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Influence of the High Dose Ion Implantation on Manganin Sensor Properties

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The simple resistance model for deeper interpretation of investigations of implanted flat elements, with well localized volume of high deposition of ions and structural defects, has been proposed. The influences of krypton and complex bismuth and krypton ions implantation to the manganin on its sensitivity to pressure has been investigated. Manganin specimens had foil type shape of 10 μm thick and of relatively large planar dimensions. The implanted dose of krypton ions was of 2.5×10^{15} Kr ion/cm^2 of energy of 245 MeV/ion and in the case of complex implantation for one side 2.5×10^{16} Bi ions/cm^2 and then both sides 2.5×10^{17} Kr ion/cm^2 and energy about 255 keV/ion. Implantation of high energy Kr ions gave only few percents changes of pressure sensitivity but for complex Kr-Bi implantation the increase of 25 % in mean pressure sensitivity of manganin have been observed. Using modelling of resistance properties of manganin specimen – as parallel electrically connected strong implanted and almost not implanted parts – it was possible to calculate the pressure coefficient of strong implanted part which appeared to be higher than those as for mean value by about 200 %. High dose implantation of Kr and Bi ions also remarkably change a temperature – resistance characteristic of manganin making it more convenient for use in temperature range close to room temperatures.

Keywords: high-pressure, manganin, implantation, Kr ion, Bi ion.

1. INTRODUCTION

The main application of manganin resistance alloy is construction of standard resistors [1]. From the beginning of passed age manganin is successfully used also in high-pressure measurement techniques [2]. Dependence of relative resistance on pressure of the specially constructed and prepared manganin pressure sensor is almost linear up to 2 GPa and changes with the pressure at the rate of about 2.5×10^{-5} MPa^{-1} (the sensor constant). Its main advantage in comparison to other metallic pressure sensors is its almost zero-sensitivity to temperature, at room temperatures and at normal pressure.

The tendency to increase the value of manganin pressure sensitivity and to conserve its low sensitivity to temperature after the Xe implantation was shortly reported in [3]. The influence Kr and Bi implantation on manganin (Cu86Mn12Ni2) properties was also a subject of more complete investigations described in [4]. Miniaturization of pressure sensor in diamond Bridgman anvils techniques requires that thickness of sensor is to be of order of 1 μm. It makes implantation techniques with energies in the range 300 keV/ion – 800 keV/ion sufficient for the modification of such a sensor characteristics.

Implantation is well establish technology mainly in semiconductors device production [5], but in metallic problems only very high dose and high energy implantation has any sense [6]. Modification of manganin properties using implantation technology, as presented by authors, is a beginning of new implantation application in modern technology.

2. MODELLING

In many cases of flat element implantation we often have situation when, with some approximation, implanted elements have layer structure see, Fig. 1. When the problem of resistance is under consideration and change of resistance due to active parameters (pressure, temperature) are phenomenon of interest it is convenient to use described bellow electrical resistance model. This model gives information about real value of resistivity in layers. Having computer program for ions and defects deposition function it is possible to define the effective boundaries of enhanced implantation volume, see Fig. 2.

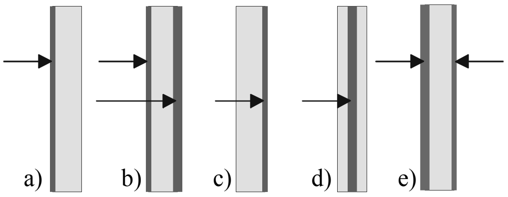

Fig. 1. Schematic presentation of layer structures in real ion implantation process. The arrows show direction of implantation

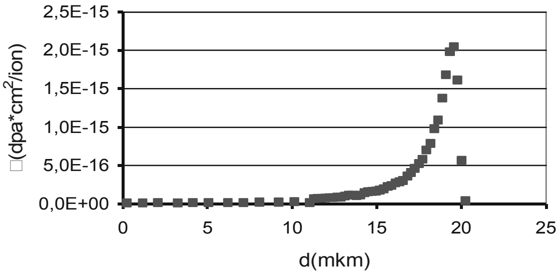

Fig. 2. Effective surface per Kr ion 245 MeV for atom displacement (for dose as in text) as a function of depth penetration in an aluminium-manganin foils sandwich calculated using TRIM program, JINR, Dubna (mkm = μm)

It is possible to find position and thickness of some layer in which the physical properties are changed significantly. Proposed by us model gives possibilities to find those changes as for example change of manganin

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resistivity due to implantation then due to pressure, temperature and so on.

In the case of electrical properties, layers have strongly changed physical properties which are very difficult for investigation. In the case of electrical resistance investigation simple modelling of this structure in form of two (or more) parallel connected resistors allows to draw out more information as regard to properties of strongly implanted part of investigated materials [4]. For example the coefficient of pressure sensitivity of foil type resistance manganin sensor of strongly implanted part reveals much higher value than those for non implanted sensor.

The proposed modelling is acceptable for isotropic and homogenous materials with supposition that those layers have also the same character in two planar directions.

Let us call thickness of foil by h, thickness of non-implanted volume by h_1 and strongly implanted layer by h_2. At normal condition the resistance of manganin specimen is R_0 (measured usually using four probes method).

The layer is virtually separated and according to rule for parallel connection of two resistors proper equation can be found (see Fig. 3), where $R_{1,0} = (h_1+h_2)R_0 / h_1$ and $R_{2,0} = (h_1+h_2)R_0 / h_2$.

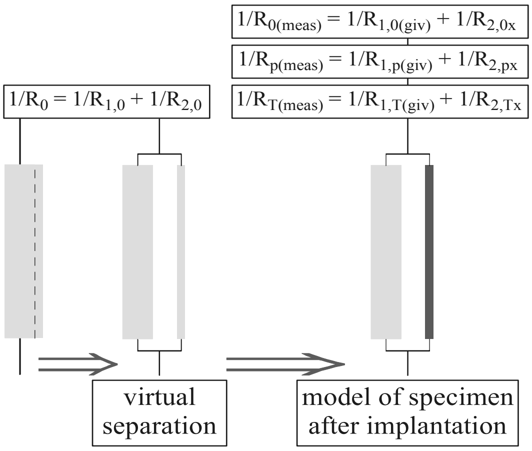

Fig. 3. The electrical resistance model of one side implanted manganin specimen. Damage and ion deposition volume due to implantation is presented by black line. $R_{1,0}$ and $R_{2,0}$ resistances of virtual separated parts of specimen, $R_{0(meas)}$, $R_{p(meas)}$ and $R_{T(meas)}$ measured equivalent resistance of implanted specimen under normal condition, under pressure and at some temperatures, $R_{1,0(giv)}$, $R_{1,p(giv)}$, $R_{1,T(giv)}$ given data for not implanted part at normal condition, under pressure and at some temperatures, $R_{2,0,x}$, $R_{2,p,x}$, $R_{2,T,x}$ resistances of implanted part of specimen which can be calculated

3. EXPERIMENTAL SET UP

The investigated pressure sensors were foil type of 10 μm thick, 1 mm wide and 75 mm long. Manganin foils were obtained from "Isabellenhütte" (Germany) [1]. The samples of desired dimensions with well performed side-surfaces were obtained using the YaG laser-cutting machine in Tele and Radio Research Institute in Warsaw. After cutting procedure the samples were heat-treatment, typically as for manganin sensors. High-energy Kr ions were implanted at a cyclotron U-400 in the Laboratory of Nuclear Reaction at Joint Institute for Nuclear Research (Dubna, Russia). The effective surface per Kr ion of host atom displacement as function of depth penetration was calculated using TRIM program [4]. The distribution function for implanted ions was supposed to be close to that as for displacement host atoms. Complex implantation of Kr and Bi ions was realized using implantation device UNIMAS-79 in the Institute of Physics of University of Marie Curie-Skłodowska in Lublin (Poland). The atom displacement and ion distribution inside in samples were calculated using SRIM-2000 program [4]. Ions and structural defects were mainly located, as result of implantation, in the small volume being close to surfaces of specimens. In this situation a simple model of electrical resistance of pressure sensor – in form of two parallel-connected resistors – was used [4, 8]. In the first case Kr ions were accelerated to energy of 245 MeV with dose of 2.5×10^{15} Kr ion/cm^2 from one side of specimen (Fig. 1, c). In the second case of specimen was one side implanted by Bi ions with energy of 255 keV and dose of 2.5×10^{16} Bi ion /cm^2 and then from both sides implanted by Kr ions with energy of 255 keV and dose of 2.5×10^{17} Kr ion/cm^2 (Fig. 1, e). In order to avoid in second case calculate complication in introduced modeling by us we have used only two resistors model with implanted thickness equal to 1 μm.

If sensitivity of manganin pressure sensor is defined as $\alpha = \Delta R / (R_0 p)$, (since $R = R_0(1 + \alpha p)$), pressure measurement is based on measurement of R, where α and R_0 should be known. Depending on prediction of thickness layers, defined by used parameters of implantation, we have: in case of Kr implantation, (h_2 = 2.5 μm)

$$\frac{1}{R} = \frac{3}{4R} + \frac{1}{4R} \tag{1}$$

and for Bi + Kr implantation, ($2h_2$ = 1 μm).

$$\frac{1}{R} = \frac{9}{10R} + \frac{1}{10R}\,. \tag{2}$$

4. RESULTS

4.1. Pressure sensitivity

Measurement of resistance of pressure sensor gives information about mean coefficient of the manganin sensor $<\alpha>$. Expected value of pressure coefficient for strongly implanted volume of manganin α_{imp} we can calculate using the model. So we can write following (basic) equation

$$\frac{1}{R_0(1+<\alpha>p)} = \\ = \frac{3}{4R_0(1+\alpha p)} + \frac{1}{4R_0(1+\alpha_{imp}p)}\,. \tag{3}$$

From above relation, taking under consideration that obtained mean value after only Kr implantation $<\alpha> = 2.47 \times 10^{-5}$ MPa^{-1} (the 0.8 % increase), for pure manganin – $\alpha = 2.45 \times 10^{-5}$ MPa^{-1}, and $\alpha_p<<1$, we can easy to calculate $\alpha_{imp} = 2.52 \times 10^{-5}$ MPa^{-1} (the 2.8 % increase). Those results give only a tendency of changes and are in good agreement with data presented in [3]. In the case of implantation with bismuth and krypton, the $<\alpha> = 2.82 \times 10^{-5}$ MPa^{-1} (see Fig. 4), $\alpha = 2.45 \times 10^{-5}$MPa^{-1} as previously and hence $\alpha_{\mathrm{imp}} = 6.0 \times 10^{-5}$ MPa^{-1}. For those measurements, using the pressure standard of accuracy class of 0.05 and precise HP Multimeter 3457A, the uncertainty of α was estimated to be $\delta\alpha = \pm 0.01$ MPa^{-1} (0.4 %).

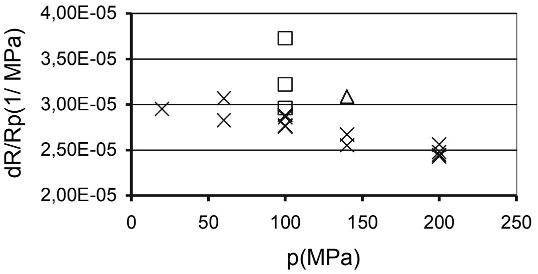

Fig. 4. Pressure sensivity of Bi-Kr implanted manganin specimen versus pressure *p*

4.2. Temperature sensitivity

In the case of determination of thermal dependence of implanted layer, our divagation will be concentrated on typical high-pressure manganin sensors problem**.**

It is well known property of manganin i.e. it equals to zero thermal coefficient of electrical resistance at room temperature.

Taking under consideration proposed by Beavitt [7] parabolic dependence of manganin resistance versus temperature

$$\frac{R - R_{\max}}{R_0} = -0.5a\left(T - T_{T\max}\right)^2 \qquad (4)$$

where experimentally determined parameter $a = (0.6 - 1.1) \times 10^{-6}$ deg^{-2}, and T changes from 273 K up to 313 K only we can say that under pressure this parabolic dependence is moving up to higher value of pressure and to the right to the higher temperatures. So, optimal situation from metrological point of view at normal (small) pressures is not optimal one under high pressures (at high pressure manganin sensor is sensitive to temperature as well). In the case of appearance of some plateau near to $R_{\max}$, the optimal metrological situation should be realized in small and high pressure too.

From our investigation it is seen that close to room temperature for implanted with Kr + Bi ions in the manganin sensor such plateau exists. Using proposed model it was possible to calculate the parameter "a" in Beavitt's equation, which appeared to be much smaller. So, one can expect that at wider range of temperature close to the room temperature thermal coefficient of manganin resistance is very small. For our needs we will use form $R = R_{\max}(1 - a(T_{R\max} - T)^2)$. So for krypton implantation basic equation can be written

$$\frac{1}{R_{\max}\left[1 - \langle a\rangle\left(T_{R\max} - T\right)^2\right]} = \frac{0.75}{R_{\max}\left[1 - a\left(T_{R\max} - T\right)^2\right]} + \frac{0.25}{R_{\max}\left[1 - a_{imp}\left(T_{R\max} - T\right)^2\right]} . \qquad (5)$$

Taking into account that $a(T_{R\max} - T)^2 << 1$, and that $R_{\max}$ is the same for three cases, after easy transformation we have: $\langle a\rangle = 0.75a + 0.25a_{imp}$ and

$$a_{imp} = 4\langle a\rangle - 3a \ . \qquad (6)$$

Having data for $<a>$ and a [4] we can demonstrate in Fig. 5 temperature dependence of implanted layer resistance which is most smooth one. If $<a>$ is smaller then ¾ a, a_{imp} changes his sign.

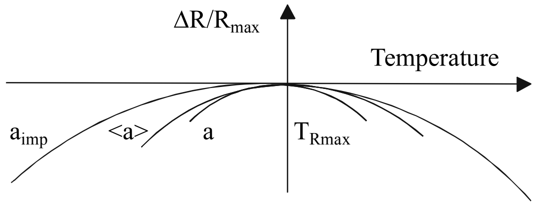

Fig. 5. Illustration of method for $R(T)$ for Kr implanted layer in manganin foil

4.3. Other information

As was mentioned above the Kr dose $D = 2.5 \times 10^{15}$ ion/cm^2. That means that mean density of Kr ion in probes was $<d>_{10\ \mu\mathrm{m}} = 2.5 \times 10^{18}$ Kr ion/cm^3. If we suppose that krypton concentration inside specimens is the same as damage distribution the mean density of Kr ions in a strongly implanted region $<d>_{2.5\ \mu\mathrm{m}} = 1.0 \times 10^{19}$ Kr ions/cm^3. If we take under consideration that number of cooper atoms in one cm^3 is $N_{\mathrm{Cu\ atoms\ in\ cm3}} = 4$ (atoms Cu in basic cell) / $3.62^3 \times 10^{-24}$ cm^3 $= 8.6 \times 10^{22}$ (Cu+Mn+Ni) atoms/cm^3 we can calculate the relative concentration: 0.11×10^{-3} Kr atom/host atom, which appear to be small.

In the second case Kr dose (both side) was 2.5×10^{17} ion/cm^2 and Bi (one side) dose 2.5×10^{16} ion/cm^2 relative concentration was much higher.

Taking under consideration the fact that thickness of implanted layer were of order of 1 μm the relative concentration of ions is of order 0.29×10^{-2} Bi atom/host atom and 2.9×10^{-2} Kr atom/host atom.

CONCLUSIONS

1. The increase of sensitivity to pressure of implanted manganin can be explained by introducing inside to materials multi vacancy defects and additional macro lattice defect (Brinkman's zone). On the other hand decreasing of it at above some threshold of pressure (see Fig. 4) can be explained by a decrease of this "empty micro space" after over-crossing locally stress limits of plastic flow.

2. Using the described model it is possible to make a correlation between densities of implanted ions in layers and sensitivity of manganin to pressure. In the case of Kr its concentration is about 0.011 % and in the case of second implantation, the concentration of Kr and Bi ions is about 3.5 % i.e. much higher than observed increasing of pressure sensitivity. The number of structural defects is of course, much higher. In the second case, probably, we are

close to amorphous state of manganin. So further investigations are necessary.

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