Static and Dynamic Electric and Magnetic Imaging

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Electron holography on ripple-shaped magnetic permalloy thin films

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By means of off-axis electron holography (see e.g. refs. [1-3]), we study the distribution of the magnetic induction within and around a poly-crystalline permalloy ($Ni_{81}Fe_{19}$) thin film. Its deposition on a silicon substrate with a given periodic surface morphology emerging through concerted Xe^+ ion beam erosion introduces a ripple shape to the permalloy thin film [4]. The created ripple morphology is expected to pronounce magnetization within the permalloy and to induce dipolar stray fields [5]. Micro-magnetic simulations estimate those stray fields in the order of only 10 mT. Consequently, their experimental determination by electron holography at nanometer spatial resolution is highly demanding and requires advanced acquisition and reconstruction techniques [6].

To ensure the desired spatial resolution under a magnetic field-free object plane, the holographic imaging is conducted using a FEI TECNAI F20 transmission electron microscope with an aberration corrected pseudo-Lorentz lens provided by CEOS company [7]. To separate electric and magnetic contributions of the phase shift we reversed the magnetic field in-situ by using the objective lens [8].For the resulting two opposite magnetization directions, we acquire series of 20 object and corresponding empty holograms, respectively. The subsequent reconstruction of the hologram stacks is performed with the Triebenberg holography software package [9]. The spatial resolution in the reconstructed phase images reaches 5 nm and the mean phase noise level reduces to $2\pi/250$ rad by wave averaging. Instabilities during hologram series acquisition and hysteresis effects after saturation and magnetization reversal mainly induce drift of the object position, defocus, and image distortions. Consequently, the improvement of signal resolution by averaging and the separation of electric and magnetic phase shifts require the reliable removal of such systematic deviations, e.g. by incorporating non-linear fitting routines.

The resulting electric phase images indicate the material contrast due to different mean inner potentials and the object thickness distribution (Figure 1). The magnetic phase image shows a magnetized thin film (Figure 2), in which the magnetization direction follows the given morphology. Furthermore, a closer look to the permalloy/carbon interface reveals systematic magnetic phase signatures at the ripple flanks (Figure 3). The estimated strength of the magnetic stray fields at the detection limit of the method is in the order of 10 mT and agrees well with micro-magnetic simulations [10].

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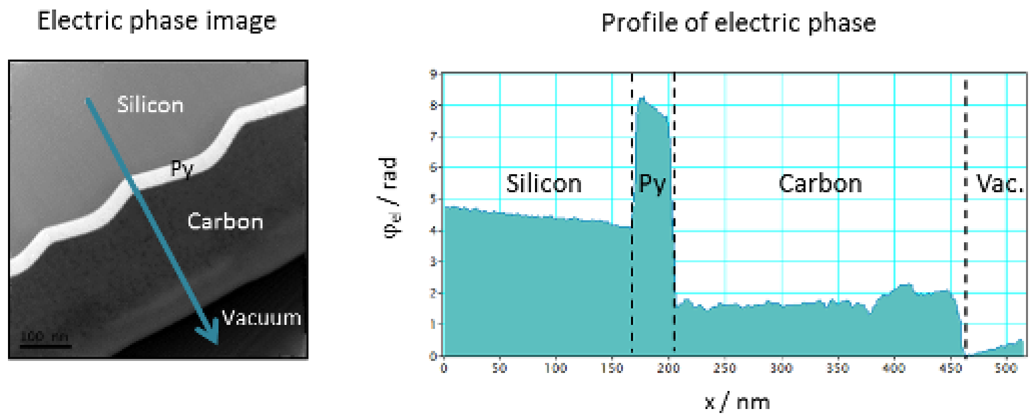

Figure 1 Electric phase image showing the morphology of the ripple-shaped permalloy (Py) thin film. Different mean inner potentials and the sample thickness distribution determine the contrast. From the known mean inner potential of silicon (12 V) the object thickness within the permalloy region (40-45 nm) and its mean inner potential (24.8 V) can be derived.

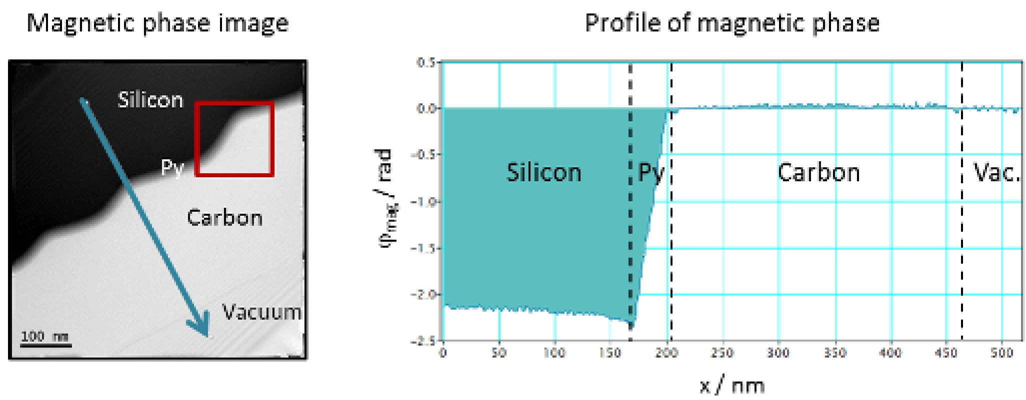

Figure 2 Magnetic phase image exhibiting a strong phase gradient across the permalloy thin film of about 0.07 rad/nm. With the results of Figure 1 a, the magnetic induction of B = 1.1 T can be determined.

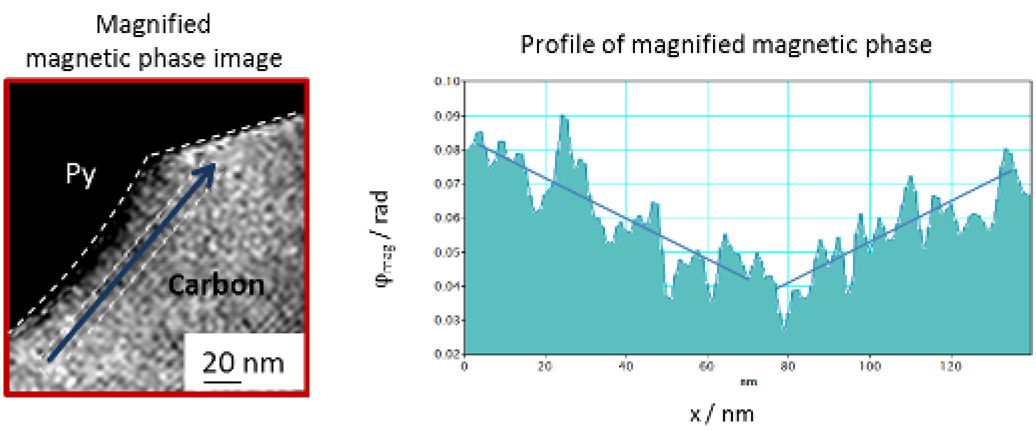

Figure 3 Magnified inset of the magnetic phase shift in Figure 2. The interface is depicted as a dashed white line. The image indicates phase signatures in the carbon film due to magnetic stray fields appearing as a dark convexity at the short ripple flank. The profile shows weak phase gradients of about 0.6 mrad/nm corresponding to field strengths of approximately 10 mT.