Effect of radiation-induced defects on the high-field magnetoresistivity of compensated transition metals

V.V. Marchenkov [a,b,1], V.E. Arkhipov [a], H.W.Weber [c]

[a] *Institute of Metal Physics, Kovalevskaya Str. 18, 620219 Ekaterinburg, Russia*
[b] *International Laboratory of High Magnetic Fields and Low Temperatures, Gajowicka 95, Poland*
[c] *Atomic Institute of the Austrian Universities, Stadionallee 2, A-1020 Vienna, Austria*

Abstract

The radiation-induced defects, produced in tungsten and molybdenum single crystals by electrons (E = 5 MeV), protons (E = 20 MeV) and krypton ions (E = 305 MeV), were studied both by magnetoresistivity and by field-ion microscopy. The magnetoresistivity was measured before and after irradiation. We show that the radiation-induced defects strongly affect the high-field magnetoresistivity which can be used to obtain new information about the radiation-induced defects.

Key words: Radiation-induced defects; Magnetoresistivity; Tungsten and Molybdenum

1. Introduction

It is known that the irradiation with high-energy particles produces various defects in metals and, therefore, changes their physical properties [1]. As for effect of the irradiation-induced defects on the electron transport properties of metals, this was studied to date only for the residual resistivity and its temperature dependence measured in zero magnetic field (see, e.g., [1]). The contribution from radiation-induced defects to the total electrical resistivity is low in comparison with the other contributions. Moreover, the absolute value of the residual resistivity of pure metals is very low. This leads to some experimental difficulties upon electroresistivity measurements and the error of determining the contribution of radiation-induced defects increases. Studies on the effect of irradiation and radiation-induced defects on the high-field magnetoresistivity are scarce [2].

The aim of this work is to show the substantial effect of radiation-induced defects on the transverse magnetoresistivity of pure compensated transition metals at low temperatures and high magnetic fields.

2. Experimental

The single-crystal samples for the investigation were spark-cut from a "massive" tungsten and molybdenum ingots with a residual resistivity ratio $\rho_{293K}/\rho_{4.2\mathrm{K}}$ of 80,000 and 30,000 respectively. The samples were irradiated by electrons (E = 5 MeV), fluence of $1\cdot 10^{18}$ el./cm^2, protons (E = 20 MeV), fluence of $3.8\cdot 10^{13}$ pr./cm^2, and heavy krypton ions (^{86}Kr$^+$ ions, E = 305 MeV), fluences of $5\cdot 10^{12}$ and $1\cdot 10^{15}$ ions/cm^2. The magnetoresisivity of these crystals was measured before and after irradiation. We measured the angular, field and temperature dependence of the transverse magnetoresistivity in a temperature range 4.2 - 80 K and in magnetic fields up to 15 T. The sample structure was studied with the universal field-ion microscope ITEF [3].

[1] Corresponding author. Present address: Institute of Metal Physics RAS, 620219 Ekaterinburg, Russia
E-mail: march@imp.uran.ru

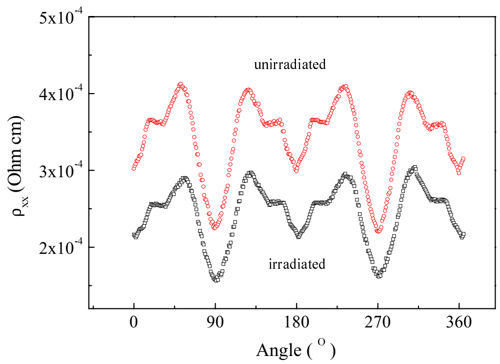

Fig. 1. Angular dependence of the magnetoresistivity for an unirradiated molybdenum crystal and for a sample irradiated by protons. T = 4.2 K. μ_0H = 10 T.

3. Results

Figure 1 shows the angular dependence of the magnetoresistivity $\rho_{xx}(\phi)$ for unirradiated molybdenum crystals and for molybdenum samples irradiated by protons. One can see the difference in ρ_{xx} for unirradiated and irradiated samples. The magnetoresistivity magnitude of the irradiated sample decreases. However, the form of $\rho_{xx}(\phi)$ for both samples is the same.

The tungsten crystals were irradiated by electrons. In this case a difference in $\rho_{xx}(\phi)$ for unirradiated and irradiated tungsten samples is larger. Firstly, the magnetoresistivity of the irradiated crystal decreases by an order of magnitude and even more in comparison with the unirradiated sample. Secondly, the shape of $\rho_{xx}(\phi)$ is changed. The radiation-induced defects also affect the magnetoresistivity magnitude in the field and the temperature dependence of ρ_{xx}. However, such defects do not change the form of ρ_{xx}(T) and ρ_{xx}(H).

The radiation damage, produced in tungsten and molybdenum samples by krypton ions, leads to a significant change in the magnetoresistivity. Such defects strongly affect the magnitude of ρ_{xx}, type of its angular, field and temperature dependence. Besides, the effects manifest themselves much more strongly in a magnetic field than without it. Figure 2 shows the changes in the residual resistivity ρ_0 without magnetic field at T = 4.2 K and the changes in the magnetoresistivity at T = 4.2 K in a field of 15 T as a function of krypton ion dose. To simplify a comparison of the results, the electroresistivity data are normalized by the electroresistivity of the unirradiated sample, and the magnetoresistivity data are normalized to the magnetoresistivity of the same unirradiated sample at T = 4.2 K in a field of 15 T. Large difference is observed, the effect being much more pronounced in the magnetoresistivity than in the electroresistivity.

A study of the sample structure shows the formation of the following three types of defects: single vacancies,

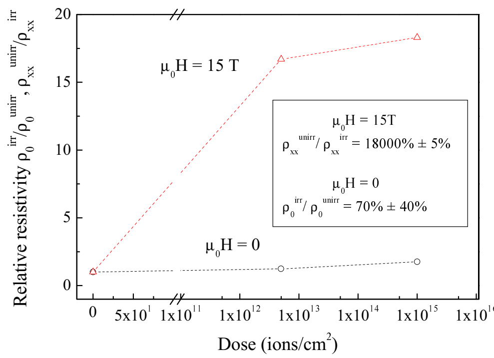

Fig. 2. Relative residual resistivity ρ_0 at T = 4.2 K and H = 0, and magnetoresistivity at 15 T and T = 4.2 K as a function of krypton ion dose. Electoresistivity data are normalized by the residual resistivity of the unirradiated sample ρ_0^{unirr}, and magnetoresistivity data by the magnetoresistivity of the same unirradiated sample in a field of 15 T and T = 4.2 K.

compact complexes of vacancies with a ratio from 2 to 10, and depleted zones with a volume up to $\sim\ 10^3\,\Omega_a$ (Ω_a is the atomic volume).

Thus, it has been shown that the radiation-induced defects, appearing in tungsten and molybdenum sinlge crystals after irradiation by electrons, protons and krypton ions, strongly affect the magnetoresistivity. We find that the magnetoresistivity is more sensitive to radiation-induced defects than the residual resistivity. The obtained results have demonstrated that the low-temperature magnetoresistivity of pure compensated transition metals can be used for studying these defects.

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