Magnetic-shape-memory Heusler thin films for thermo-magneto-mechanical systems

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Ferromagnetic shape memory materials (FSM) such as Ni-Mn-Ga belong to a class of shape memory alloys, showing a strong coupling between magnetic and structural degrees of freedom, thus giving rise to an evident correlation between magnetic, thermal and mechanical characteristics [1]. In particular, FSM thin films are of special interest due to possible integration into micro- and nanoscale thermomagnetomechanical systems with magnetocaloric, energy harvesting and actuation properties [2-5]. By varying the temperature, Ni-Mn-Ga encounters reversible thermodynamically governed phase transformation between cubic austenite and low symmetry martensite. In order to maintain the compatibility of the two phases and to accommodate the stress caused by martensitic phase transformation, martensite cells form arrays of hierarchical 3D zigzag patterns, which alternate their orientation periodically. The symmetry relation for these patterns, which are called twin variants, is determined as rotation or (and) mirror at the twin boundaries. Upon martensitic transformation, a self-accommodation of different twin variants takes place in nanometric, mesoscopic, and macroscale. In epitaxial Ni-Mn-Ga thin films, the orientation of the twin variants is determined with respect to the substrate. From the total six orientations of the possible twin boundaries along {101} cubic austenitic cell, the so-called Y-type is determined by the two equivalent twin boundaries perpendicular to the substrate, whereas in the so-called X-type, the four equivalent twin boundaries are 45° inclined to the substrate plane. Remarkably, the magnetization easy axis of the martensitic cells alternates in the plane of the film for Y-type across the boundary while the easy magnetization axis alternates in and out of plane of the film for X-type [6]. The ability to control these microstructures at different length scales will pave way towards controlling thermomagnetomechanical properties in magnetic shape memory thin films [7].

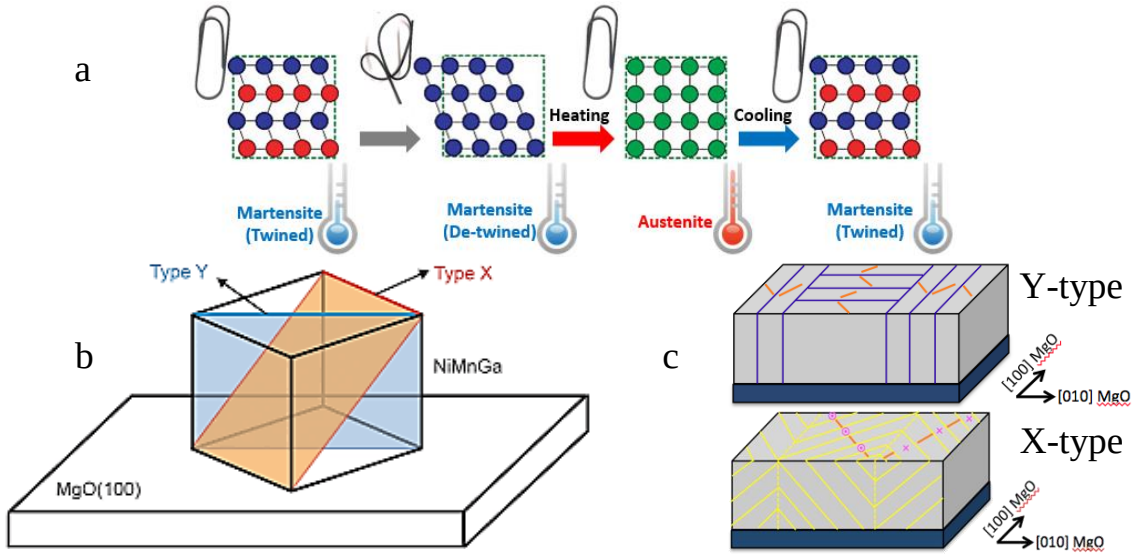

Figure 1 schematic representation of the a) shape memory alloys in different stages; the atomic scale and the bulk scale (shape memory paper clip), b) the orientations of X- and Y-type twin boundaries with respect to the substrate, c) the directions of the magnetization easy axis in the X-type and Y-type configurations (directions of the red and pink tiny arrows)

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