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Electrical properties of amorphous Ni-P: Comparison of ion implantation with other preparation techniques

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The temperature dependence of the resistivity of a $Ni_{1-x}P_x$ film implanted at 6 K was measured before and after annealing at 240 K at P concentrations between $x = 0.14$ and $x = 0.30$. These results are compared to those previously obtained on films implanted at room temperature and on $Ni_{1-x}P_x$ alloys prepared by standard quenching or deposition techniques. We confirm that for P concentrations above the amorphization threshold, the electrical properties of the alloy are independent of the implantation temperature and of the preparation technique.

Recent resistivity measurements[1] demonstrated that the electrical properties of $Ni_{1-x}P_x$ alloys prepared by ion implantation at room temperature were identical to those of amorphous $Ni_{1-x}P_x$ alloys made by evaporation or electrodeposition, as soon as the eutectic composition was reached. The purpose of this Brief Report is to show that the results reported in Ref. 1 also hold after implantation at low temperature (i.e., when the amorphous system is produced still further from thermodynamical equilibrium) although the amorphization mechanisms, as studied by Rutherford backscattering (RBS) and channeling experiments,[2-4] are somewhat different. The comparison of resistivity results obtained on $Ni_{1-x}P_x$ alloys prepared by the various techniques extends over a concentration range from 0.14 to 0.30.

The experimental conditions were essentially those of Ref. 1. The only difference was that the samples were mounted in a cryostat[5] allowing implantation at temperatures between 4.2 K and room temperature as well as *in situ* resistivity and RBS measurements in that temperature range. Sample thicknesses and implantation energies were similar to those of Ref. 1. The new results presented here were obtained on samples implanted at 6 K, at four different concentrations.

The resistivity temperature dependence of the films was measured between 4.2 and 220 K, before and after annealing the sample for 10 min at 240 K where a sharp annealing stage was found. Figure 1 shows the curves obtained during the sample cooling after annealing. These curves exhibit (i) the linear variation (slope β) at high temperature (i.e., above ~ 140 K), and (ii) the logarithmic variation (slope α) at low temperature (i.e., below ~ 10 K), already observed in the case of the $Ni_{1-x}P_x$ alloys implanted at room temperature.[1] During the heating sequence before annealing at 240 K, small annealing stages from 100 to 200 K prevent the temperature coefficient of the resistivity (TCR) from being accurately measured; the values of β displayed in Fig. 3 were thus obtained in a 20-K temperature range around 200 K.

Figure 2 summarizes the resistivity values obtained for the $Ni_{1-x}P_x$ alloys implanted at 6 K (this work) and those implanted at 300 K (Ref. 1) as well as those reported[6-8] for amorphous $Ni_{1-x}P_x$ alloys prepared by quenching or deposition techniques. The TCR values obtained on all the amorphous $Ni_{1-x}P_x$ alloys are compared in Fig. 3. The values of ρ and β measured on the film implanted at 6 K for *x above the eutectic composition* do not vary upon annealing at 240 K and are very close to those found for the $Ni_{1-x}P_x$ alloys implanted at room temperature or prepared by other techniques. The differences observed in the values of β *at lower P concentration* could be due to (i) inhomogeneities in the film composition due to the implantation profile, or (ii) a mixture of crystalline and amorphous regions. Our implantation conditions[1] and the fact that at 300 K (i.e., at the temperature where the value of β is the largest) P has been found to migrate under implantation in the damaged region[4] make hypothesis (i) very unlikely. On the other hand, RBS and channeling experiments[2,3] on $Ni_{1-x}P_x$ alloys implanted at 300 and 90 K show that total amorphization occurs for both temperatures only when the P concentration reaches 0.17–0.18 and that, at lower concentration, amorphous and disordered crystalline regions coexist. Since the TCR is in-

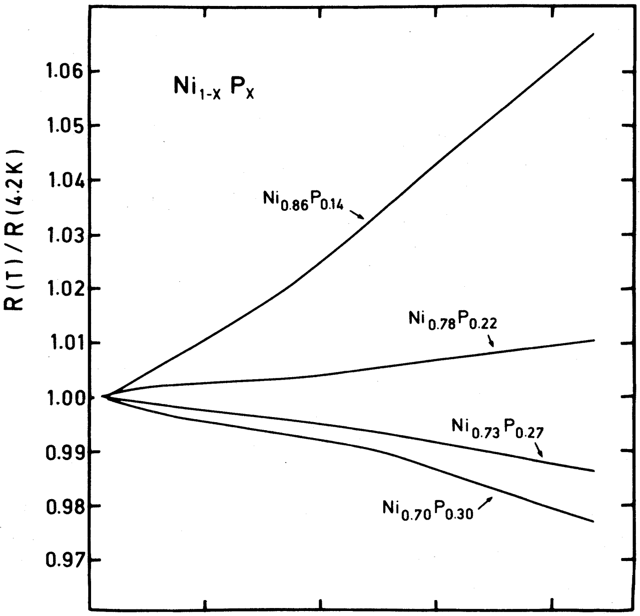

FIG. 1. Resistivity temperature dependence in the range 4.2–220 K after annealing at 240 K for $Ni_{1-x}P_x$ films implanted at 6 K.

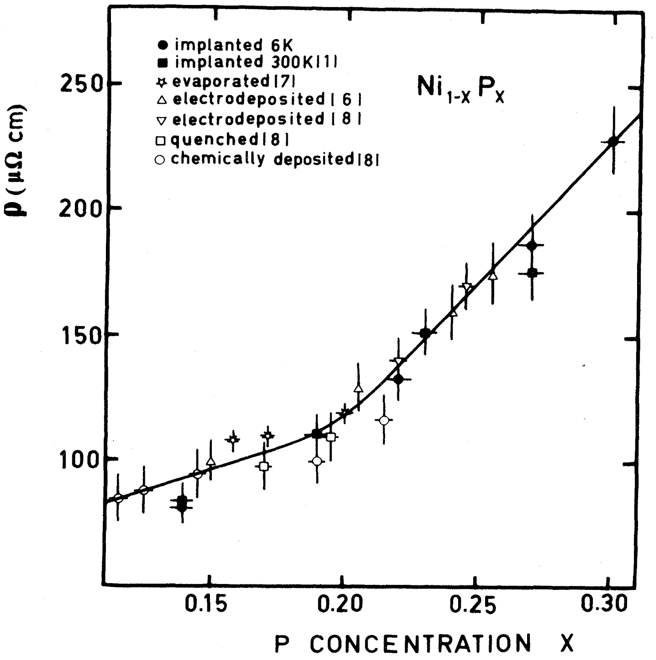

FIG. 2. Resistivity ρ vs P concentration for $Ni_{1-x}P_x$ alloys prepared by different techniques. Open symbols: standard preparation techniques; full symbols: ion implantation. The solid line is only to guide the eye.

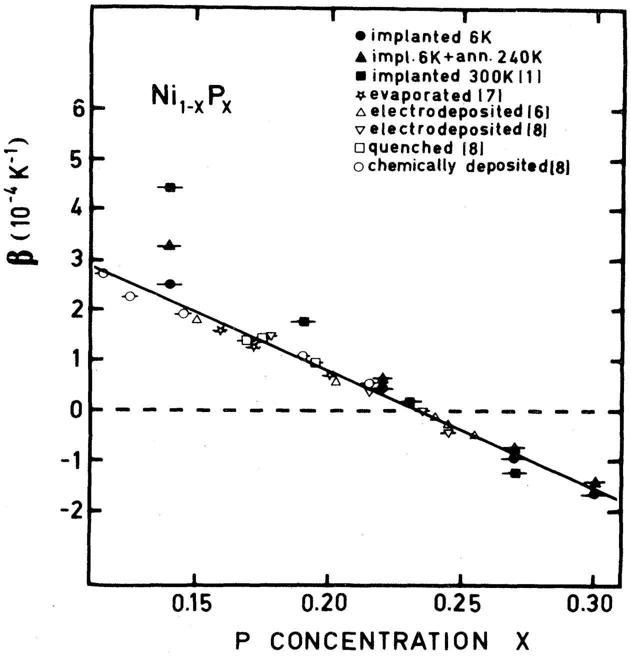

FIG. 3. Temperature coefficient of the resistivity β vs P concentration for $Ni_{1-x}P_x$ alloys prepared by different techniques. Open symbols: standard preparation techniques; full symbols: ion implantation. The solid line is only to guide the eye.

fluenced by both the volume and the structure of the crystalline phase, we conclude that the differences observed in the values of the TCR for the alloys implanted at 6 K (before and after annealing) and implanted at 300 K are representative of differences in the ratio of amorphous-to-crystalline volumes in the film and possibly also in the disorder of the "crystalline" regions.

Our experimental resistivity results, compared to other results concerning the $Ni_{1-x}P_x$ alloy, have shown that total amorphization of $Ni_{1-x}P_x$ films implanted at 6 or 300 K is achieved only when the P concentration is close to the eutectic composition, although the film implanted at 6 K is more disordered than the film implanted at 300 K below that composition. For higher P concentrations, the values of ρ and β indicate that the local order, which determines the transport properties of amorphous alloys, could be the same whether the system is prepared by ion implantation or by standard quenching or deposition techniques. More sensitive techniques, such as extended x-ray-absorption fine structure, are needed to establish this conclusion.

ACKNOWLEDGMENTS

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