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Magnetic and martensitic transformations in Ni-Fe-Ga alloy

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Abstract Magnetic and martensitic transformations have been observed in $Ni_{48}Fe_{20}Ga_{32}$ alloy prepared by arc melting AC magnetic susceptibility technique was employed to determine the martensitic transformation and Curie temperature Room temperature optical and scanning electron microscopy investigations were performed to ascertain the presence of the martensite phase and to determine the overall alloy composition The alloy exhibited a ferromagnetic martensitic phase below 237 K

Keywords Ferromagnetic shape memory alloy, ac susceptibility Curie temperature martensitic transformation

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1. Introduction

Ferromagnetic shape memory alloys (FSMAs), which exhibit both shape memory effect as well as ferromagnetism, are potential candidates for next generation actuator applications Ullakko [1] reported a large magnetic field induced strain of ~ 6% in a Ni_2MnGa single crystal Practical application of the prototype FSMA, Ni_2MnGa is restricted due to its extreme brittleness in the polycrystalline state and requirement of high magnetic field for inducing the required strain Recently, the Ni-Fe-Ga alloy, which is similar to Ni-Mn-Ga alloy in structure, was shown to undergo reversible thermo elastic martensitic transformation in ferromagnetic state [2-7] The preliminary results of work done on $Ni_{48}Fe_{20}Ga_{32}$ alloy are reported here

2. Experimental details

$Ni_{48}Fe_{20}Ga_{32}$ alloy was prepared by arc melting appropriate amounts of the constituent elements in an argon atmosphere. All the investigations were carried out on ascast sample The overall composition and microstructure of the alloy were determined using a scanning

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electron microscope (LEO1430 VP) equipped with an energy dispersive spectrometer (EDS, AZTEC) and an optical microscope (Zeiss Axiotech). An X-ray diffractometer (Seifert 3003TT) equipped with an X-ray tube with Cu target (wavelength = 1.5406 Å) was used for crystal structure elucidation. AC susceptibility (ACS) measurements were carried out using an indigenously developed [8] mutual inductance type AC susceptometer. Magnetization measurement was performed using a Vibration Sample Magnetometer (Lakeshore, Model 7410).

3. Results and discussions

Room temperature XRD pattern (Figure 1) of $Ni_{48}Fe_{20}Ga_{32}$ alloy showed a two phase structure. All the peaks were indexed to γ (fcc austenite) and β (body centred tetragonal martensite) phase, respectively. XRD peaks were simulated for fcc and bct structures using the Powder Cell program [9,10]. The simulated pattern (dotted lines in Figure 1) matched well with the experimental XRD pattern. The calculated lattice parameters were a = 5.76 Å for the γ-phase and $a = b$ = 2.69 Å, c = 4.16 Å for the β phase, respectively. The percentage of γ-phase and β-phase was estimated to be about 92% and 8%, respectively. An overall composition of $Ni_{48.46}Fe_{20.23}Ga_{31.21}$ was obtained from SeM-EDS analysis.

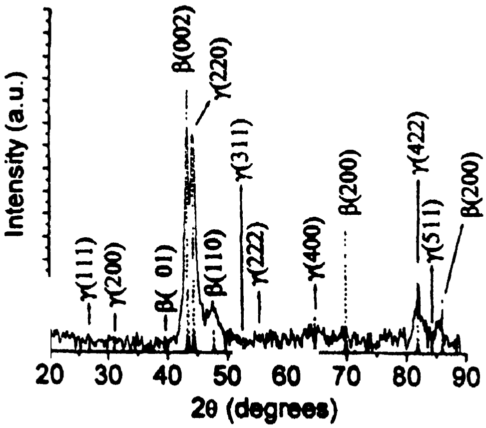

Figure 1. XRD (solid line) and simulated (dotted lines) patterns of $Ni_{48}Fe_{20}Ga_{32}$ alloy.

Figure 2. Optical micrograph of $Ni_{48}Fe_{20}Ga_{32}$ at low magnification.

Figure 2 shows weak surface relief features in $Ni_{48}Fe_{20}Ga_{32}$ alloy, which is indicative of the residual (8%) martensite phase present in the sample at room temperature.

Figure 3 shows the temperature dependence of ac susceptibility of the alloy in a magnetic field of 16 Oe (kA/m). the sharp decrease in ac susceptibility around 322 K signifies the transition from low temperature ferromagnetic phase to high temperature paramagnetic phase. The Curie temperature was found to be 326 K. Thermal hysteresis observed during the heating and cooling cycles was negligible as shown in Figure 3.

However, a clear thermal hysteresis was observed in the ACS data between 228 K and 244 K as shown in Figure 4. This is a signature of the martensitic (while cooling) and reverse martensitic (while heating) transformations occurring in the alloy The drastic change

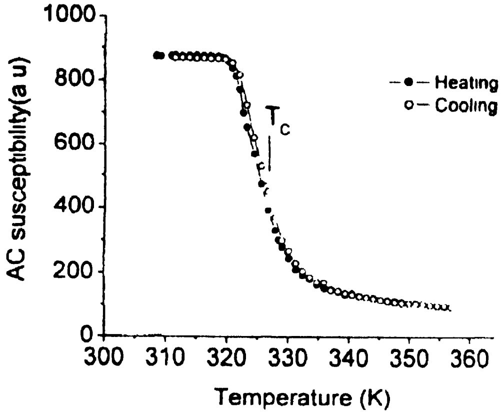

Figure 3 Variation in ac susceptibility with temperature from 325 K to 360 K

in the ac susceptibility and the thermal hysteresis are characteristics of these transformations The irreversibility between the heating and cooling cycles is attributed to the free energy minima corresponding to the parent phase and product phase, which are separated by energy barrier [11] The martensitic start temperature (M_S) and martensitic finish temperature (M_f) are marked in the cooling cycle, whereas the reverse martensitic start temperature (A_s) and reverse martensitic finish temperature (A_f) are marked in the heating cycle of the ACS data shown in Figure 4 Only one structural transformation, corresponding to the low temperature martensite phase was observed in the ACS studies in the temperature range of 200 K to 475 K The room temperature martensite phase observed in the XRD pattern and the optical micrograph could not be characterized since it did not show any transformation in the ACS studies in the temperature range of 200 K

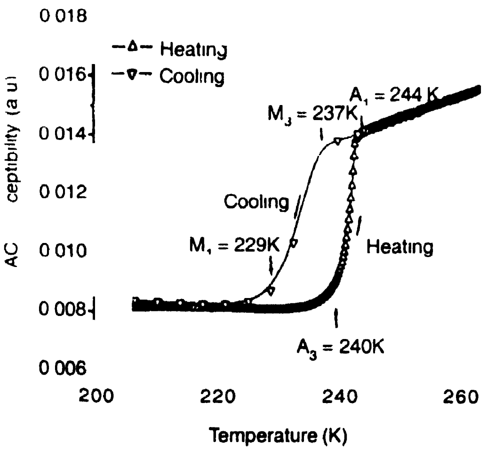

Figure 4. Variation in ac susceptibility with temperature from 205 K to 260 K

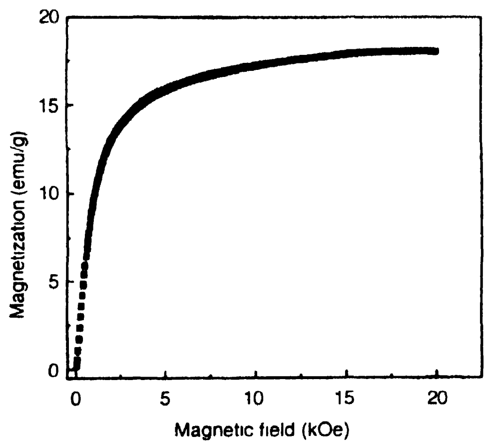

Figure 5. Initial magnetization curve for $Ni_{48}Fe_{20}Ga_{32}$ alloys (up to 20 kOe)

to 475 K. This weak room temperature martensite phase might have resulted due to inhomogeneities in the as-cast sample.

The variation of magnetization (M) with applied field (H) is shown in Figure 5. The saturation magnetization of this sample was found to be 18 emu/g at 200 kOe

$Ni_{48}Fe_{20}Ga_{32}$ alloy has a ferromagnetic martensitic phase below 240 K. Heat treatment of Ni-Mn-Ga alloy resulted in an increase in the martensitic transformation temperatures [10] and also improved the homogeneity of the alloy It would be interesting if a similar trend could be observed in this alloy If so, this would provide a means to obtain a room temperature ferromagnetic martensitic phase in this alloy

4. Conclusion

Ferromagnetic behavior was observed above the room temperature (up to 326 K) whereas the martensitic phase existed only below 240 K in as-cast $Ni_{48}Fe_{20}Ga_{32}$ alloy. Heat treatment would ensure better homogenization of the as-cast ingot and might help in raising the reverse martensitic start temperature well above the room temperature in this FSMA

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References

[1] K Ullakko J K Huang C Katner, R C O'Handley and V V Kokorin *Appl Phys Lett* **69** 1966 (1996)

[2] H Morito, A Fujita, K Fukamichi R Kainuma, K Ishida and K Oikawa *Appl Phys Lett* **83** 4993 (2003)

[3] K Oikawa, T Ota, Y Sutou T Ohmori R Kainuma and K Ishida *Mater Trans* **43** 2360 (2002)

[4] H Morito, A Fujita, K Fukamichi, T Ota, R Kainuma, K Ishida and K Oikawa *Mater Trans* **44** 661 (2003)

[5] Y Murakami, D Shindo and K Oikawa *Appl Phys Lett* **82** 3695 (2003)

[6] Y Sutou, N Kamiya, T Omori, R Kainuma and K Ishida *Appl Phys Lett* **84** 1275 (2004)

[7] Z H Liu M Zhang, Y T Cui, Y Q Zhou W H Wang, G H Wu, X X Zhang and G Xiao *Appl Phys Lett* **82** 424 (2003)

[8] S Sarma, M P C Kalita, A Perumal and A Srinivasan *Proc Natl Workshop Adv Tech Mater Charac, Vadodara* p 19 (2006)

[9] W Kraus and G Nolze *J Appl Cryst* **29** 301 (1996)

[10] www ccp14 ac uk

[11] S Majumdar, V K Sharma, R Kaul, S B Roy and P Chaddah *Solid State Commun* **136** 85 (2005)

[12] J Pons, C Segui, V A Chernenko, E Cesari, P Ochin and R Portier *Mater Sci Engg* **A273** 315 (1999)