EFFECT OF IRRADIATION ON THE STRUCTURAL PROPETIES OF IRON-CHROMIUM ALLOYS INVESTIGATED BY GIXRD

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1. Introduction

New generation of nuclear power plant requires more resistant reactor materials. The most perspective material for the new generation of fission reactors or the thermonuclear fusion reactor are currently chromium feritic/martensitic steels. Chromium is a ferrite-stabilizing element that is generally added to steels for oxidation and corrosion resistance.
This paper discusses properties of Fe-Cr binary alloys with high chromium (9 at.%) content and low (2.5 at.%) chromium content under radiation treatment.Different doses of helium (0.2 to 0.5 C/cm^2) up to $3x10^{18}$ cm^{-2} was used for simulation the neutron flux which create the well-defined implantation damage in near surface area. The fact that neutron bombardment creates interstitials and vacancies within the material gives rise to changes in the physical dimensions and the mechanical properties of the material when placed under stress. The helium implantation induces microstructural changes, which could give the origin of residual stress in implanted materials. The influence of residual stresses to mechanical properties have been observed. To investigation mechanical properties have been studied by X-ray diffraction. This paper has the objective to study the influence of chromium content and dose to residual stresses. For study well-defined implantation damage in near surface area was proposed GIXRD method. Our research was focused to investigation: the determination of stress, coherent domain size, and lattice parameter.

2. Sample preparation

Helium implantation at 250 keV energies and 4 different dose levels has been performed at the linear accelerator of the Slovak University of Technology in Bratislava. The accelerator has a possibility to accelerate ions in a wide energy range from 10 keV to 900 keV. High-energy implantation is performed in an extra vacuum chamber that is mounted on the 10 degree branch. Lower bending angle allows using heavier ions at higher energies compared to the 90 degree line. The high-energy implantation line consists of an entrance collimator, the switching magnet (10 degree branch), exit collimating slits, a beam diagnostic block and an implantation chamber (see Fig.1). The beam after passing the switching magnet is shaped by the exit collimating slits that define the size of the beam on the sample. The helium implantation was chosen due to participation of this element on the radiation damage of the structural materials during fission or fusion reaction. [1,2]

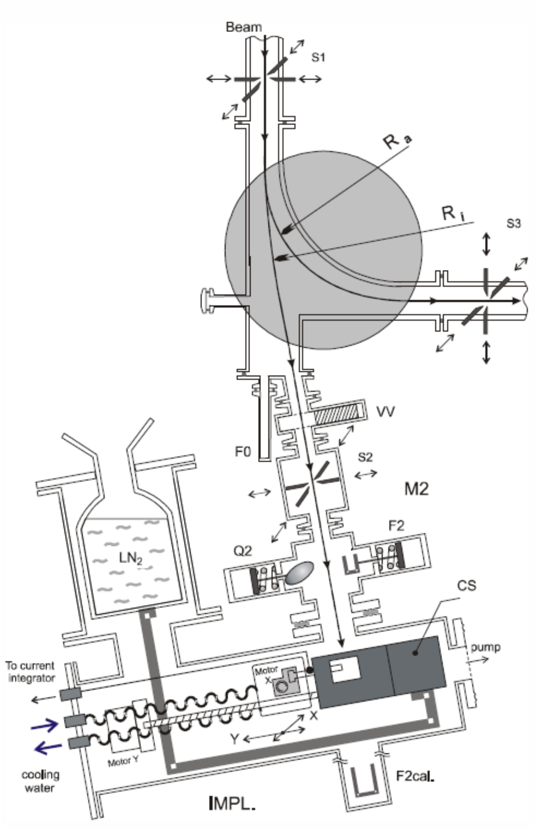


Fig.1:*Schematic view of the high-energy implantation line* [3]

3. X-ray setup

Diffraction measurements were performed in parallel beam geometry with parabolic Goebel mirror in the primary beam. Bruker D8 DISCOVER diffractometer was used with X-ray tube with rotating Cu anode operating at 12 kW. The measurement of the diffractogram is performed such that the angle α is kept constant, while the detector is moved along the 2θ circle.

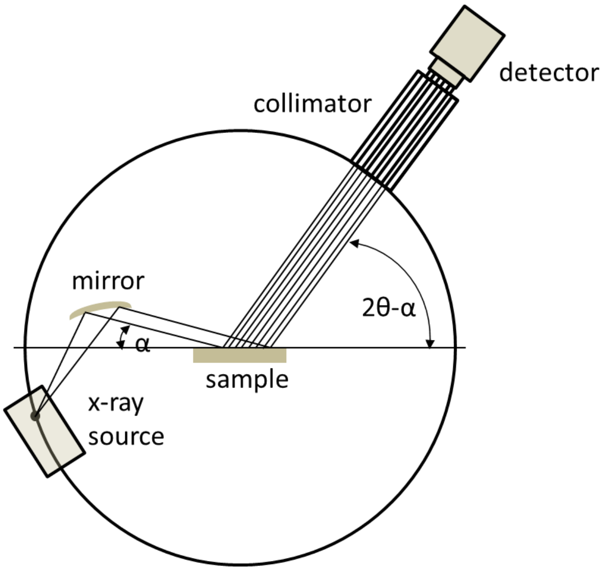


Fig. 2: *GIXRD configuration*

Fig. 2 display, now widely used, GIXRD configuration with parallel beam setup. This setup makes use of shaping the primary beam into a parallel bundle just after it leaves the x-ray source. This technique can be performed by laterally graded multilayer mirrors. [4]

For determination lattice parameter and coherent domain size we used software TOPAS.The strain $\varepsilon_{\varphi\psi}$(hkl) can be determined from a change in the interplanar spacing $d_{\varphi\psi}$ of the diffracting planes (hkl),

$$\varepsilon_{\varphi\psi}\,(hkl) = \frac{d_{\varphi\psi} - d_0}{d_0} \tag{1}$$

where d_0 is the interplanar spacing of the unstrained material. The strain results can then be converted into stress using a suitable value of the stiffness (elasticity).The strains are generally represented in so-called $\sin^2\psi$ plots (plots of the strain versus $\sin^2\psi$).[5]

4. Results

Study of the influence of the chromium concentration on the changes properties, two Fe-Cr binary alloys with different Cr content have been investigated. XRD diffraction results show that lattice parameter, coherent domain size, and residual macro stress correspond positron lifetime in the defects which correspond to the size of the vacancy type defects (vacancy clusters) is increasing with the implanted dose in all specimens. [6]

XRD measurements were performed in two angle of incidence: 1.5° and 2° which correspond depth of penetration approximately 0.2 and 0.303 micrometres, in figures are showed in red and black. Blue curve represent positron lifetime in defects. For 250 keV He is maximum damage area about 0.5 micrometres. Therefore, black curve in graphs it is close to maximum damage.

Fig. 3 and 4 display dependence lattice parameter on the dose which we compared with result from [1] where authors investigated positron lifetime in defects.

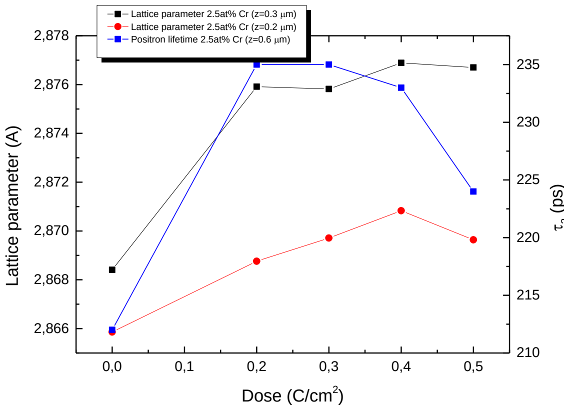


Fig. 3 *Dependence lattice parameter on the different dose for sample with 2.5 at.% Cr*

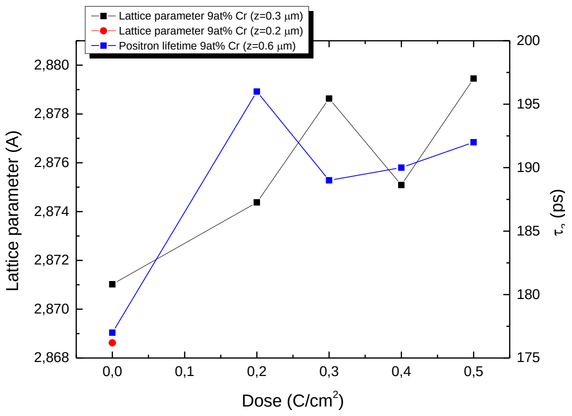
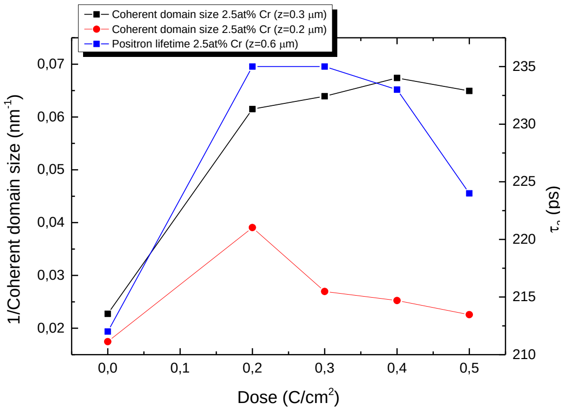


Fig. 4 *Dependence lattice parameter on the different dose for sample with 9 at.% Cr*



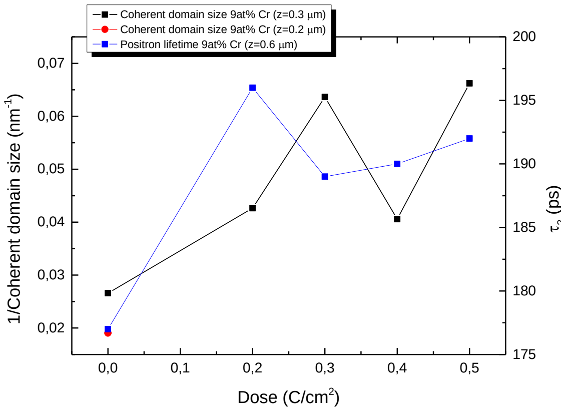
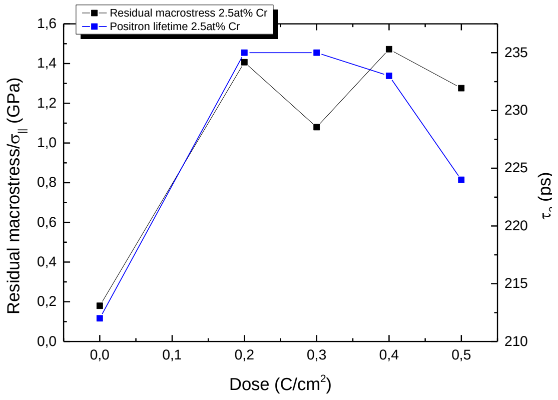


Fig. 5 *Dependence coherent domain size on the different dose for sample with 2.5 at.% Cr*

Fig. 6 *Dependence coherent domain size on the different dose for sample with 9 at.% Cr*

Fig. 5 and 6 show change 1/coherent domain size on the dose which again is compared with positron life time.



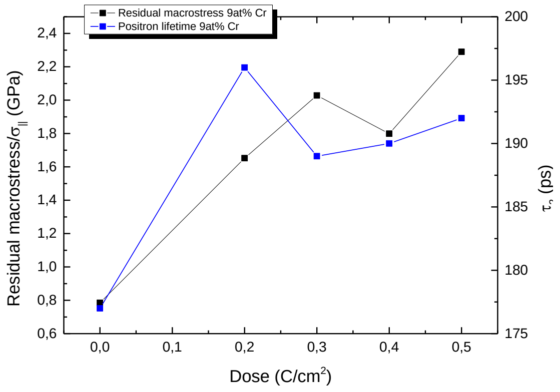


Fig. 7: *Dependence stress on the different dose for sample with 2.5 at.% Cr*

Fig. 8: *Dependence stress on the different dose for sample with 9 at.% Cr*

Fig. 7 and 8 display increasing macro stress with implanted dose which more or less correspond positron life time in defects. This increasing of the residual macro stress has significantly effect on the quality of Fe-Cr alloys.

5. Conclusion and discussion

The main objective of this work was to compare two Fe-Cr alloys with high and low chromium content under different helium implantation doses. XRD determination of structure parameters has been performed for He implanted Fe 2.5 and 9at% Cr. The depth dependence of lattice parameter, coherent domain size is observed for both specimen, it correspond to inhomogeneity of He implantation profile. Similar dose dependence of lattice parameter, inverse coherent domain size and positron lifetime in defect was found. Level of residual macrostress increases due He implantation. However, for better correlation we must continue in the measurements and increase depth of penetration more close to maximal damage profile of helium.

Acknowledgement

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