism for the tetragonal distorted films is related with the appearance of 1 Å high-filaments.

Keywords: Metal homoepitaxy; Ni ultrathin films; Strain; STM; RHEED

Through the deposition of ultra-thin films it is possible to stabilize the structure of certain materials, which then display interesting and striking properties which deviate substantially from those shown by the bulk. Roughness, strain and intermixing between the film and the substrate can modify the structural properties of the thin layer. The appropriate combination of materials can then be used to tune the electronic and magnetic properties of the film [1]. In this report we have examined the influence of the lattice strain induced by the substrate on the structure of an Ni film grown on Pd(1 0 0) (lattice parameter $a = 3.89$ Å). The Pd fcc substrate has been chosen in order to favor a contraction of the Ni layer in the vertical direction (fct: a tetragonal distortion of an fcc cell) due to an increased intralayer strain, induced by the early pseudomorphic growth of the thin film. The difference in the bulk lattice parameters of Ni and Pd is 9.5%. Previous reports have described the structure of the strained Ni films [1–3], our investigation have focused instead on the growth, morphology close to the phase transition. An improved understanding of the structural properties will clearly facilitate the description the singular magnetic behavior of these films.

Ni films (0.2–13 ML) were deposited on a (1 0 0)-oriented Pd single crystal at room temperature (RT), using e-beam evaporation, from Ni wires in ultra-high vacuum (UHV) conditions. Substrate was prepared by a series of RT Ar^+ sputtering cycles at 1 keV, followed by 910 K annealing of the sample. This procedure was repeated until a clean and well-ordered surface with large atomically flat terraces was obtained, as confirmed by Auger electron spectroscopy (AES) and scanning tunneling microscopy (STM). The Ni deposition rate was 0.6 Å/min as measured by a quartz crystal microbalance.

For 0.2 ML Ni (Fig. 1a) the Pd surface is covered by monolayer high-islands with irregular shapes and no preferential nucleation sites. These undefined shapes islands are seen up to 2.0 ML (Fig. 1b). For this coverage, the second layer Ni islands display a rectangular shape (see inset), with edges oriented preferentially along [0 1 1] and $[0\,\bar{1}\,1]$ crystallographic directions. The presence of third layer islands indicates the beginning of a trend into multilayer growth. The same shape and orientation of the islands are also seen up to 5.5 ML.

For 5.5 ML the islands are more elongated than rectangular. The average heights for these islands are in agreement with the fact that at these coverages the Ni films grow with fct parameters [4]. At higher coverages (around 6.5 ML) the surface landscape changes with the appearance of islands with heights of 1.00 ± 0.11 Å.

For 7.5 ML coverage, the internal structure of the islands is formed by a set of filaments, as shown in Fig. 1c (inset). These filaments on the seventh and eighth layers are

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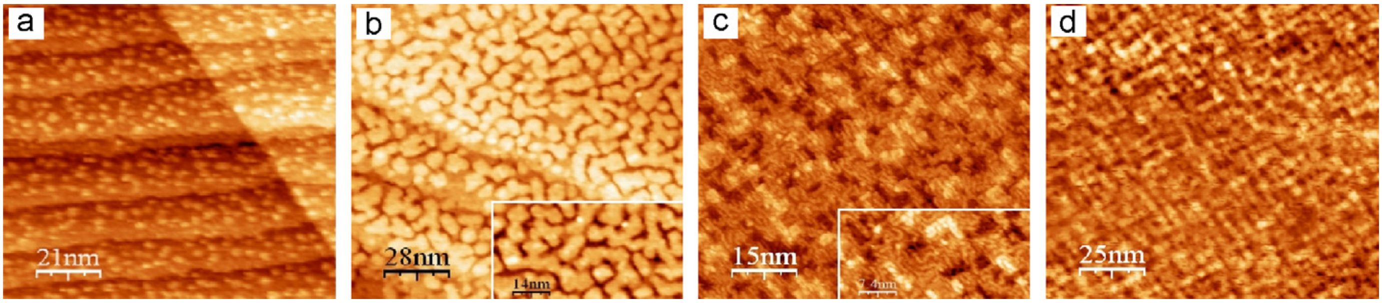

Fig. 1. STM images for Ni films grown on Pd(1 0 0); the coverage was (a) $\Theta = 0.2$ ML, (b) $\Theta = 2.0$ ML, (c) $\Theta = 7.5$ ML, and $\Theta = 12.5$ ML.

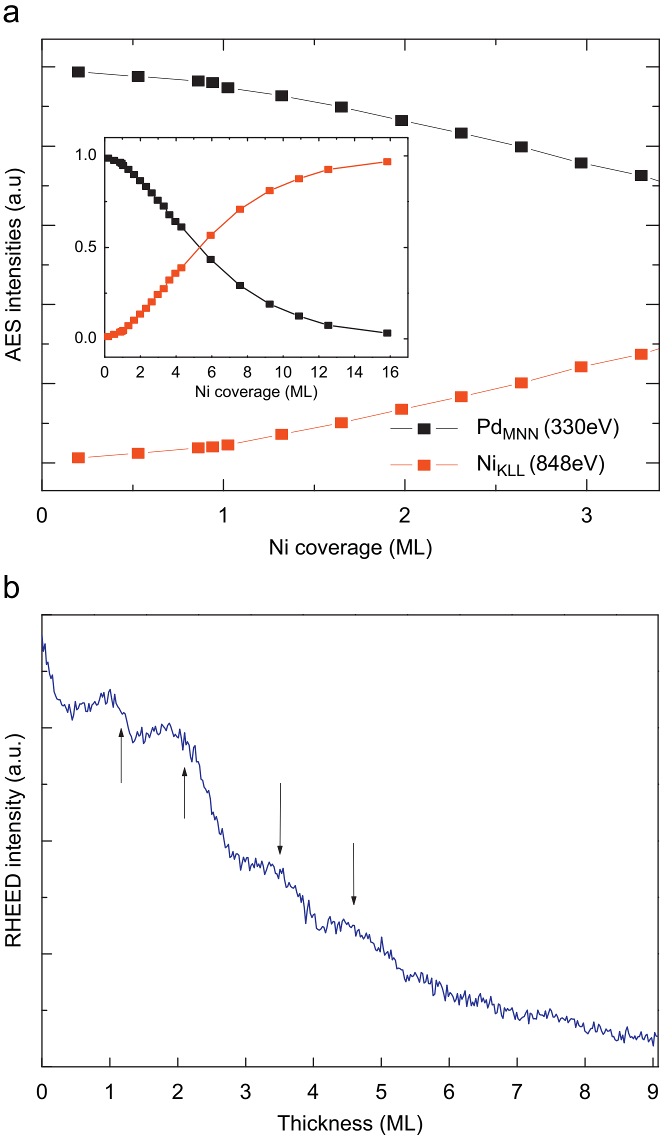

Fig. 2. (a) Ni and Pd AES intensities as functions of coverage, (b) RHEED intensity measured during the growth.

0.98 ± 0.17 Å high. This value is not related to any known Ni lattice interlayer distance. Numerical calculations of the film structure could provide a suitable model to explain these results. At 10.5 ML the onset of a new interlayer height 1.76 ± 0.1 Å is seen. This value is consistent with the recovery of fcc–Ni structure. At a higher coverage, 12.5 ML, the surface pattern evolves to a net-like structure (Fig. 1d) which interconnects the whole surface as a weft. The height of the threads is 1.74 ± 0.2 Å and the spacing between them is 50.15 ± 3.6 Å.

Fig. 2 summarizes the growth information obtained from RHEED and AES. The evolution of the 330 eV Pd and 848 eV Ni Auger lines intensities as a function of Ni coverage are shown in the Fig 2a. A change in the slope is seen at 1 ML and up to 3 ML the actual intensities have a linear dependence with coverage. Fig. 2b shows the RHEED intensities as a function of coverage. Four RHEED oscillations are seen at the initial stage of Ni deposition. The AES and RHEED data are consistent with an initial layer-by-layer growth mode. However, the fast decay of the oscillation amplitudes indicates the surface becomes rough above 5 ML. The oscillations are stronger below 3 ML, indicating that multilayer growth already starts around 2 ML.

Our study demonstrate that the early growth of Ni films on Pd(1 0 0) is nearly layer-by-layer. Up to 6 ML the vertical lattice parameter is in agreement with fct growth. The subsequent appearance of filaments on the surface is presumably connected with the strain relief mechanism of the fct structure. For coverages higher than 10 ML the standard fcc growth is recovered.

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