Effect of magnetic field on the first order Martensite phase transition in Ni$_{55}$Fe$_{20}$Al$_{25}$ shape memory alloy

Archana Lakhani
UGC-DAE, Consortium for Scientific Research, University Campus, Khandwa Road, Indore-452001, India
E-mail: archnalakhani@gmail.com

Abstract. The temperature and magnetic field effect on the transport and magnetic properties of a ferromagnetic shape memory alloy Ni$_{55}$Fe$_{20}$Al$_{25}$ has been studied. The resistivity and thermo magnetization results provide the evidence of martensite transformation and the presence of coexisting austenite and martensite phases by first order magnetic phase transition (FOMT) at different fields. Martensite transformation temperature ($T_m$) shifts towards higher temperature with the application of magnetic field which reveals the sensitivity of this alloy. Ni-Fe-Al alloys are potential new candidates for ferromagnetic shape memory alloys.

1. Introduction
Ferromagnetic shape memory alloys (FSMAs) have been the subject of current interest due to the magnetic field induced first order phase transition (FOPT). Similar to various intermetallic alloys and manganites, FSMAs also show field induced structural transition giving rise to functional properties such as giant magnetoresistance, giant magnetocaloric effect, magnetostriction and superelasticity etc. They are technologically potential candidates due to their possible usage in actuators, sensors and in the magnetic refrigeration technology [1,2]. Magnetic field induced transition materials have revitalized the interest in FOPT not only due to their possible applications but also due to the interesting fundamental studies around FOPT. In FSMAs, this field induced martensite transformation (MT) is associated with change in structure and magnetization both. [3]

The temperature at which MT/FOMT occurs in various compounds can be optimized by the careful choice of composition and thermal treatment. Ni-Fe-Al shape memory alloys are originated from Ni-Al binary shape memory alloys. The doping of Fe in Ni-Al system increases the ductility and reduces the MT temperature in Ni-Fe-Al alloys. The site occupancy of Fe in Ni-Fe-Al shape memory alloys plays a decisive role in defining the structural and magnetic properties of these systems. The effect of site disorder on the MT in Ni$_{55}$Fe$_{20}$Al$_{25}$ has been studied by Abhyankar et al. by Neutron Diffraction and Magneto transport measurements [4,5]. Ni-Fe-Al alloys show a transition from high temperature cubic austenite to low temperature tetragonal martensite phase. Magnetically it undergoes a para to ferromagnetic phase transition at $T_c$ [6].

Here we present a resistivity and thermomagnetization study on an annealed and subsequently quenched sample with composition Ni$_{55}$Fe$_{20}$Al$_{25}$ in order to distinguish the effect of temperature and field on the MT and on the coexisting austenite and martensite phases associated with para and ferromagnetic phases respectively.
2. Experimental
In Polycrystalline sample with composition Ni$_{55}$Fe$_{20}$Al$_{25}$ is prepared by arc melting of the constituent elements with purity better than 99.99% in pure argon atmosphere. The ingot was melted several times to ensure homogeneity. As-prepared ingot was annealed at 1100°C in an evacuated quartz tube followed by subsequent quenching. Resistivity measurements were performed by standard four probe technique using a commercial cryostat from Oxford Instruments, UK in the temperature range of 5-300K and up to 8T magnetic fields. The magnetization measurements were performed using a 14-T VSM-PPMS from Ms. QD, USA.

3. Results and Discussion
The Figure 1 shows resistivity plots as a function of temperature during cooling and heating cycles without magnetic field and in three different measurement protocols, viz: zero field cooled warming (ZFCW), field cooled cooling (FCC) and field cooled warming (FCW) at 8T field. The arrows in cooling and heating cycles show the start and finish of martensite ($M_s$ and $M_f$) and austenite ($A_s$ and $A_f$) phases. The temperatures corresponding to $M_s$, $M_f$, $A_s$ and $A_f$ in absence of magnetic field are 155K, 77K, 83K and 163K respectively. The phase coexisting region reclines between ~160-80K with a hysteresis of approximately 80K. Thermal hysteresis in FSMAs is considered to be the signature of temperature induced first order martensite phase transition. On increasing the field from zero to 8T, there is not much change in the width of hysteresis whereas martensite transition temperature ($T_m$) increases from 120K to 127K. Here $T_m$ is defined as $T_m = [(M_s+M_f)/2+(A_s+A_f)/2]/2$.

![Figure 1](image)

**Figure 1.** $\rho$ vs T plots for Ni$_{55}$Fe$_{20}$Al$_{25}$ sample obtained in ZFC, FCC and FCW manner in zero field and in 8T fields.

Figure 2 shows magnetization as a function of temperature in three different measurement protocols viz: zero field cooled warming (ZFC), field cooled cooling (FCC) and field cooled warming (FCW) at H= 500 Oe, 1T and 8T. For clarity, cooling and heating cycles of Magnetization at 500 Oe are shown in the inset of figure 2. The thermal hysteresis is observed in the cooling and heating cycles of M(T) curves also, although it is more pronounced in $\rho$(T) curves. The characteristic temperatures defined for the onset and finish of martensite and austenite phases are marked by arrows in the inset shown. The $T_m$ gradually increases with increase in field from 500 Oe to 8T from 100K to 117K. These values are smaller than the $T_m$ values obtained from resistivity measurements but the change in
martensite transition temperature ($\Delta T_m = 7\text{K}$) in the span of 8T is same. There is almost 1K shift in $T_m$ per Tesla field which reveals the sensitivity of this alloy with magnetic field.

Figure 2. $M$ vs $T$ plots for Ni$_{55}$Fe$_{20}$Al$_{25}$ sample obtained in ZFC, FCC and FCW manner at applied fields of 500 Oe,1T and 8T.

At 500 Oe, the magnetic moment increases by ~ 10 emu/g after the martensite phase transition, indicating transition from low magnetic state to higher magnetic state as reported earlier [5]. Isothermal magnetization curve at 5K is shown in figure 3 revealing the ferromagnetic nature of the state in the system. The saturation magnetization value ($M_s$) at 10T field is ~ 57 emu/g which is almost equal to the saturation magnetization (~59 emu/g) obtained for the melt quenched ribbon sample at 7T discussed by Kaul et al. [5]

Figure 3. Magnetization as a function of field at $T= 5\text{K}$ for Ni$_{55}$Fe$_{20}$Al$_{25}$ alloy.
The sensitivity of austenite to martensite phase transformation to applied magnetic field can be understood by considering the effect of magnetic field on the free energies of the respective phases. On lowering the temperature, when martensite state becomes the low energy state, the system undergoes a first-order austenite to martensite phase transition. Since the martensite state exhibits a ferromagnetic behavior, the application of magnetic field lowers its free energy, and therefore the martensite state attains the status of low energy state at a relatively higher temperature. This results in an enhancement of martensite transition temperature ($T_m$) on increasing the magnetic field.

In conclusion we have studied the effect of field and temperature on an annealed and subsequently quenched shape memory alloy of Ni$_{55}$Fe$_{20}$Al$_{25}$ by resistivity and magnetization measurements and demonstrated the field sensitivity of the alloy which reveals its technological importance. The physical significance behind the enhancement of $T_m$ is explained in terms of change in free energy of the two magnetic states.

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5. References
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