RADIATION RESISTANT MICROSENSORS OF MAGNETIC FIELD

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Abstract

Radiation resistant microsensors of magnetic field based on the Hall effect are developed. The microsensor sensitivity change one month after exposure to fast neutrons (fluence $2\cdot10^{14}$ $n\cdot cm^{-2}$) is equal to 0.1% at the determination error of 0.03%. The works on further improvement of microsensor radiation hardness are directed to the optimization of the metallurgical doping technology and its combination with the nuclear doping of III-V semiconductor microcrystals. This enables one to improve the microsensor radiation hardness by one order and to use them for the magnetic field monitoring in accelerators under the real experiment conditions.

1 INTRODUCTION

Among the great number of magnetic measuring problems the ones which are featured with the high radiation level stand apart. The radiation hardness of available magnetic measuring devices does not meet yet the growing demands. That is why methods of rough estimation of the magnetic field induction are used at many objects till the present time that results negatively on the magnetic field parameter determination accuracy.

Besides, the number of specific research problems could not be solved with the typical industrial sensors and probes of magnetic field. Such are the measurements of strongly non-uniform magnetic fields complicated by the cryogenic temperatures, and so on.

Therefore, the customized magnetic field microsensors based on the Hall effect could be very useful in these cases.

2 CONSTRUCTION

The magnetic field microsensors are based on the discrete microcrystals of III-V semiconductor compounds. Method of obtaining the crystals allows one to get microcrystals with such dimensions that they could be the sensitive elements of microsensors without any processing [1]. Due to their good crystalline structure, sensors based on such crystals are featured by long-term stability.

The dimensions of sensitive elements $(0.05\times0.05\times0.02)$ mm^3 and $(0.15\times0.05\times0.03)$ mm^3 allow one to design miniature transverse and axial probes for measurements in gaps with <0.1 mm width and holes with <1 mm diameter [2].

Sensitive elements with dimensions $(10\times0.1\times0.05)$ mm^3 are used to fabricate multisensors. Multisensor is the line of 6 to 10 separate microsensors with 0.6 mm spacing, which are formed on one whisker. The separate microsensor sensitivity deviation from the mean value does not exceed 4%. Such multisensors are much more convenient than the mechanical coordinate shift systems, especially at the cryogenic temperature conditions. One can also develop the coordinate array for the determination of the spatial distribution of magnetic induction in small volumes of high-gradient magnetic systems, for instance in the undulator magnets.

3 CHARACTERIZATION

According to the semiconductor material type and the doping level the microsensors are obtained with the following parameters given in the Table 1: n - concentration, I - current, K_B - sensitivity, U_0 - residual voltage, D - dimensions.

Table 1 - Characteristics of magnetic microsensors

Material	InSb			GaAs
Type	IS-1	IS-2	IS-3	GA-3
Impurity	Te	Sn	Sn	Te
n, cm^{-3}	$2\cdot10^{16}$	$2\cdot10^{17}$	$2\cdot10^{18}$	$1\cdot10^{18}$
I, mA	8	20	40	100
K_B, mV/T	50	25	4	120
U_0, mV	0.2	0.1	0.05	0.1
D, mm^3	$(0.15\times0.05\times0.02)$			

The microsensors are capable to operate in the temperature range of from cryogenic one 4.2 K to 300 K, and the measuring range of the magnetic field induction is $10^{-4}\div12$ T. There is no saturation at the higher limit of the range. The temperature coefficients of sensitivity for different types of sensors are in the range of from 0.04 $\%\cdot deg^{-1}$ up to 1 $\%\cdot deg^{-1}$.

The radiation hardness of microsensors is achieved by means of microcrystal doping during growth. At the defined combination of the main dopant (Sn, Te) with rare-earth elements and special admixtures the materials for microsensors are obtained which, having been exposed to fast neutrons, do not change their sensitivity more than 0.1%. These data are collected in one month after the exposure to fast neutrons with the energy $0.1\div13$ MeV, fluence up to $2\cdot10^{14}$ $n\cdot cm^{-2}\cdot s^{-1}$ at the Pulsed Fast Reactor IBR-2 in JINR (Dubna, Russia) in February, 1998. The sensitivity change determination error was equal to 0.03%.

γ-quanta irradiation influence on microsensors does not exceed the measurement error. In several microsensors exposed to high-energy protons with energy 24 GeV and fluence up to 10^{14} $p\cdot cm^{-2}$ the sensitivity change is from 1% to 3% while the measurement error equal to 1.2%. These investigations continue.

Particular interest is paid to the microsensor parameter measurements directly under exposure and such experiments are planned to be carried out in the next year. This would allow one to optimize the technology of further improvement of radiation hardness of microsensors. And the gathered experience of numerous investigations on the irradiation influence upon the III-V semiconductor materials [3,4,5] evidences that magnetic microsensors designed by the specific technologies on the base of III-V semiconductors, could be capable under irradiation, in spite of certain changes of semiconductor sensitive elements under the irradiation. It is explained by the fact that the charge carrier concentration change after irradiation in such semiconductor materials could be minimized while the changes of their mobility are rather observable. As Del Medico et al. [6] argue, the charge carrier mobility influence upon the magnetic sensor parameters is the secondary factor, while the carrier concentration change which is inversely proportional to the sensitivity, is the factor defining the radiation hardness of magnetic sensors based on the Hall effect.

4 APPLICATION. CONCLUSIONS.

Radiation resistant magnetic microsensors could be used in magnetic measuring systems for the magnetic field monitoring in accelerators under the real experiment conditions.

The means of further improvement of their radiation hardness are as follows: the development of doping technology of semiconductor crystals and optimization of dopants, the combination of metallurgical doping with nuclear one, and the creation of technical basis for precise measurements. Having summarized all these factors, one can provide the radiation hardness of the magnetic field microsensors close to the value of 0.01 %. These rather high requirements are preferred at modern Large Hadron Collider-like (LHC) accelerators [7], in its detectors Compact Muon Solenoid (CMS) and ATLAS [8].

The investigations on the influence of γ-quanta and proton irradiation upon microsensor parameters continue.

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