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Journal of Magnetism and Magnetic Materials 177–181 (1998) 1299–1300

journal of magnetism and magnetic materials

Stranski–Krastanov layers of Fe on W(1 1 0): A combined MOKE, LEED, SAM and stress measurement investigation

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Abstract

The Stranski–Krastanov growth of Fe on W(1 1 0) at 700 K leads to the formation of three-dimensional (3D) Fe islands on a first Fe layer that covers the W substrate pseudomorphically, as confirmed by scanning Auger microscopy (SAM) and low-energy electron diffraction (LEED). In situ stress measurements reveal the reduction of film stress as a dominant driving force for the coalescence of Fe into islands. An in-plane reorientation of the easy axis of magnetization from ⟨− 1 1 0⟩ for layer-by-layer grown films at 300 K to ⟨0 0 1⟩ in the 3D islands is found by magneto-optical Kerr effect (MOKE) experiments. This in-plane spin reorientation transition is attributed to the crossing of a critical Fe thickness of order 100 Å in the Fe islands. © 1998 Elsevier Science B.V. All rights reserved.

Keywords: Electron diffraction; Kerr measurements; Scanning electron microscopy; Spin reorientation transition; Stress – in situ measurement

It is well known from the experiments of Prinz et al. [1] that the direction of the easy axis of magnetization of Fe(1 1 0) films depends on the film thickness. Whereas films thicker than 50 Å grown on GaAs(1 1 0) have the same in-plane easy axis of magnetization along ⟨0 0 1⟩ as known from bulk Fe, below a critical Fe thickness of 50 Å the easy axis of magnetization switches to ⟨− 1 1 0⟩. The same switching of the easy axis of magnetization from ⟨0 0 1⟩ to ⟨ − 1 1 0⟩ has been observed for Fe on W(1 1 0) to occur for a Fe thickness below 100 Å. This switching behaviour has been ascribed to the dominant contribution of surface anisotropies to the overall energy density for decreasing film thicknesses [2]. The aim of this paper is to demonstrate that the Stranski–Krastanov growth mode of Fe at elevated temperatures induces a switching of the direction of the easy axis of magnetization already for Fe depositions of order 20 Å. Our results indicate that the same structural and magnetic properties characteristic of Stranski–Krastanov Fe films are obtained for annealing a room temperature grown film to 700 K.

The magnetism of Fe films deposited at 300 and 700 K was investigated by MOKE [3]. A rotatable electromagnet produced fields of up to 0.4 T in-plane along ⟨0 0 1⟩ and out-of-plane along ⟨1 1 0⟩. An additional electromagnet produced in-plane fields of up to 0.1 T along ⟨− 1 1 0⟩. Kerr-effect measurements in the transversal

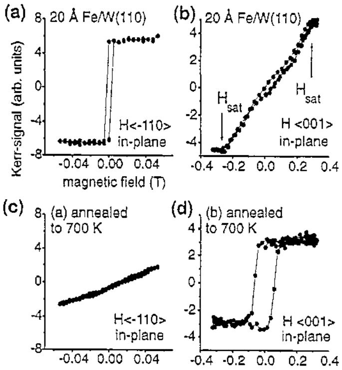

Fig. 1. MOKE experiments of 20 Å Fe on W(1 1 0) in transversal (a) and (c) and longitudinal (b) and (d) Kerr geometries. (a)–(b): Film as grown at 300 K (c)–(d): Same film after annealing to 700 K for 10 min.

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PII S0304-8853(97)00753-1

(Fig. 1a and Fig. 1c), longitudinal (Fig. 1b and Fig. 1d), and polar (not shown) geometry were employed to study the magnetic properties. Whereas films thinner than 100 Å deposited at 300 K show an easy axis of magnetization when magnetized in-plane along ⟨− 1 1 0⟩ [2, 4], hard-axis curves are observed for magnetization in-plane along ⟨0 0 1⟩, as shown in Fig. 1a and Fig. 1b, respectively. A saturation field of order 0.25 T is measured for the 20 Å Fe film of Fig. 1b. Annealing the room temperature grown films at 700 K for several minutes or depositing the same amount of Fe at 700 K leads to a switching of the easy axis of magnetization. As shown in Fig. 1c and Fig. 1d, after annealing a magnetization along ⟨− 1 1 0⟩ produces hard-axis loops, whereas magnetizing along ⟨0 0 1⟩ gives rectangular hysteresis curves, indicating an easy axis of magnetization in-plane along ⟨0 0 1⟩. Our polar Kerr measurements showed hard-axis curves for magnetization normal to the film plane, for both, room temperature grown films and annealed films, indicating an effective anisotropy opposing polar magnetization.

The change of the growth mode from layer by layer to Stranski–Krastanov produces Fe islands (Fig. 2a) of considerably increased height, compared to the nominally deposited amount. This coalescence of deposited Fe into high islands leads to the transition of the critical thickness for the reorientation of the easy axis. The Fe islands show an easy axis of magnetization in-plane along ⟨0 0 1⟩, the pseudomorphic monolayer Fe in between the islands does not contribute to the ferromagnetic response, as our experiments are performed above the Curie temperature of the monolayer [5]. From scanning Auger microscopy shown in Fig. 2a the island size can be determined to be of the order 10 μm × 1 μm. The islands are elongated along W⟨1 0 0⟩ and reside on a monolayer thick Fe layer, as checked by Auger analysis of the grey areas between the black Fe islands. The corresponding LEED pattern in Fig. 2b shows a twofold BCC(1 1 0) diffraction pattern, characteristic of the pseudomorphically strained first Fe layer and the pattern due to relaxed Fe from the top of the islands.

The driving force for the change of the growth mode is attributed to the reduction of the strain energy of the Fe film. The large lattice mismatch between Fe and W of more than 9% leads to a heavily strained first pseudomorphic Fe layer. A considerable strain energy per Fe atom of the strained layer of order 0.3 eV results [4]. For increasing coverage, the misfit is relaxed by misfit dislocations at the interface between the 1st and the 2nd Fe layer [6], leaving the Fe atoms in layers 3 and above practically stress free. Direct experimental evidence comes from our in situ stress measurements, presented in Fig. 2c. In short, we use a 0.2 mm thin W(1 1 0) crystal that is only clamped at its upper end to a sample manipulator. Stress in the growing Fe film on the crystal front side leads to a minute bending of the substrate that is detected by an optical deflection technique [4]. Thus, a position signal proportional to the film stress is measured. The compressive stress for ultralow coverages is attributed to a surface stress effect [4]. Note that already after the deposition of 2.5 Å (1.5 ML) Fe at 1000 K, a plateau in the stress curve is reached. We ascribe the onset of the plateau to the formation of a misfit dislocation network at the interface between the first and second layer [6]. Thus, the further deposition of 10 Å Fe does not increase the film stress. After terminating the deposition, a stress relaxation sets in, leading to a stress of 4 N/m, characteristic of a strained first monolayer [4]. Films grown at 1000 K film show the structural and magnetic properties of Stranski–Krastanov Fe films, as discussed above. The formation of islands reduces the energy cost for the formation of misfit distortions, as the distortions are limited to a much smaller area within the bottom layer of the islands compared to a homogenously covered first Fe layer. The Fe islands are practically stress free and show the magnetic anisotropy of bulk Fe.

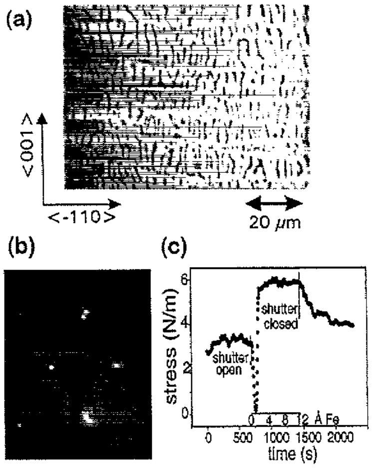

Fig. 2. Stranski–Krastanov growth of Fe on W(1 1 0) at elevated temperatures. (a) SAM image of 30 Å Fe after annealing. Fe islands (black) on the first Fe monolayer (grey) are shown. (b) LEED of 12 Å Fe after annealing. (c) Stress measurement during growth of 12 Å Fe at 1000 K.

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