In-situ TEM observation of the interaction between magnetic domain walls and twin domain walls below the Verwey transition in magnetite

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The Verwey transition has an enormous impact on the magnetic properties of magnetite at low tempeatures - the magnetocrystalline anisotropy increases by an order of magnitude and the magnetic easy axis switches from the <111> directions of the cubic phase to the [001] direction of the monoclinic phase. On cooling through the transition, the [001] easy axis of the monoclinic phase may be chosen to lie along any one of three <100> directions of the parent cubic phase, resulting in the development of transformation twinning. Numerous studies have proposed that a strong interaction exists between the ferroelastic twin walls and the ferrimagnetic domain walls in magnetite. Nevertheless, the nature of this interaction remains highly controversial. Key questions include: i) are the ferroelastic twin walls strongly pinned, or can they be moved by application of a stress and/or magnetic field? ii) are magnetic domain walls strongly pinned by the twin walls or can they be moved indepedently? and iii) how does the twin microstructure that develops on cooling through through the transition depend on the magnetic microstructure that exists above the transition, and vice versa? To address these questions we have performed an in-situ study of the cubic to monoclinic phase transition in synthetic multi-domain magnetite using low-temperature transmision electron microscopy. The Fresnel mode of Lorentz microscopy was used to make simultaneous observations of the nucleation and translation of transformation twins and magnetic domain walls as the sample was repeatedly cycled through the phase transition. The phase transition is first-order in character and proceeds by the rapid movement of an abrupt phase interface separating the cubic and monoclinic phases. For temperatures just below the transition point, heating of the sample by the electron beam is sufficient to cause rapid movement of the phase interface and internal rearrangement of the transformation twins within the monoclinic phase. There appears to be little "twin memory", i.e. a different set of transformation twins is often observed each time the sample is cooled through the transition. The distribution of magnetic domains above and below the transition was generally very different. The cubic phase is characterised by a low density of magnetic domain walls, whereas the monoclinic phase contains a higher density of closely-spaced

lamellar domains. In contrast to previous studies, magnetic closure domains within the monoclinic phase were also observed to be relatively common. Regions showing a clear interaction between magnetic domain walls and twin domain walls were observed. Typical features include the pinning of magnetic domain walls at the tips of needle twin domains and the shearing of needle twins by an intersecting magnetic domain wall.