MAGNETIC AND ELECTRICAL RESISTIVITY BEHAVIOUR OF AMORPHOUS Ni-Co-P FILMS

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Abstract Magnetic and Electrical Resistivity Study of Electroless Amorphous Ternary System (Ni-Co-P) show a qualitative dependence of crystalline phases formed during transformation on the annealing temperature and composition. Electrical Resistivity values increases with increase in cobalt content and samples with higher resistivity show lower temperature coefficients. The Initial increase in magnetization is due to separation of crystalline magnetic phases (α-Cobalt and f.c.c. Nickel), and tends to decrease by formation of equilibrium phases at higher temperature.

Key Words Magnetic Resistivity, Electrical Resistivity, α-Cobalt, fcc Nickel, Ni-Co-P

چکیده در این بررسی تجربی، خواص الکتریکی و مغناطیسی آلیاژ آمورف نیکل-کبالت-فسفر (Ni-Co-P) مورد مطالعه قرار گرفت. با افزایش مقدار کبالت در آلیاژ آمورف، مقاومت ویژه الکتریکی افزایش و ضریب دمایی مقاومت (TCR) کاهش می‌یابد. افزایش اولیه در مقدار مغناطیس شدگی نمونه ها به خاطر جدایش فازهای مغناطیسی Ni و Co-α بوده و با تبلور کامل آلیاژ کاهش می یابد.

INTRODUCTION

Composition and temperature dependence of magnetization and electrical resistivity contain valuable information on crystallization behaviour of amorphous alloys. Magnetization studies of binary amorphous Ni-P and Co-P have been conducted by many researchers [1,2,3]. In these studies different simplified models have been developed to describe the phenomena of lowering the magnetic moment on alloying. The most distant position is reported to be occupied by rigid band model [4].

A variety of TM-M (Transition Metal-Metalloid) ternary alloys were prepared and data agreed resonably well with the rigid band model with assigning the electrons transferred from metalloids as; 1 for B, 2 for Si and 3 for P. The information on the electronic transport properties of amorphous alloys comes from measurement of electrical resistivity such as experimental magnitude, their temperature and composition dependence. Mooij [5] reported a correlation between the magnitude of electrical resistivity "φ" and temperature coefficient of resistivity. TCR, "α" by analyzing available data in amorphous transition metal alloys. The electrical resistivity measurements of Ni-P and Co-P of different compositions are reported [2,6] while available data on TM-M ternary or quaternary systems are for amorphous alloys prepared by melt quenching techniques.

This paper reports the results of "as -deposited" and annealing behaviour of magnetization and electrical resistivity for ternary amorphous electroless Ni-Co-P system.

EXPERIMENT

Amorphous samples of Ni-Co-P were prepared by electroless deposition technique using alkaline bath similar to one used by tyagi et al. [7] where the

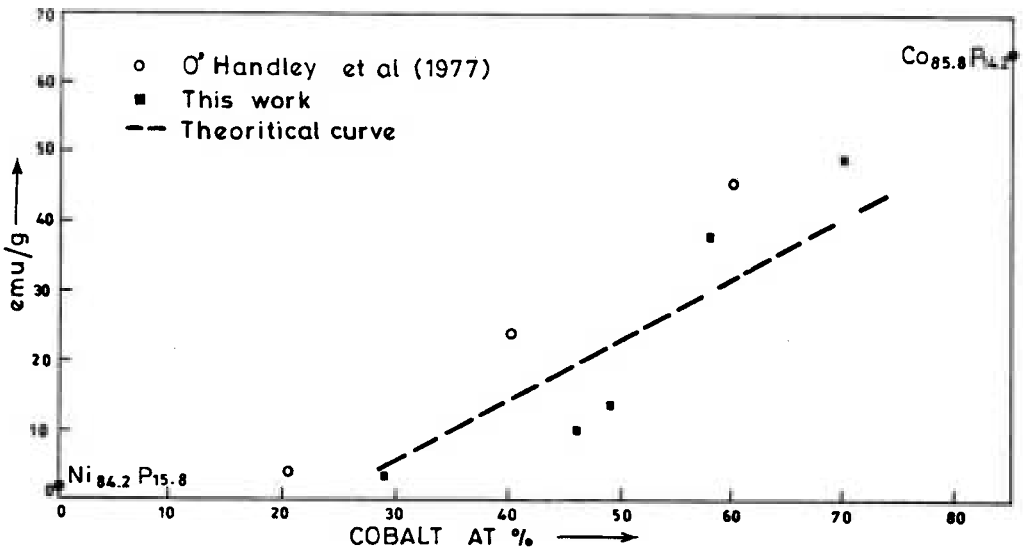

Figure 1. Variation of "As-deposited" magnetic moment with cobalt content.

Inductively Coupled Plasma (I.C.P. 8440 plasmalab model) was used for compositional analysis of the "as-deposited" samples with accuracy better than ±1%. Foner type vibrating sample magnetometer (princeton applied research corporation) was used for magnetic characterization of the samples up to temperature of 873 K in an applied filed of 5 KG.

A series of rectangular samples with dimensions of 10 mm×2mm×3-8μm were chosen from the central portion. Thickness of the samples was measured using Dektak IIA surface profile measurement. Electrical resistivity measurements were performed in vacuum up to 850 K using standard four probe DC set up.

RESULTS AND DISCUSSION

Nature of "as-deposited" electroless Ni-Co-P films are examind using Selected Area Electron Diffraction under TEM and X Ray Diffraction. Patterns were characteristics of amorphous materials [8].

Figure 1 shows the variation of magnetic moment with Cobalt precentage for five samples. Experimental values of electroless Ni-Co-P reported by O'Handley [9] are presented in the same figure for the sake of comparison. As can be seen, the magnetic moment of "as-deposited" films increases as the Cobalt content increases. Yamauchi and Mizoguchi [4] proposed a formula for the theoretical calculation of the magnetic moment based on rigid band model. This theoretical curve for our Ni-Co-P ternary system is shown in Figure 1. Assuming the number of electrons transferred from metalloid to be 4.5 (n=4.5), a good agreement is found for our amorphous alloys.

The variation of resistivity and TCR at about 300K for different samples are shown in Figure 2. Electrical resistivity increases with increase in cobalt composition from sample $Ni_{55.5}Co_{29.0}P_{15.5}$ to $Ni_{39.0}Co_{46.0}P_{15.0}$. Further addition of Cobalt does not change the resistivity of "as-deposited" films for the samples with 49.1, 58 and 70 at % Cobalt. TCR introduced by Mooij is observed to decrease from the 13.06×10^{-5} K^{-1} for $Ni_{55.5}Co_{29.0}P_{15.5}$ sample to 4.07×10^{-5} K^{-1} for $Ni_{39.0}Co_{46.0}P_{15.0}$ sample but remains almost constant for other compositions. The value of TCR for $Ni_{55.5}Co_{29.0}P_{15.5}$ is near to that of reported for Ni-P alloys of having high phosphorous (20 at%) concentration [10]. However, different values of TCR are reported for Ni-P samples prepared by other methods [11]. Although the present data does not

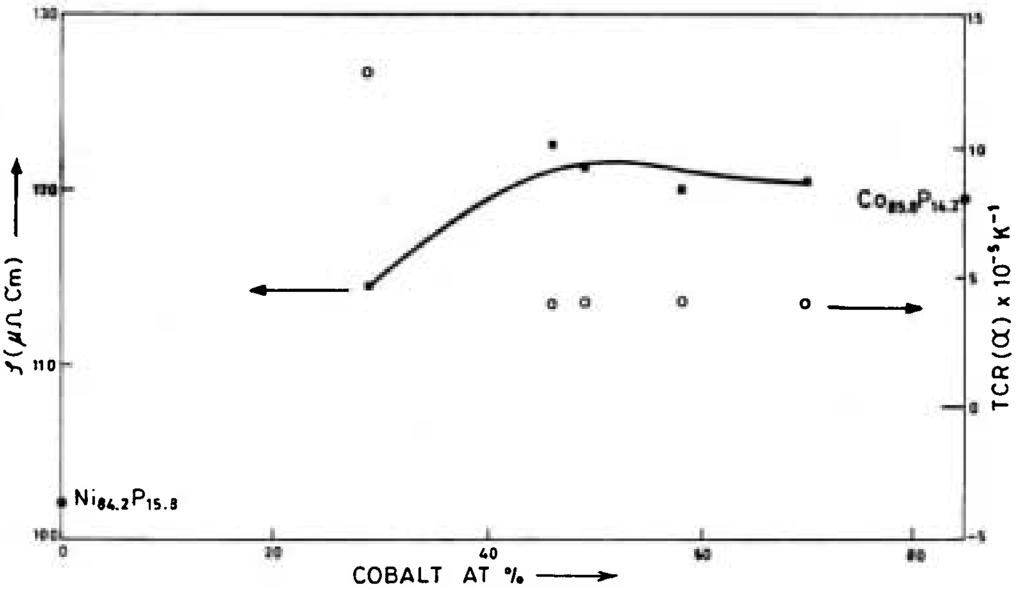

Figure 2. Variation of resistivity (φ) and temperature coefficient of resistivity (α) at 300 K with Cobalt content.

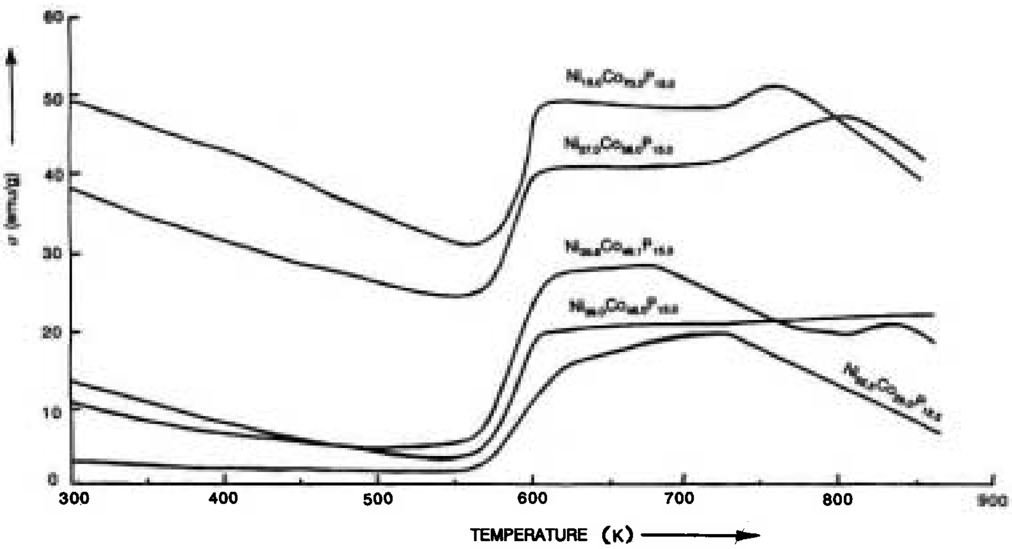

Figure 3. Change in magnetization with temperature for Ni-Co-P samples.

extend up to negative values of TCR, and there are no samples with resistivity greater than 150 $\mu\Omega$cm, one can clearly observe that samples with higher resistivity values have lower temperature coefficients.

Figure 3 shows the magnetic moment annealing behaviour of Ni-Co-P films. The heated samples show different behaviour which depends on their initial compositions. Temperature range over which these changes takes place and the height of magnetization peaks depends upon the rate of heating. The initial increase in magnetization at about 560 K for all samples is due to the continuous process of separation of hcp Cobalt (α-Cobalt) and fcc Nickel as indicated by electron microscopy and X-ray diffraction

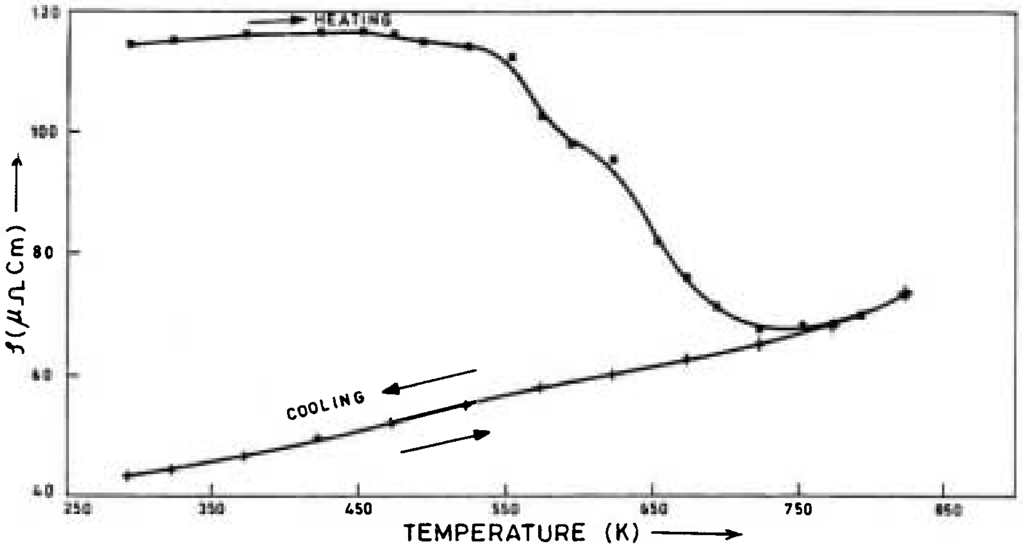

Figure 4. Change in resistivity (φ) with temperature for $Ni_{55.5}Co_{29.0}P_{15.5}$ Samples.

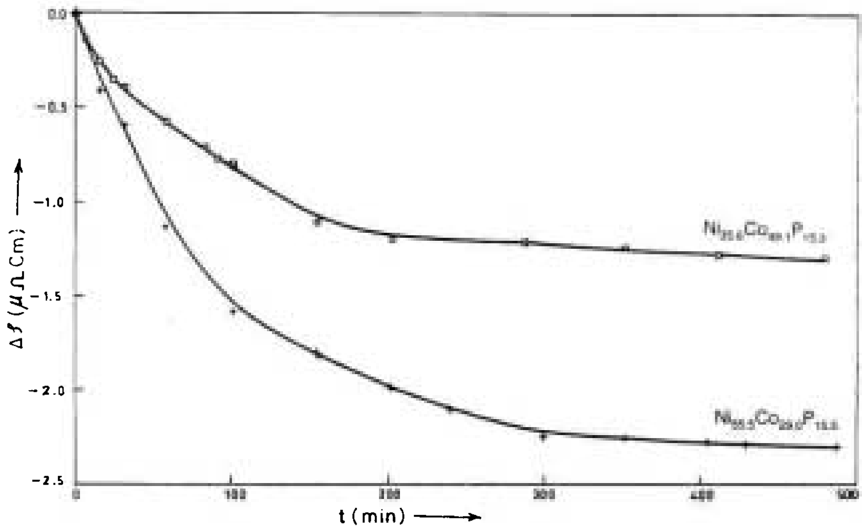

Figure 5. Resistivity change (Δφ) during structural relaxation with respect to time (ta= 533 ±2K)

studies [8].

In specimen containing 29 at% Cobalt, magnetization tends to decrease at about 720 K which is because of equilibrium phase formations. Quite a different trend in magnetization shown by $Ni_{39.0}$ $Co_{46.0}P_{15}$ and $Ni_{35.6}$ $Co_{49.1}P_{15.3}$ indicates continuous crystallization of phases which compensates for the magnetic moment reduction up to 850 K. As Cobalt content of electroless Ni-Co-P increases to 58 and 70 at%, the temperature corresponding to the second maxima decreases because of the tendency to form equilibrium phases at the composition near to that of binary system. This is beleived to be the result of crystallization of amorphous matrix to new magnetic phases like equilibrium Co_2P.

Typical changes in resistivity are shown in Figure 4 where different annealing behaviours are observed for different samples when they are heated with 20±3 K/min heating rate up to about 823 K. There is no major change in resistivity up to 553 K; however slight deviation from linear behaviour is observed from 450 K onwards up to 550 K. A reduction in electrical resistivity is observed to occur between 553K to about 750 K beyond which there is an increase in resistivity with temperature, the characteristics of crystalline alloys. As it is observed, electrical resistivity increases up to 450 K which is mainely because of thermal vibrations. Values of TCR related to this extent of increase is shown in Figure 2. The lowering of electrical resistivity up to 553 K is observed to coincide with the region of small peaks in D.S.C. experiments [8] and can be attributed to atomic relaxation process. The samples are heated up to 533±2 K, before the sharp decrease in electrical resistivity and the annealing behaviour is studied with respect to time. Samples with 46, 49.1, 58, 70 at% Cobalt show comparitively similar behaviours. The typical values for samples $Ni_{55.5}Co_{29.0}P_{15.5}$ and $Ni_{35.6}Co_{49.1}P_{15.3}$ are shown in Figure 5.

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