Ferromagnetic Shape Memory Alloys

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Several alloy systems, like Ni-Ti, Cu-Zn-Al, Cu-Al-Ni, Au-Cd or Ni-Al, among others, exhibit a thermoelastic martensitic transformation, which can be thermally or stress-induced. This is a first order diffussionless phase transition in solid state, with a relatively low degree of irreversibility and narrow hysteresis. These materials are denoted as "shape memory alloys" because they present unusual properties like the "shape memory" or "superelasticity" effects, which are directly related to the thermoelastic martensitic transformation [1].

Some shape memory alloys are also ferromagnetic at temperatures below the corresponding Curie point, which is composition dependent. This fact was not considered to be very relevant until the observation of large magnetic-field-induced strains in single crystals of Ni-Mn-Ga [2]. This new behavior, which sometimes is denoted as "magnetic shape memory effect", raised spectacularly the interest about ferromagnetic shape memory alloys (FSMA), and they constitute, nowadays, a field of intense research. With some suitable preparation of the material, uniaxial strains of about 6% in single crystals, under magnetic fields of the order of 1 Tesla, are now standard [3]. This value is much higher than the maximum strain attainable by magnetostriction (about 0.2% in Terfenol D); thus, from the applied point of view, FSMA are expected to improve the performances of the magnetic field actuators. The magnetic shape memory effect does not directly involve the thermoelastic martensitic transformation. The effect takes place at constant temperature, with the material in martensitic state, and proceeds through the reorientation of the martensitic variants impelled by the external magnetic field [3]. Two conditions must be fulfilled: high magnetic anisotropy energy (to difficult the rotation of the magnetic moment inside a martensite variant) and low variant reorientation stress. FSMA also exhibit other effects very interesting from the fundamental point of view, like magneto-elastic coupling, a weak first order premartensitic transition by a soft phonon mode condensation mechanism, large magnetocaloric effect, ... Ni-Mn-Ga is, by far, the mostly studied alloy system, but other FSMA like Ni-Fe-Ga, Co-Ni-Al, Co-Ni-Ga,... are also being investigated.

The lecture will illustrate the concepts commented above. In addition, the thermodynamics of thermoelastic martensitic transformations and some phenomenological models for the mechanism of the magnetic shape memory effect will be reviewed.

[1] K. Otsuka and C.M. Wayman, *Shape Memory Materials*, Cambridge University Press, 1998.
[2] K. Ullakko, J.K. Huang, C. Kanter, V.V. Kokorin and R. C. O'Handley, *Appl. Phys. Lett*. **69,** 1966, (1996).
[3] S.J. Murray, M. Marioni, S.M. Allen, R.C. O'Handley and T.A. Lograsso, *Appl. Phys. Lett.* **77**, 886, (2000).