

In situ Kerr microscopy for ultrahigh vacuum applications

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A simple Kerr microscope designed for *in situ* investigation of magnetic ultrathin films in ultrahigh vacuum environment is described. The system permits quick visualization of domain patterns with 10 μm lateral resolution. Simultaneous optical magnetometry is also possible. The performance of the system is illustrated with domain images in a few layers thick Fe films on Cu(001) and W(110).

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Magnetization reversal processes in ultrathin magnetic films are expected to be strongly correlated with their structural and morphological properties. *In situ* domain imaging performed on films prepared in clean ultrahigh vacuum (UHV) environment on well characterized single crystal surfaces offer the best chance to establish and understand this correlation. There exist a number of techniques for direct domain observation in UHV. Scanning electron microscopy with polarization analysis (SEMPA) has excellent resolution (20 nm) together with the ability to resolve two components of magnetization but can only be performed in very low fields. Magnetic force microscopy offers potentially higher resolution, while x-ray magnetic circular dichroism is element specific. Despite its capability to image domains in an applied field, magneto-optical (Kerr, Faraday, Voigt) microscopy¹ is usually² performed *ex situ* using modified polarization microscopes with samples that have to be passivated and are often reflection coated to improve the inherently weak magneto-optical contrast. Below we describe a Kerr microscope designed as a simple add-on device to an existing UHV chamber with sufficient performance to allow for *in situ* domain observations in films that are only several atomic layers thick.

The microscope, Fig. 1, has two separate sections: an illumination subsystem and the microscope proper, each occupying a separate port (window) on the UHV chamber. The illumination part is assembled on an optical bench that is attached to a 2 3/4 in. vacuum window. It consists of a high pressure mercury lamp (100 W), collimating optics, an infrared blocking filter, a 50 nm interference filter, a focusing lens, and a polarizing element (sheet polaroid). The optical bench arrangement facilitates alignment and permits easy incorporation of additional optical elements if needed.

The sample is mounted on a UHV manipulator with provisions for sample heating and cooling. Its nominal location is in the center of the chamber to allow access to a standard set of surface science characterization/preparation tools. An electron-beam heated iron source is located above the optical plane. With this arrangement it is even possible to observe domain patterns while the film is being deposited.

The light reflected by the sample exits through a 6 in. vacuum window to which a highly rigid assembly consisting of a sheet polarization analyzer mounted on a high precision

rotation stage; a long-distance microscope and a CCD camera is attached. The microscope is QM-100, a Masutov Cassegrain catadioptric design by Questar³ with an optimal lateral resolution of 1.1 μm . The advantage of catadioptric design (reflective optics) is its ability to produce high spatial resolution at working distances much longer than dioptric optics (refractive) can deliver for the same resolution. The actual working distance in this design is 25 cm. The imaging element (1 in. CCD device) of the Hamamatsu⁴ C4880 dual-mode, cooled camera is positioned in the microscope's focal plane. The camera is controlled by the computer program described in Ref. 5. With software based two-fold binning, the camera operates effectively in a 16-bit mode and generates images with 500 \times 500 pixel resolution. The field of view of the system can be varied between 3 \times 3 to 1 \times 1 mm². Of particular utility was the program's capability to record the integrated intensity of a number of small areas on the image as a function of time. This was used to record magnetization loops while at the same time observing domain patterns. The time to obtain domain images depends on the magnetic system. For the perpendicular anisotropy Fe on Cu(001) a satisfactory signal to noise level is seen with exposures as short as 0.5 s even with films as thin as 3 monolayers (ML). The effective spatial resolution of the system is estimated at 10 μm . This is lower than the best resolution of the microscope because of nonoptimal working distance and because of vibrations induced by liquid nitrogen cooling system.

As an illustration of the capabilities of the system Fig. 2

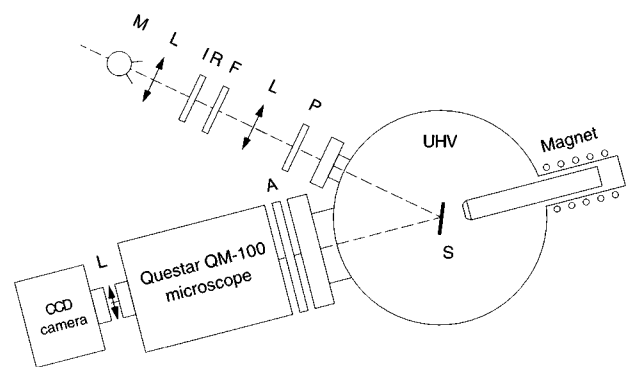


FIG. 1. (a) Schematic diagram of the Kerr microscope. M—mercury lamp, L—lenses, IR—infrared blocking filter, F—interference filter, P and A—polarization elements, S—sample.

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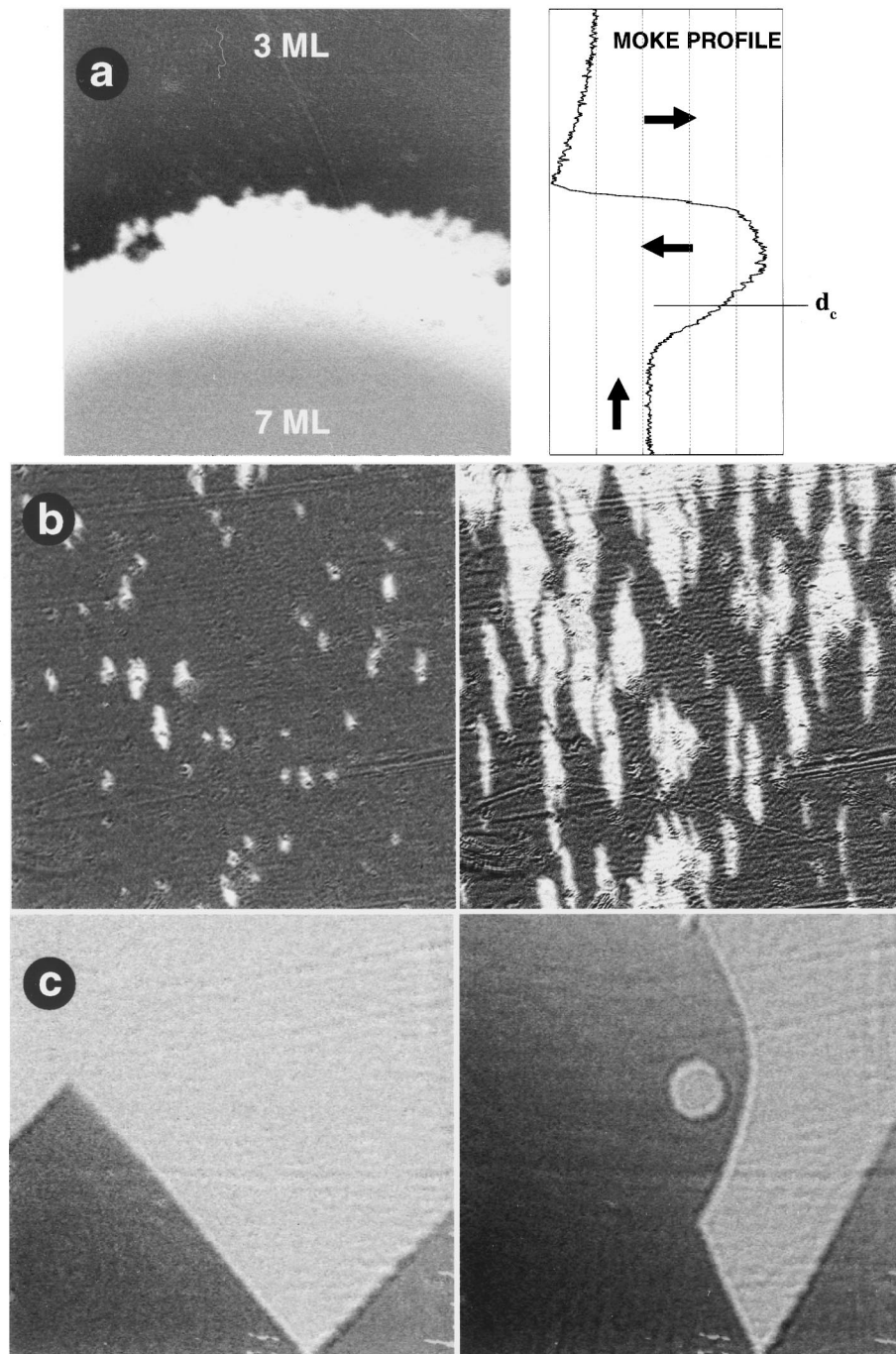


FIG. 2. *In situ* magnetic contrast images of oligatonic Fe films. (a) 7–3 ML/Cu(001) wedge evaporated at -120°C and imaged ($2.6 \times 2.6 \text{ mm}^2$) at -150°C under a remagnetizing field. Intensity profile taken along the wedge shows a domain wall separating two polar states (sharp black-white boundary) and a gradual magnetization rotation in the region of spin reorientation transition d_c . (b) Time evolution of a domain pattern in a 3 ML Fe/Cu(001) film under constant remagnetizing field at -50°C . The images ($1.2 \times 1.2 \text{ mm}^2$) were taken 20 s apart. Cooling-process induced vibrations are responsible for the residual morphological contrast seen in these images. (c) Field dependent domain patterns in a system with in-plane magnetization, 4 ML Fe/W(110), obtained *in situ* at room temperature. The image ($1.1 \times 1.1 \text{ mm}^2$) is an average of 26 exposures.

shows several domain images obtained *in situ* on Fe films deposited on Cu(001) and W(110). In all cases the images are difference images referenced to an image that does not contain magnetic contrast, $I = (I_M - I_{NM})/I_{NM}$. This normalization helps to remove most of the morphological contrast.⁶ Otherwise the images are raw, no usual image enhancing

techniques (smoothing, filtering, etc.) were used to produce the figures.

Figure 2(a) shows magnetic contrast seen on a 7 to 3 ML Fe/Cu(001) wedge in an applied field. Three regions with distinct magnetization states are clearly visible as described in the caption. An example of domain nucleation and propa-

gation in a nominally uniformly thick film with magnetization pointing out of plane is shown in Fig. 2(b). The signal to noise ratio in these single 0.7 s exposure images is better than 3, an already satisfactory figure that can be easily improved with standard image averaging techniques. Finally, Fig. 2(c) shows domain images in a 4 ML thick Fe film on W(110). The magnetization here is in-plane with a much lower MOKE contrast. To improve the image quality, Fig. 2(c) is the average of 26 independent remagnetization cycles with the exposure time of 2 s.

In summary, we demonstrated here the first Kerr microscope design capable of *in situ* imaging of magnetic states during deposition of magnetic films that are only a few monolayers thick. Such capability is expected to be ex-

tremely useful as a means of determining the type of coupling taking place in the multilayer magnetic material during its production.

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