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Investigation of Impact of Neutron Irradiation on Properties of InSb-based Hall Plates

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Introduction

All diagnostics in future fusion reactors will face harsh radiation environment significantly more demanding compared to the present day devices. Moreover, all used diagnostics have to survive reliably for very long time, e.g. *20* years. We studied impact of neutron irradiation on properties of InSb based Hall sensors which are candidate steady state magnetic field sensors needed for ITER tokamak [1]. Effect of neutrons on material can be divided in two parts. Fast fusion neutrons (about *14 MeV*) mainly damage the inner structure of the material. This damage can be partially retrieved by annealing by elevated temperature. At second, slow neutrons with energy bellow *0.1 MeV* mainly cause transmutation of atoms. Transmutation cannot be retrieved by any process, but can be reduced by shielding of the sensors from these slow neutrons by materials with high cross-section for neutron capture, e.g. cadmium, boron, etc. Expected neutron flux density on ITER tokamak, assumed for the probes placed at outer side of the ITER vacuum vessel, is up to $7.71\times10^{10}\ n/cm^2s$ and total fluence of neutrons after *4700* hours of operation will be up to $10^{18}\ n/cm^2$.

Irradiation

Hall sensors, compatible with elevated temperature up to $300\ ^oC$, based on *InSb* layer deposited on crystal of Al_2O_3 (corundum) and *AlN* were prepared in Poznan University of Technology [2]. Some of the samples were shielded by *CdTe/InSb* plates to assess effect of reduced transmutation. All the Hall sensors together with samples of the *InSb* layers, array of activation foils, and aluminium cylindrical filling were inserted in aluminium container, and irradiated in the reactor LVR-15 in Nuclear Research Institute in Řež on 12th December 2008. The container with samples in the reactor channel was cooled by water with temperature of $45\ ^oC$. Samples were irradiated for *30* minutes at average neutron flux density of $\varphi=6.22\times10^{13}\ cm^{-2}s^{-1}$, reaching the total neutron fluence of $1.12\times10^{17}\ cm^{-2}$. The irradiation channel had no shielding on the sides of the channel. Therefore, the energetic spectrum of the neutrons was practically the spectrum of the fission reactor. For the fusion application, it is important the ratio of number of neutrons with energy higher than *1MeV* and lower than *0.1 MeV*. This ratio was about *0.0458* during this experiment.

Physical properties of Hall sensors before and after the irradiation

Visual inspection of sensors after irradiation revealed significant radiation induced changes on *InSb/CdTe* shields, see Fig.1. The shields completely darkened showing signs of partial melting of the surface layer. Input and output resistances, sensitivity, and an offset voltage of the Hall sensors were measured before and after the irradiation. Table 1 gives the measured values of these properties for one of the sensors as an example. Data for remaining sensors are fairly similar. Additionally, there are values of free charge carrier density *n* and free charge carrier mobility μ computed as:

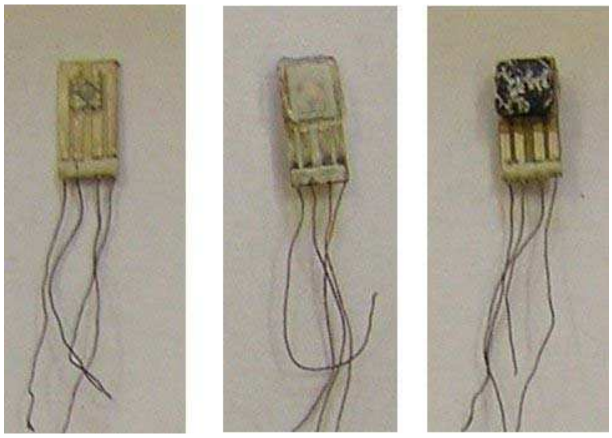

Figure 1: Left panel – bare Hall sensor before irradiation, middle panel – Hall sensor with sensing layer protected by InSb/CdTe glass shield, right panel – shielded Hall sensor after irradiation.

$$n = \frac{1}{et}\frac{I_H B}{V_H} \qquad \mu = \frac{l}{w}\frac{1}{R_{in}}\frac{V_H}{I_H B}$$

parameter	unit	before irr.	after irr.	change
R_{in}	Ω	8.11	8.80	8.4 %
R_{out}	Ω	7.06	7.77	10.1 %
offset	mV	0.239	0.726	0.487 mV
sensitivity	mV/AT	1616.05	1598.89	-1.1 %
n	10^{24} m^{-3}	4.30	4.34	1.07 %
μ	cm^2/Vs	4980	4540	-8,82 %

Table 1: Physical parameters of Hall sensor C2 (not shielded) before and after the irradiation.

All the values are the mean values from about *200* measurements each.

The radiation induced changes of parameters of the sensors are very small and comparable for shielded and unshielded sensors, so no apparent effect of the *CdTe/InSb* shielding was observed, see Fig. 2. On average, change of resistances is slightly higher for unshielded sensors. Effect of irradiation is possibly overridden by thermal effects. It was not possible to measure temperature of the samples during irradiation. Estimation of the irradiation temperature inside the container is complicated by very complex geometry of the container with *Al* filling and the samples themselves, complex material composition of the samples, and large uncertainty in the effective thermal conductivity between the *InSb* sensing layer and channel cooling water. Further, these conditions differ for each individual sample. Analysis of the thermal situation of the samples during the irradiation is on-going.

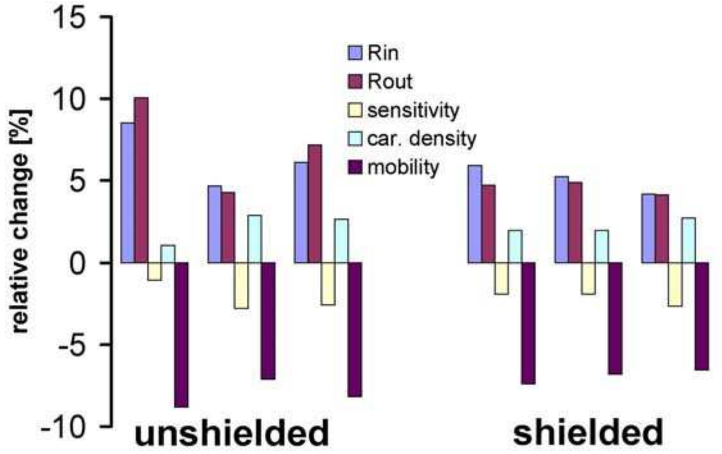

Figure 2: Comparison of relative change of physical parameters of the Hall sensors before and after the irradiation for shielded and unshielded samples.

Reduction of structural damage in *InSb* sensing layer of Hall sensors

Annealing of the sensors at temperature of 350 ^{o}C with duration of about 20 minutes was tested as a possibility for reduction of inner-structural damage. Temperature cycling lead to partial recovery of the sensitivity of the Hall sensors. CdTe/InSb shielding glass has almost no impact on results obtained from annealing, see Fig. 3.

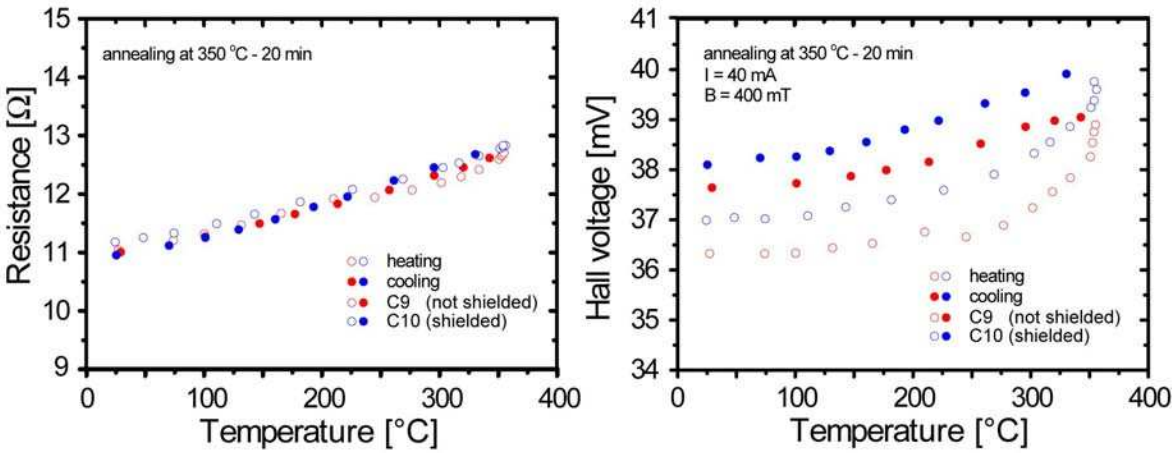

Figure 3: Impact of post irradiation annealing on sensors properties (left panel – Input resistance; right panel – Hall voltage for I_H=40 mA and B=400 mT).

Analysis of transmutation products from *InSb*

Probable amounts of some isotopes within the *InSb* sensing layer of Hall sensor, particularly tin and highly radioactive ones, produced by transmutation from *InSb* were calculated from the known fluence (achieved from measurement on activation foils) by FISPACT code.

Input parameters for calculation by FISPACT program are:

- time of irradiation: *30* minutes

- full neutron energetic spectrum for used irradiation channel of LVR-15 reactor
- neutron flux density: $6.22\times10^{13}\ cm^{-2}s^{-1}$

It was found out, that dominant process is production of ^{116}Sn from Indium with relative concentration 7.49×10^{-6}, and ^{122}Te and ^{124}Te from antimony with relative concentrations 4.75×10^{-7}, resp. 2.42×10^{-7}. Only these isotopes can significantly modify the physical properties of the sensitive *InSb* layer. The number of *Sn* and *Te* atoms produced by transmutation (FISPACT simulation) is similar to measured change of free charge carrier density *n* in the *InSb* sensing layer. Both values are in the order of 10^{11} particles.

Amounts of the *Sn* and *Te* isotopes will be also measured by mass spectroscopy on samples of layers of *InSb* and compared with the simulation.

Summary

Irradiation of Hall sensors, based on thin *InSb* layers and developed in Poznan Technical University, was performed in fission reactor LVR-15 in NRI in Řež. The sensors were exposed to neutron fluence of $1.12\times10^{17}\ cm^{-2}$ with fission-like neutron spectra. Part of the samples was shielded with *CdTe/InSb* glass in order to assess effect of transmutation on physical properties of the Hall sensors.

Input/output resistances, offset voltages, sensitivities, free charge carrier density, and charge mobility before and after the irradiation were measured. The radiation induced changes of parameters of the sensors are very small and comparable for shielded and unshielded sensors, so no apparent effect of the *CdTe/InS*b shielding was observed. Possibly, the occurred minor changes of sensors parameters are affected by elevated temperature during the irradiation rather than by the irradiation itself. The thermal situation of the Hall sensors during the irradiation is now under investigation.

Change of free charge carrier density is similar to values obtained from simulation of the transmutation of *InSb* sensing layer. Amounts of transmuted atoms will be measured by mass spectroscopy.

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References

[1] Bolshakova I., Ďuran I., Holyaka R., Hristoforou E., Marusenkov A., Performance of Hall Sensor-Based Devices for Magnetic Field Diagnosis at Fusion Reactors, Sensor Letters, 5 (2007), p.283-288.

[2] Oszwaldowski M., Berus T., High temperature Hall sensors, Sensors and Actuators A, 136 (2007) 234-237.