MAGNETIC SUSCEPTIBILITY MEASUREMENTS OF SOFT-MAGNETIC METALLIC GLASSES UNDER ION IRRADIATION

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1. Introduction

Soft-magnetic metallic glasses are considered for magnetic cores of accelerator radio-frequency (RF) cavities. In this particular application, they are exposed to ion radiation caused by the lost beam particles, which may alter their magnetic properties [1]. The spectrum of irradiating particles is rather complex (different particle species, energies and fluencies) because they origin from interaction of lost primary heavy ions with the beam-pipe wall. That is why a systematic study of the influence of ion irradiation on magnetic properties of the soft-magnetic metallic glasses is necessary.

Previous studies concentrated on light-ion part of the spectrum of irradiating particles, namely protons and nitrogen ions [2]. Unfortunately, the data obtained for light ions cannot be extrapolated to heavy ions, because the mechanism of radiation damage is qualitatively different for light vs. heavy ions [3]. That is why recent studies cover heavy-ion part of the spectrum, namely tantalum, gold and uranium. This paper presents the results of magnetic susceptibility measurements of VITROPERM® [4] irradiated with gold and uranium ions at two different energies. Results for VITROVAC® irradiated with tantalum and gold ions were presented at the APCOM2011 conference [5].

2. Experimental Details

VITROPERM®800 ($Fe_{73}Cu_1Nb_3Si_{16}B_7$) was irradiated by Au ions at 11.1 MeV/u and U ions at 5.9 MeV/u using the UNILAC accelerator at GSI Darmstadt. At these energies, the range is longer than the sample thickness (about 23 μm) [6] and all ions pass through the sample. Corresponding radiation damage profiles and ionization (electronic stopping) profiles are shown in Figure 1 and Figure 2 for 11.1 MeV/u Au ions and 5.9 MeV/u U ions, respectively. Irradiation fluences from 1.0×10^{11} ions/cm^2 up to 5.0×10^{12} ions/cm^2 were applied.

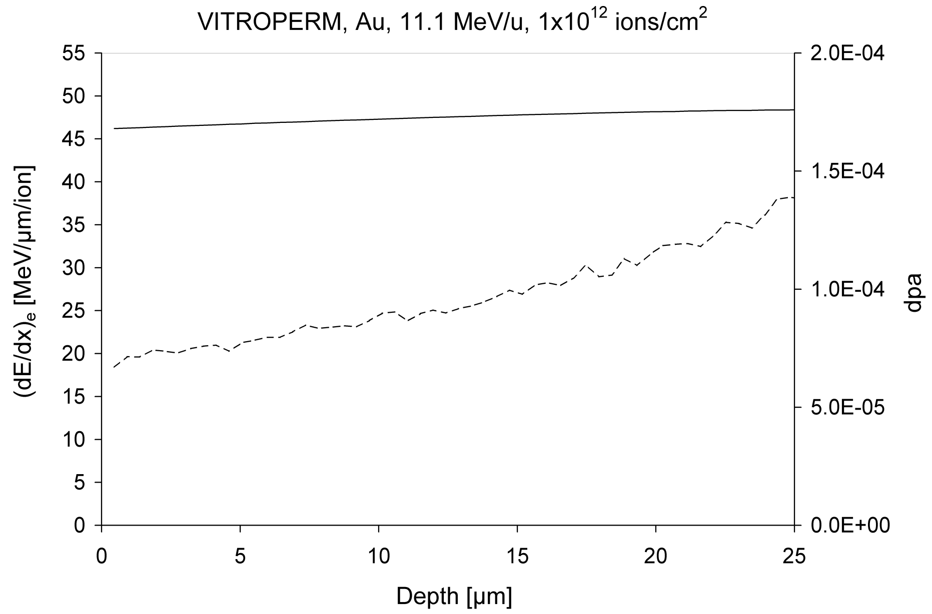

Fig.1: *Ionization (solid-line, left scale) and radiation damage (dashed-line, right scale) in VITROPERM irradiated by 1×10^{12} Au ions/cm^2 at 11.1 MeV/u as calculated with SRIM2010. Radiation damage is expressed in dpa = displacements per atom.*

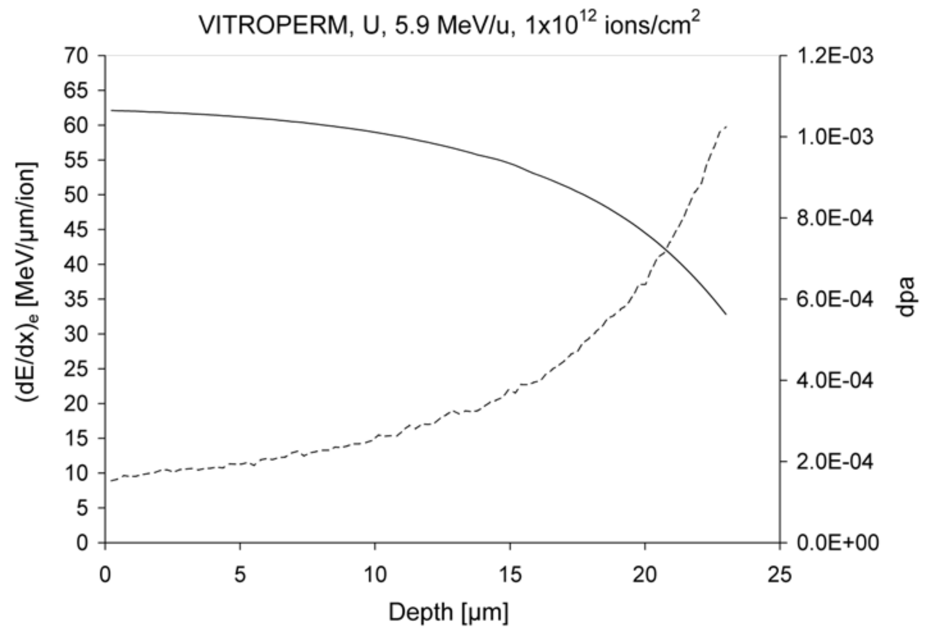

Fig.2: *Ionization (solid-line, left scale) and radiation damage (dashed-line, right scale) in VITROPERM irradiated by 1×10^{12} U ions/cm^2 at 5.9 MeV/u as calculated with SRIM2010. Radiation damage is expressed in dpa = displacements per atom.*

The samples were analysed by magnetic susceptibility measurements using Kappa-bridge KLY – 2 [7]. In order to measure relative changes of magnetic susceptibility before and after irradiation, the samples where glued on a special sample-holder allowing for susceptibility measurements as well as ion irradiation without any direct manipulation with the sample in-between. In this way, identical position of the sample in the Kappa-bridge before and after irradiation was guaranteed. The measurement is based on inductivity changes in a measuring coil due to the presence of the measured sample inside the coil. Figure 3 shows the principal scheme and view of the Kappa-bridge device. The samples were measured at 304 K and 307 K and the average from these two temperatures was taken as a representative value.

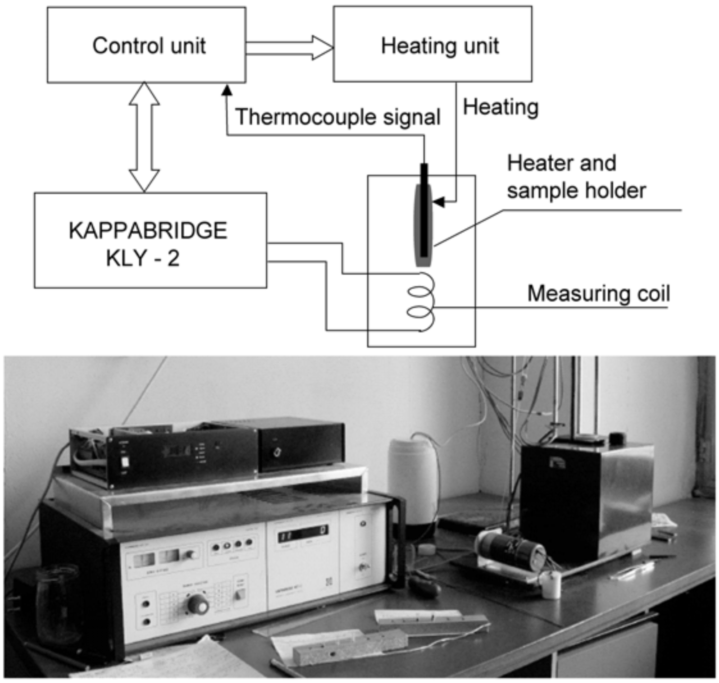

Fig.3: *Kappa-bridge principal scheme (upper) and photo (lower).*

3. Results, discussion and conclusions

Relative change of magnetic susceptibility as a function of irradiation fluence is shown in Figure 4 for Au ions at 11.1 MeV/u and U ions at 5.9 MeV/u.

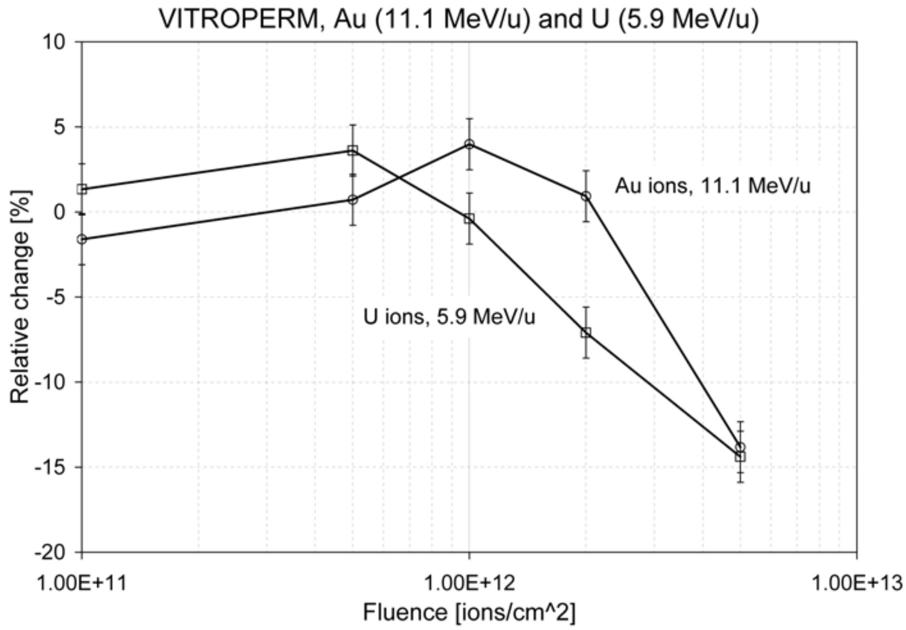

Fig.4: *Relative change of magnetic susceptibility as a function of irradiation fluence, VITROPERM. Circles = Au, 11.1 MeV/u, squares = U, 5.9 MeV/u.*

It can be seen that heavier ions start damaging the material at lower fluences compared with the lighter ones. The magnetic susceptibility starts decreasing at 5×10^{11} U ions per cm^2 whereas in case of Au ions, this fluence is 1×10^{12} ions/cm^2. It must, however, be noticed that the beam energy was different for these two ion species. That is why the results should better be compared with respect to the ionization density corresponding to the different ions. The ionisation density of Au ions at 11.1 MeV/u was 46 MeV/μm, the ionisation density of U ions at 5.9 MeV/u was 62 MeV/μm (both in VITROPERM, calculated by SRIM2010). At the same time, the radiation damage due to the elastic nuclear scattering is very low for both ion species (dpa $\cong 1\times10^{-4}$). This suggests that the main mechanism of radiation damaging for heavy ions is related to the electronic stopping and the ionisation density is a suitable parameter to scale / compare / predict radiation damage of materials caused by swift heavy ions.

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