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In-situ Lorentz TEM Study of magnetic Domain Wall Mobility in Amartensitic Ni-Mn-Ga Alloy

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The phenomenon of magnetic field induced strain (MFIS) in magnetic shape memory alloys (MSMAs) has received considerable attention in the recent past. Recoverable MFISs of up to 10% have been reported in certain Ni-Mn-Ga based alloys. Faster response times (as small as 1 ms) and a larger induced strain compared to giant magnetostrictive materials such as Terfenol-D, render MSMAs excellent candidates for actuator devices [1]. MSMAs are essentially multi-ferroic materials exhibiting successive ferroic (ferromagnetic and ferroelastic) phase transformations. During each transformation, a domain structure is formed due to a lowering of the crystal symmetry. In Ni-Mn-Ga alloys, we find elastic domains (twin variants) due to the ferroelastic (martensitic) transformation and magnetic domains for the ferromagnetic transformation. The MFIS originates from the interaction of elastic and magnetic domains under the influence of applied magnetic field which subsequently gives rise to preferred growth of certain twin variants [2]. The primary objective of this work is to study the interaction of magnetic domains with twin variants using *in-situ* Lorentz TEM. Using a special magnetizing holder, the motion of magnetic domain walls under the influence of an applied magnetic field can be recorded in real time. When combined with a phase reconstruction algorithm, Fresnel images obtained in Lorentz TEM can be used to interpret the magnetization configuration inside the sample [3].

Movement of magnetic domain walls (MDWs) in a $Ni_{49.9}Mn_{28.3}Ga_{21.8}$ alloy was studied in a dedicated JEOL 2100F Lorentz TEM. A special Hummingbird Scientific magnetizing stage was used to apply a magnetic field in the plane of the sample. Fresnel images were recorded as a function of the field to understand the interaction of MDWs with microstructural features such as twin boundaries (TBs) and anti-phase boundaries (APBs). Fig. 1(a-d) show the movement of MDWs (bright lines) in the vicinity of an APB located along the curve marked with points o, p, & q. A magnetic field of about 300 Oe was needed to drive the MDW past the APB. The domain wall motion was reversible but with significant hysteresis. The color maps of integrated induction in Fig. 1(e-g) reveal how the magnetization changes locally during the motion of the MDW. Fig. 2(a-f) show the de-pinning of MDWs from TBs; the applied field had to be increased beyond 400 Oe to displace the MDWs associated with the TBs. These observations are consistent with theoretical models describing the role of MDWs in generating the MFIS, which suggest that the motion of MDWs away from TBs occurs prior to the actual movement of those boundaries [4]. *In-situ* Lorentz TEM observations on other interesting domain structures in this alloy, such as maze-like domain configurations, will also be presented.

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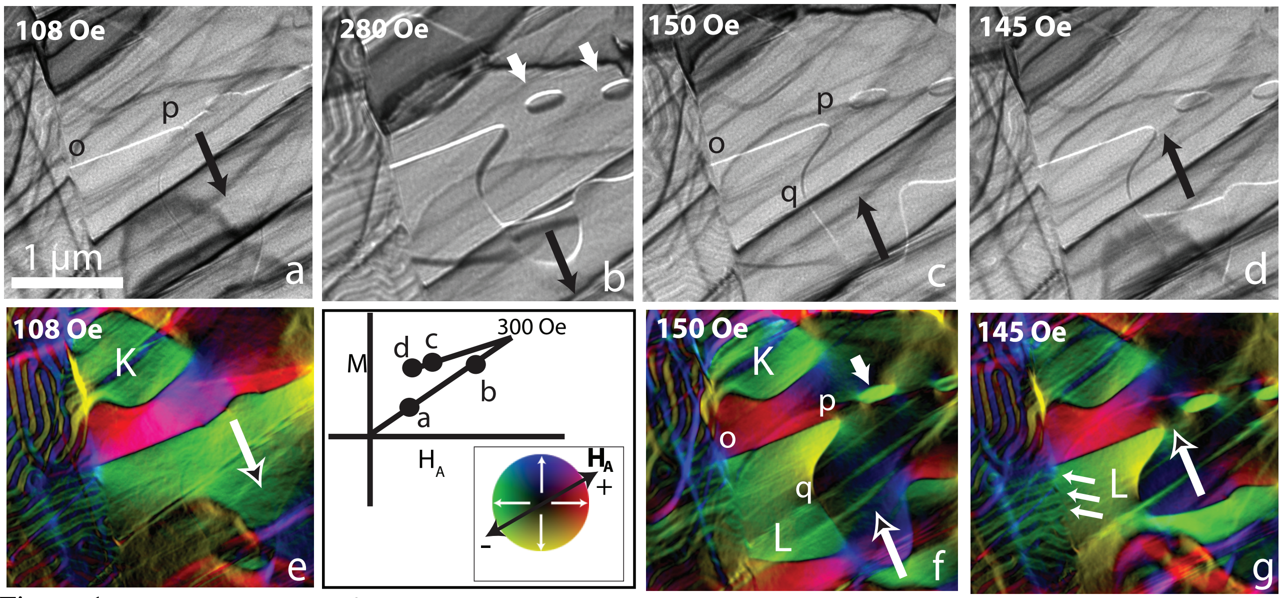

Figure 1: Interaction of a 180° magnetic domain wall with an anti-phase boundary (APB) under increasing and decreasing magnetic field values. (a)-(d) are Fresnel images showing the location of pinned domain walls at different field values; (e), (f) and (g) are color maps of integrated magnetic induction at different field values.

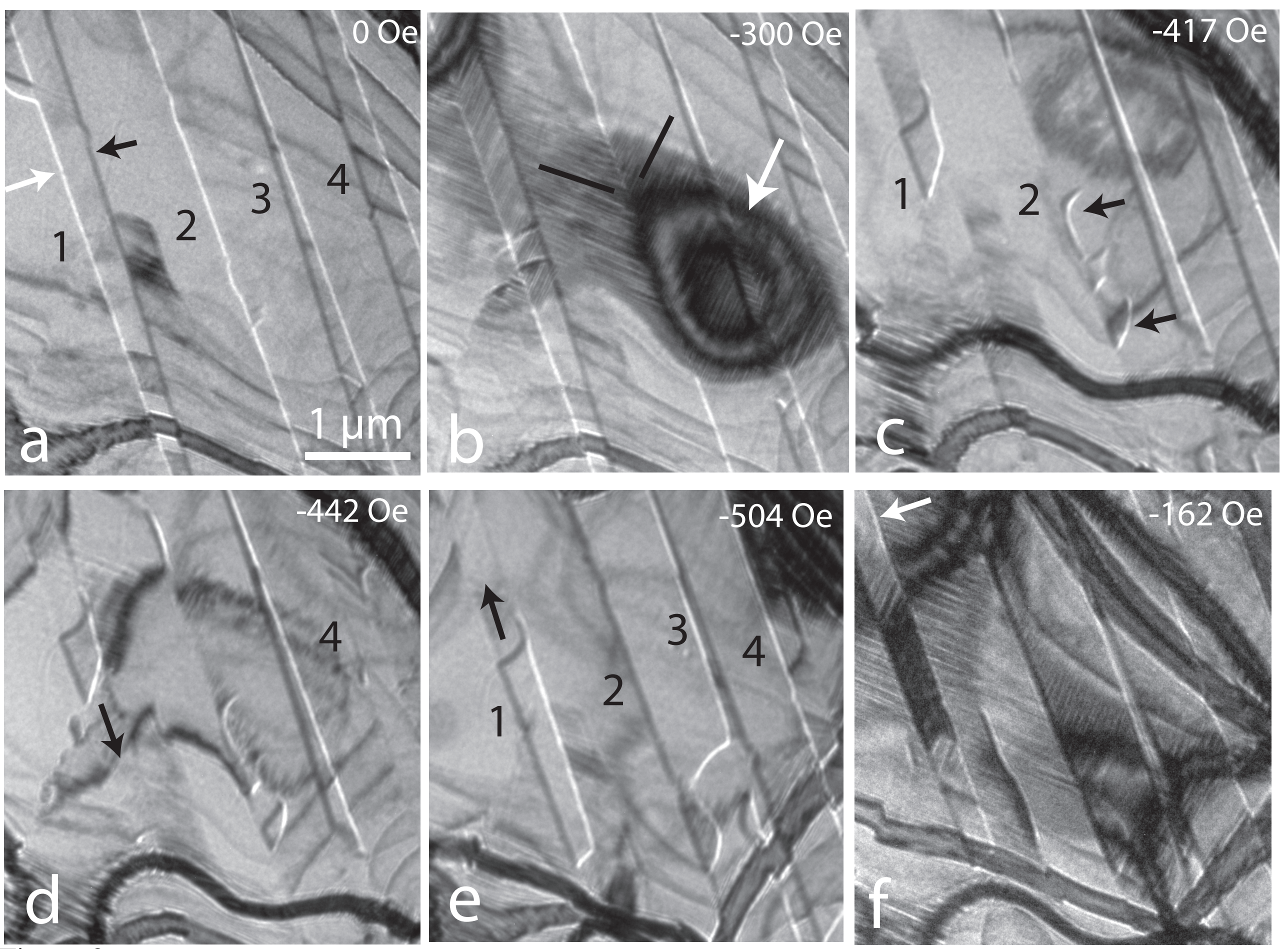

Figure 2: Movement of magnetic domain walls pinned at twin boundaries. (a)-(f) are Fresnel images recorded at different values of applied magnetic field. Note that the striations visible inside the twins are due to stacking faults. The movement of bend-contours is due to a slight bending of the TEM foil at higher applied field values.

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