RADIATION RESISTANT MAGNETIC SENSORS FOR ACCELERATORS

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Abstract

Radiation resistance of semiconductor magnetic field sensors was stydied during the fast neutron irradiation up to high fluences of $10^{15}\div10^{18}$n·cm^{-2}.

It was shown that semiconductor sensors' characteristics on the basis of the materials developed according to the special technology, can be very stable in harch radiation conditions.

Magnetomeasuring devices created on such sensors' basis and possesing selfdianostics and selfcorrection, can be well used for mafnetic field monitoring with high accuracy 0.01÷0.1%.

INTRODUCTION

In the course of R&D works the technology of radiation resistance semiconductor materials for magnetic field sensors was developed and till now the stability of Hall sensors has been reached on 0.05% level under fast neutron irradiation up to the fluence of $3\cdot10^{16}$n·cm^{-2}. These results were obtained at IBR-2 reactor in Dubna in the course of the experiment on the direct measurement of sensors in process of irradiation.

For such experiment realization, a special magnetomeasuring system with high-precision measuring channels, possessing selfdiagnostics and selfcorrection functions, was created.

In this work, the results of microsensors investigation are presented, which were obtained during this experiment that lasted 3 months in 2003. There are presented the principles of the magnetic field monitoring system functioning as well.

The results of such sensors' testing were recently, in June 2004, obtained at even higher fluences of $1.1\cdot10^{18}$n·cm^{-2} at LVR-15 reactor in Rez (Czech Republic): all the tested sensors remained operable and the sensitivity change of the best ones did not exceed 6-7% [1].

EXPERIMENT

The study, performed earlier, of radiation resistant semiconductor Hall sensors were indirect and included several stages: sensors measurement at laboratory, irradiation in reactor, then the measurement at the laboratory again[2,3,4].

At this, the "quarantine" time after the irradiation depended on the radiation dose and lasted from one to several days for low doze, and in case of high radiation dozes – up to several months. During such a long term, different relaxation processes might occur in the samples, which are called "defects annealing" in radiation physics. For the indium antimonide semiconductor material under the investigation used for highly sensitive magnetic field sensors, the annealing of radiation defects may occur even at the room temperature because of small value of band gap width.

Therefore the information about the behavior of semiconductor material properties directly under their irradiation is very important for radiation resistant devices creation, as well as for radiophysical processes understanding, which occur in the material under the influence of high energetic neutrons.

The direct investigation of the influence of fast neutrons onto the semiconductor material of magnetic sensors sensitive elements has been carried out in the channel of Fast Pulsed Reactor IBR-2 at Joint Institute of Nuclear Research in Dubna (Russia). The experiment lasted for 90 days. The reactor operation mode is shown in Fig. 1.

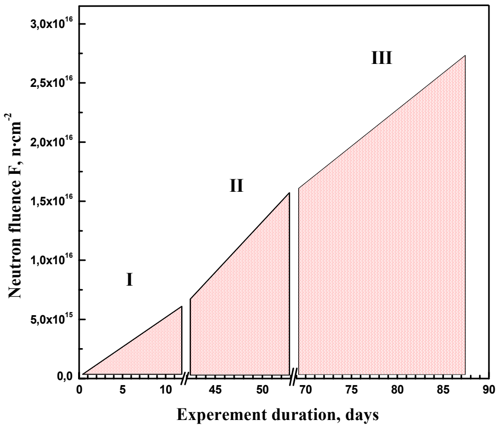

Fig.1. The operating mode of neutron reactor during the experiment.

During the first session of the reactor operation, the samples under the investigation were irradiated up to the fluence of $\Phi_1=7{,}4\cdot10^{15}$n·cm^{-2} till the end of II session – up to the fluence of $\Phi_2=1{,}0\cdot10^{16}$n·cm^{-2} and till the end of the III session – up to the fluence of $\Phi_3=3{,}1\cdot10^{16}$n·cm^{-2}. Average reactor neutron energy was equal to E=1.5 MeV, the portion of thermal and intermediate neutrons in total neutron flux in the experiment presented was equal to 20% and 25% respectively of the integral fast neutron flux.

There were investigated structurally perfect microcrystals in the form of whisker and usual thin InSb films. The investigated samples were placed in the gap between the poles of permanent magnet and together with the magnet were placed into the nuclear reactor channel. They were connected by the special cable with the measuring facility, being situated at 30 meter distance from the channel reactor. By this cable the feed current for samples was supplied and the signals of hall voltage were transmitted from the samples to the measuring facility.

Such experiment with the magnetic field source and Hall samples allocation in the neutron reactor channel was performed for the first time. It became possible due to the specially created magnetomeasuring MMS1 facility, being able to extract, to amplify and to protect from noises and to transfer the weak signals for a long distances, which are generated by hall voltage magnetic field in the miniature samples.

In a MMS1 magnetomeasuring facility, the special noise resistant methods for signal processing, which are based on the synchronous detection [5], are used. The developed facility is multifunctional. It provides the measurement accuracy of 0,01% of those parameters' changes that occur in the investigated samples during the neutron exposure. Besides, it allows controlling the temperature in the zone of samples' allocation with the accuracy of 0,1°C. It also allows periodically controlling the possible changes of induction of permanent magnet, being placed in the neutron reactor channel under the influence of fast neutrons flux. For this purpose the testing measuring method is used, with which the Hall sensor, placed between permanent magnet poles, measures by turns the magnetic fields of permanent magnet and actuating coil, which is formed on the cylindrical poles of permanent magnet and is fed by alternating current. As a result of the appropriate processing of the obtained results the drift of pole of the permanent magnet is calculated, which can take place while the fast neutrons exposure onto the permanent magnet material. In this case within the limits for experiment accuracy the permanent magnet pole, made of $SmCo_5$, did not practically change during the experiment as far as obtained maximal dose of irradiation of $3.1\cdot10^{16}$ $n\cdot cm^{-3}$.

The record of measurements' results, as well as correction of measuring device functions was performed in automatic mode. Only for three months of experiment there were performed more than 300.000 measurements, their results were transferred via Internet to the laboratory. During the whole long-term period of experiment the facility was operating without failures. Moreover thanks to the high sensitivity of measuring channels, the facility noted the failures, occurred while reactor operating.

RESULTS

Among 6 samples under investigation, three , labeled 1, 2, and 3, were manufactured from discrete monocrystalline whiskers with initial carrier concentration of $n_1=8,6\cdot10^{16}$, $n_2=6,4\cdot10^{17}$, and $n_3=9,7\cdot10^{17}$, respectively. The other three, labelled 4, 5, and 6 belonged to film InSb samples with a carrier concentration of $n_4=3,0\cdot10^{18}$, $n_5=7,5\cdot10^{17}$, and $n_6=3,4\cdot10^{17}$, respectively. The level of electron concentration in each sample was regulated by the introduction of an amount of major impurity Sn. The other impurity complex added, i.e., Al and Cr, played the role of getters for background impurities and radiation defects drains.

The results of measurement related to sensor sensitivity change under irradiation are shown in Fig. 2, where the experimental points representing numerous measurements (about three hundred thousands) are merged in solid lines on a given scale.

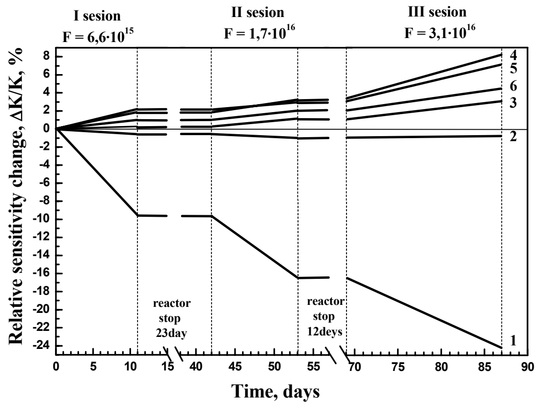

Fig. 2. The relative sensitivity change of sensors based on whiskers (curves 1,2,3) and based on films (curves 4,5,6) of InSb under the neutron irradiation (direct measurements).

From the analysis of the measurement results shown in Fig.1, it follows that sensor 2 is the most stable during whole fluence interval. The initial electron concentration in this sample is $n_2=6,4\cdot10^{17}cm^{-3}$. Up to the neutron fluence of $3,1\cdot10^{16}n\ cm^{-2}$, the change in its sensitivity did not exceed 1% relatively to the initial value, and at the fluence of $1\cdot10^{15}n\ cm^{-2}$, it amounts to only 0,05%.

The stability of the film sensors with an electron concentration being close to the optimal one for whiskers, is considerably worse: at the same concentration at a fluence of $3,1\cdot10^{16}$ $n\cdot cm^{-2}$, their sensitivity has changed by approximately 7%. It may be possibly caused by the structure defects, as thin films following the way of development present more defects than whiskers monocrystals, obtained during a free crystallisation from gas phase.

During reactor stops in between irradiation sessions, the facility continued to perform measurements during the next several days in order to find out if sensors characteristics were affected by relaxation after the irradiation.

The results of the measurements showed, that the characteristics of sensors based on whiskers do not relax at all after the reactor stop (Fig.3).

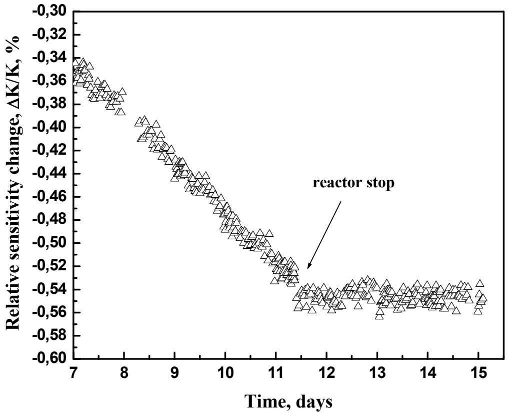

Fig. 3. The log fragment of time dependence of relative sensitivity change of crystalline sensor (whisker 2) at the end of 1st irradiation session and during the 1st reactor stop.

Some relaxation could be observed in film samples after the reactor stop (Fig.4).

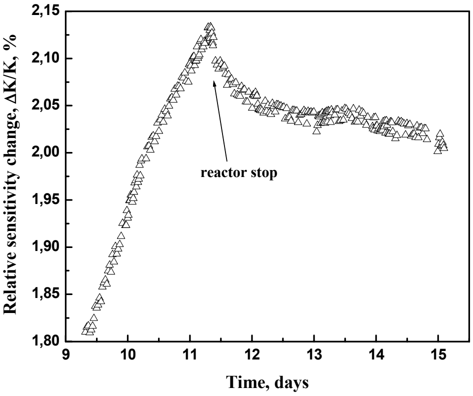

Fig.4. The record fragment of time dependence of relative sensitivity change of film sensor (sample 5) at the end of 1st irradiation session and during the 1st reactor stop.

In Fig.5, is shown the fragment of measurement of a sensor on the other scale. One can see that the accuracy of the facility measuring channels is very high and amounts to ±0,01%. Such high measurement accuracy allowed us to state even short-term power discharges of the reactor, one of which can be seen in this figure.

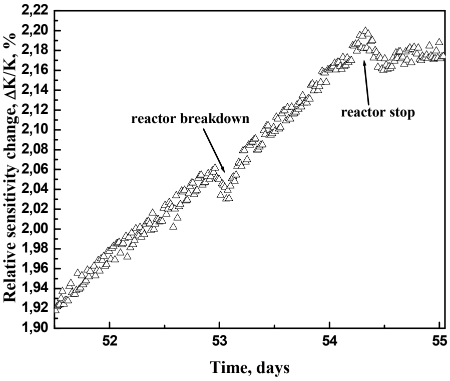

Fig. 5. The fragment of time dependence of relative sensitivity change of film sensor (sample #6) sensitivity during the 2nd irradiation session and reactor breakdown

CONCLUSION

The direct measurement of semiconductor magnetic sensor characteristics was performed for the first time during the fast neutron exposure in the reactor channel.

It was shown that the semiconductor sensors can be very stable up to very high fluences $10^{15}\div10^{18}$n·cm^{-2} and can be used for magnetic field measurement in accelerators' radiation environment.

For magnetic field monitoring the special magneto-measuring system with measuring channels accuracy of 0.01%, possessing selfcontrol and selfcorrection functions was created.

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