

THE HALL EFFECT AND THE ELECTRICAL RESISTIVITY IN AMORPHOUS NiBSi ALLOYS

J. Ivkov* i E. Babić**

* - Institute of Physics of the University, Zagreb

** - Department of Physics, Faculty of Science, Zagreb

ABSTRACT

The values for the normal Hall coefficient R_0 , electrical resistivity ρ and the room temperature coefficient of resistivity α for ten amorphous NiBSi alloys with metalloid concentration ranging from 20 to 39 at% are reported. R_0 and α continuously decrease with increasing metalloid content or, for the fixed metalloid content, with increasing silicon concentration and α changes sign for $\rho \gtrsim 140 \mu\Omega\text{cm}$. The values of the Fermi wave vector deduced from R_0 (within the framework of the free electron model) indicate that the transport properties of Ni-metalloid alloys can be interpreted in terms of the Ziman-Faber theory. The concentration dependence of R_0 indicates a significant charge transfer from metalloid atoms to the conduction band.

The knowledge of the electronic properties of amorphous Ni-metalloid alloys can improve the understanding of the properties of amorphous transition metal-metalloid alloys in general. In Ni-metalloid metallic glasses the resistivity ρ increase while the room temperature coefficient of the resistivity $\alpha = (1/\rho)d\rho/dT$ decreases with increasing metalloid content. For resistivities close to $150 \mu\Omega\text{cm}$ α , as one would expect from Mooij /1/ correlation, changes sign and becomes negative. It is argued /2,3/ that such a behaviour, as well as the electronic transport in these alloys, can be explained in terms of the diffraction model (i.e. Ziman-Faber theory). As the exact values of the Fermi wave vector k_F (necessary for the use of the diffraction model) were not known, k_F has been taken as an adjustable parameter. Therefore it is interesting to see whether the values for k_F , deduced from R_0 in the free electron approximation, support the applicability of the Ziman-Faber theory to NiBSi alloys. We also wished to find out whether a clear correlation between R_0 and ρ or α exists.

The Hall resistivity (at liquid nitrogen and room temperature), the electrical resistivity and the room temperature coefficient of the resistivity were measured for ten amorphous NiBSi alloys with the metalloid concentration ranging

from 20 to 39 at%. The alloys were prepared by the melt-spinning technique /4/. The samples were ribbons about 1,5-2 mm wide and on average 24 μm thick. The largest error in the Hall resistivity arises from the uncertainty in thickness and it amounts to about 5 %. The actual measurements were performed using the standard DC technique.

All our alloys are parramagnetic and the Hall resistivity is a linear function of magnetic field. The values for R_o , for the particular alloy, at liquid nitrogen and room temperature are the same. This indicate that there is no anomalous magnetic contribution to the Hall effect in our alloys.

The values for R_o , ρ and α for all NiBSi alloys are listed in Table 1. In figure 1 we plotted the values for α and R_o as a function of electrical resistivity. As expected α decreases with increasing resistivity and changes sign for $\rho \geq 140 \mu\Omega\text{cm}$. We note that the Hall coefficient also decreases strongly with increasing resistivity.

TABLE 1

Concentration			$-R_o$	ρ	α	n_a	$2k_F$	n_m
Ni	B	Si	$(10^{-10} \text{m}^3 \text{A}^{-1} \text{s}^{-1})$	$(\mu\Omega\text{cm})$	(10^{-4}K^{-1})		(10^{-10}m^{-1})	
80	18	2	1.00	83	1.80	0.65	2.46	0.85
80	15	5	0.93	87	1.80	0.71	2.52	1.15
80	10	10	0.88	85	1.70	0.76	2.56	1.40
78	12	10	0.74	89	1.35	0.89	2.72	1.92
75	20	5	0.76	97	1.20	0.82	2.68	1.48
75	15	10	0.70	95	1.10	0.91	2.76	1.84
75	10	15	0.70	110	1.00	0.93	2.76	1.92
67	33	0	0.50	122	0.22	1.13	3.10	2.21
67	22	11	0.49	138	0.00	1.21	3.12	2.43
61	39	0	0.45	160	-0.22	1.17	3.20	2.06

Data for NiBSi alloys: R_o , ρ , α , the number of conduction electrons per atom n_a , k_F and the number of electrons that the metalloid atoms possibly contribute to the conduction band n_m .

In order to explore in more detail how the transport properties of our alloys depend on the metalloid concentration we plotted in figure 2(a) and 2(b) α and R_o as a function of silicon to the total metalloid content ratio. From these figures it can be concluded that, for fixed silicon to boron ratio, both α and R_o decrease with increasing total metalloid content as well as that,

for fixed nickel concentration, both α and R_0 decrease if boron is substituted by silicon.

Having assumed that the use of the free electron model for the description of the electrical transport in our Ni-metalloid alloys is justified /5/ we calculated from R_0 the number of electrons per atom n_a . The results are given in Table 1 and figure 2(c). We see that n_a increases with increasing metalloid concentration and, for fixed nickel concentration, with increasing silicon concentration as would be expected from the valencies of boron and silicon in a simple charge transfer model.

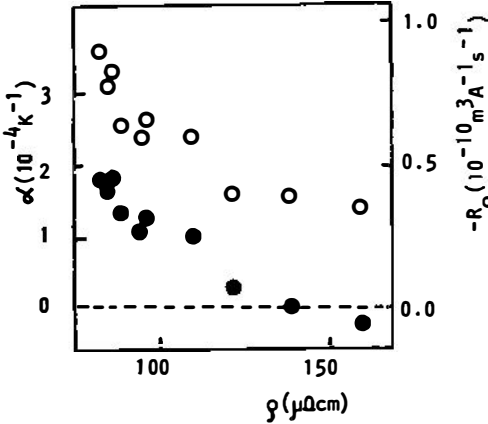


Fig.1. R_0 and α as a functions of the resistivity in amorphous NiBSi alloys listed in Table 1.

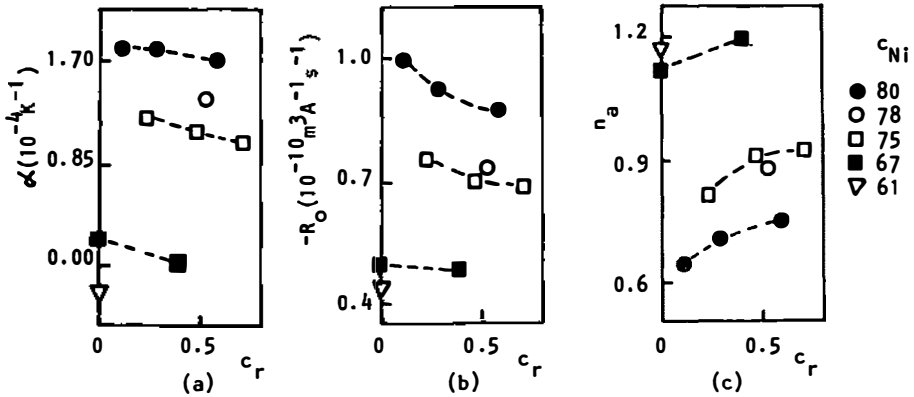


Fig.2. α (a), R_0 (b) and a number of the conduction electrons per atom n_a (c) as a function of silicon to the total metalloid content ratio c_r . c_{Ni} is nickel concentration.

From the conduction electron density we also calculated the values of the Fermi wave vector k_F (Table 1). The concentration dependence of k_F is similar

to that of n_m (fig.2(c)). $2k_F$ increases from $2.46 \cdot 10^{-10} \text{ m}^{-1}$ in $\text{Ni}_{80}\text{B}_{18}\text{Si}_2$ alloy to $3.20 \cdot 10^{-10} \text{ m}^{-1}$ in $\text{Ni}_{61}\text{B}_{39}$ alloy. At the same time the position of the first peak k_p in the static structure factor $S(k)$ of amorphous Ni-metalloid alloys is practically independent of the concentration in this concentration range /6/ and amounts to $3.0\text{-}3.2 \cdot 10^{-10} \text{ m}^{-1}$. From the above we can conclude that the dependence of the resistivity and of the temperature coefficient of the resistivity on composition in amorphous NiBSi alloys can be interpreted in terms of Ziman-Faber theory. In agreement with this theory the resistivity increases with increasing k_F and a negative temperature coefficient of the resistivity above the Debye temperature occurs when $S(2k_F) > 1$ i.e. when $2k_F$ approaches k_p .

Furthermore we estimated what is the number of electrons (if the simple picture of the charge transfer is assumed) that the metalloid atoms contribute to the conduction band. For this estimate we have assumed that the number of conduction electrons that comes from nickel is equal to 0.6 electrons per nickel atom. The number of electrons that the metalloid atoms contribute to the conduction band n_m is listed in Table 1. We note that n_m increase significantly with increasing metalloid or silicon concentration. Such composition dependence of n_m may indicate that as the d-band is being filled, more electrons from the metalloid atoms enter the conduction band.

In conclusion, a correlation between R_o , ρ and α in amorphous NiBSi alloys have been found. The values for k_F (deduced from R_o in the free electron model) are consistent with the interpretation of the electrical resistivity of Ni-metalloid alloys in terms of Ziman-Faber theory. We also note that the number of the conduction electrons in these alloys significantly increases with increasing metalloid concentration.

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