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THE EFFECT OF Fe IMPURITIES ON SUPERCONDUCTING AND MAGNETIC PROPERTIES OF Nb-Ga ALLOYS WITH A15 STRUCTURE

J. Sosnowski, M. Drys, T. Mydlarz, and M. Horobiowski

Institute for Low Temperature and Structure Research Polish Academy of Sciences, Wroclaw

Abstract. Measurements of the critical temperature $T_c$, normal state magnetic susceptibility $\chi$, magnetization curves at 4.2 K and upper critical field temperature dependence $H_{c2}(T)$ have been done on the alloys $\text{Nb}_y\text{Ga}_{100-y-x}\text{Fe}_x$ ($y=75, 78, 80$ and $0 \leq x \leq 10$). Magnetic susceptibility follows the Curie-Weiss law with the negative value of $\Theta$. $H_{c2}$ has been estimated using magnetization curves. The temperature dependence of $H_{c2}(T)$ has been interpreted on the basis of Maki's theory.

Magnetic impurities have a strong influence upon superconducting parameters because of Cooper's pair-breaking effect in the process of spin-flip scattering. Apart of a critical temperature $T_c$ lowering effect, there may also occur Jaccarino-Peter's effect /1/, causing the increase of the critical field $H_{c2}$. The influence of magnetic impurities on the superconducting properties of the A15-type compounds have been investigated among others in /2,3/.

In this paper we report the results of our investigations on the superconducting and magnetic properties of $\text{Nb}_y\text{Ga}_{25-x}\text{Fe}_x$, $\text{Nb}_7\text{Ga}_{22-x}\text{Fe}_x$ and $\text{Nb}_{50}\text{Ga}_{20-x}\text{Fe}_x$ alloy, where $0 \leq x \leq 10$. The samples, weighing about 1.5 g, were obtained by arc melting in purified argon atmosphere and by subsequent annealing at 700°C for 50 h. X-ray analysis showed, that besides of the main phase A15, the small amounts of sigma phase and/or $\text{Nb}_5\text{Ga}_3$ phase were present. The results of $T_c$ measurements for arc-melted and annealed samples are shown in Figure 1. We observed a considerable decrease of $T_c$ with rising Fe content. The values of $\Delta T_c/\Delta x$ were: 0.8, 0.9 and 1.2 K/at. % Fe respectively for samples with 75, 78 and 80 at. % Nb. After the annealing at 700°C they change to: 1.05, 1.6 and 2.8 K/at. % Fe. The annealing increases $T_c$ values and reduces the scatter of experimental points.

The magnetic susceptibility measurements in the temperature range of 15-300 K were performed using a string magnetometer /4/. The results are shown in Figure 2. The magnetic susceptibility follows the Curie-Weiss law with the negative $\Theta$ value, what indicates the antiferromagnetic type of interaction. We observed a gradual increase of magnetic moment with Fe concentration. Not to large changes of magnetic susceptibility with Fe content suggest that only a small part of all Fe atoms retains their magnetic character in $\text{Nb}_y\text{Ga}_x$. This depends probably on the position of Fe atoms in the crystalline lattice with is suggested in Reference /2/.

Similar conclusions can be drawn after analysing the $T_c(x)$ dependence. In Figure 1 the dashed line indicates the dependence of $T_c(x)$, as predicted by Abrikosov-Gorkov theory /5/, fitted to experimental points for the arc-melted samples $\text{Nb}_{78}\text{Ga}_{22-x}\text{Fe}_x$. Although the fitting is good the small value of $\lambda_{AG}$ characterising pair-breaking interaction, suggest a small number of magnetically active Fe atoms as compared to their total number. We must however keep in mind that this conclusion is correct only neglecting the influence of nonmagnetic Fe atoms on superconducting properties. After the annealing of samples the character of the $T_c(x)$ dependence has been...
changed especially for the smallest Fe contents, where the $T_c(x)$ curves go steeply upward (Figure 1).

**Fig. 1:** The dependence of $T_c$ on Fe concentration for the arc-melted /x/ and annealed at 700°C for 50 h samples Nb-Ga-Fe /o/. The dashed line represents the predicted AG-values.

The results of magnetization measurements at 4.2 K for the Nb$_78$Ga$_{22-x}$Fe$_x$ alloys annealed at 700°C for 50 h are shown in figure 3. We observed the decreasing irreversibility of magnetization curves with increasing Fe content, what suggests the lowering of critical current density. For hard superconductors like the Nb$_3$Ga, it is difficult to obtain accurate values of $H_c$ from magnetization measurements. An accurate analysis of the shapes of curves permits only approximately determine the value of the magnetic field; in which first deviation from the ideal diamagnetism occurs.

**Fig. 3:** The magnetization curves of the Nb$_78$Ga$_{22-x}$Fe$_x$ samples annealed at 700°C for 50 h.

The obtained value of 0.2 kOe is in good agreement with that calculated from the equation:

$$H_{c1} = \frac{\frac{\phi_0}{4\pi^2} \ln \frac{\mu}{0.08}}{H_{0}} = 0.212 \text{ kOe}$$

where the values of penetration depth $\lambda$ and of GL-parameter $\kappa$ have been taken as equal to that for the sample with 79.5 at. % Nb /6/. The temperature dependence of $H_{c2}$ is shown in Figure 4 in reduced scale $T_c/T_{c0}$ ($T_{c0}$ is the critical temperature of a sample without Fe). The full lines represent the values of $H_{c2}$ calculated on the basis of Maki's theory /7,8/.

**Fig. 4:** The temperature dependence of $H_{c2}$ for the Nb$_{78}$Ga$_{22-x}$Fe$_x$ samples annealed at 700°C for 50 h. The full lines represent the values of $H_{c2}$ calculated according to /6,7/.

In calculation of $H_{c2}$ the Pauli's paramagnetism of conduction electrons (parameter $a$) and spin-orbit interaction (described by $\lambda_{so}$) were taken into account. The calculated values of $H_{c2}(a)$ are higher than 200 kOe for the samples with $x<1$. 
References


/7/ Maki, K., Physics 1 (1964) 127

/8/ Hake, R.R., Phys Rev. 158 (1967) 266.