Bend Testing of Tin Doped Bismuth Microwire

M. Dyntu, S. Donu, D. Iacobciuc
Institute of Electronic Engineering and Industrial Technologies, Academy of Sciences
of Moldova, Academiei str. 3/3, Chisinau MD 2028, Republic of Moldova
dynyara@rambler.ru

***Abstract* — The paper presents the results of mechanical bend testing of tin doped bismuth microwire in glass isolation with internal diameters (1.5 – 15) µm and external (10 – 60) µm. The impurity of tin in quantity 0.01, 0.05 and 0.075 atomic percentage was introduced in initial ingots in the process of material synthesis.**

The criterion of estimation of mechanical bend testing of the microwire, as the measure of their flexibility, is the value of critical bending radius (r_{cr}) and the bend was carried out up to rupture.

It was established, that reduction of both internal and external diameters of tin doped bismuth microwire conducts to reduction of the critical bending radius, i.e. to the growth of their flexibility for all investigated concentration of tin. It is necessary to note, that tin doped bismuth microwire are much more elastically in comparison with microwire crystals from pure bismuth. It was established, that for some bismuth microwire doped by 0.01 at % of tin and internal diameters d ≤ 3 µm samples were not broken off even in case of achievement of critical bending radius. This possibly, is connected with the presence of plastic deformation of investigated samples.

The received results of bend testing show that tin doped bismuth microwire crystals possess high flexibility, that give the possibility of their practical use as sensitive tiny elements of strain gauges.

***Index Terms* — wire, bismuth, critical radius, crystal, bismuth doped.**

I. INTRODUCTION

As it is known, elastic deformation limit of thin bismuth wire in the glass shell have elongation values of 2% at room temperature, which is an order greater than the value in bulk samples [1]. The study of glass wire on the shell bending is a problem of great interest. In this paper we study the mechanical properties of thin bismuth wire and tin treated bismuth, and these properties are investigated in the situation - at bending deformation.

II. EXPEREMENT

Cylindrical single crystals of Bi and Bi_{1-x} Sn_x, alloys with diameters from 1 to 10µm in glass coating were fabricated by the Ulitovsky method [2]. With the help of analysis the Shubnikov-de Haas oscillations (fig.1) and rotational transverse magnetoresistivity diagrams (fig.2), is was found that all the samples had the same orientation - wire axis coincided with the ΓL direction in the reduced Brillouin zone. In this case one of the bisector axis C_S made up with the wire axis an angle 19,5° in corresponding specular plane of the crystals so that one of the binary axes is perpendicular to it and the third order axis C_3 is inclined to the wire at an angle of ≈ 70°. This orientation corresponds to the natural direction of the bismuth crystal growth.

Glass coating did not 15-20µm and reliably defended the sample from ambient atmosphere and also gave the ample a side support during the extension experiments.

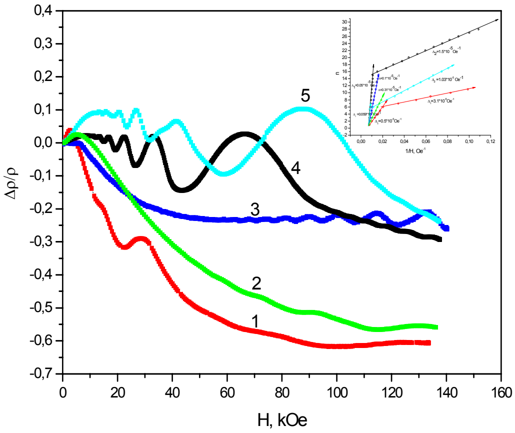

Fig. 1. Field dependencies of the LMR ΔR(H) of BiSn wires with different concentrations and diameters at T=4.2K. 1.Bi, d=0.48µm, 2. Bi-0.01at%Sn, d=0.55 µm, 3. Bi-0.02at%Sn, d=0.5µm, 4. Bi-0.05at%Sn, d=0.55 µm, 5. Bi-0.07at%Sn, d=0.6 µm. Insert: dependences of the quantum number n of the ShdH oscillations on reverse field H^{-1}.

The magnetic-field depending resistance R(H), was measured in the temperature range 4,2 – 300 K and magnetic fields up to 14 T, in a Bitter-type magnet and in a superconducting solenoid in the International Laboratory of High Magnetic Fields and Low Temperatures Wroclaw, Poland.

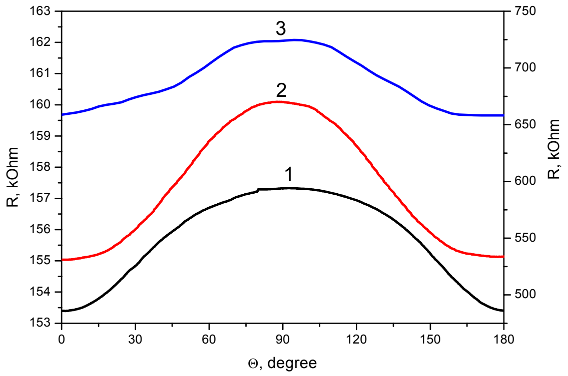

Fig.2. Angle diagrams of transverse magnetoresistance R(θ) in BiSn wires with different concentrations and standard orientation $(10\bar{1}1)$:1. d=0.075 µm, H=1 T, T=4.2 K; 2. d=0.2 µm, H=0.5 T, T=4.2 K; 3. d=0.6 µm, H=0.5 T, T=4.2 K.

III. RESULTS AND DISCUSSION

Strain bending test was carried out by means of a modified installation described in [3]. For mechanical testing, samples or their parts with a length of 10-12 mm were selected. A special attention was paid to the surface quality: we tested only the samples in which surface defects and microcracks had not been found under the optical magnification of 500 times. Geometric dimensions of the samples were measured by virtue of an MBI-11 optical microscope. The wire diameter (d) and the glass coating thickness (D) of each sample were determined by measuring under microscope at the edges and in the center of the sample at least 10 times; thereupon, the average value was determined. We tested 8-10 samples with identical diameter and constant length of 0.5 mm.

The accuracy of optical microscopes (~0.4-0.3 µm) is not sufficient to measure diameters smaller than 1 µm. One edge of the samples was glued to a stationary holder using BF-2 glue or zapon varnish, which have good adhesion to glass, and to stainless steel (needle). The place of the sample fixation to the needle was recovered by another layer of glue or varnish. It was important that the glue from the sample must not go beyond the holder. A blade was brought to the second edge of the sample (free), which was in contact with it at a distance from the point of fixation. The measurement of the length of the section subjected to bending was carried out by means of an MBS-9 microscope.

The bending strength of thin wires as a measure of their elasticity was determined from the critical bending radius (r_{cr}) of the sample, which, according to the method used, was calculated as the ratio of the sample length subjected to bending l in mm to the bending angle φ in degrees; $r_{cr} = l/2\sin\varphi$, mm. The samples were bent to rupture.

The paper presents the results of bending tests of thin wires of pure bismuth and bismuth doped with tin in a glass isolation obtained by liquid phase casting by the Ulitovsky method with internal diameters (d) from 1.5 to 15 µm and [1,2] external diameters D from 10 to 60 µm. Impurities of tin in an amount of 0.01, 0.05, and 0.075 at % were introduced into the charge in the synthesis of the material. Experimental results are presented in Tables 1 and 2 and in figure 3.

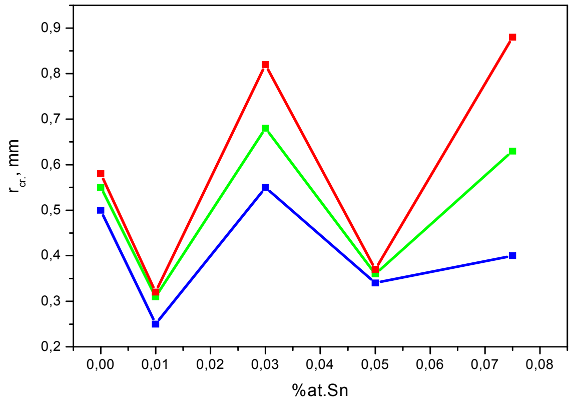

Fig.3 Dependencies of critical bending radius of thin doped Bi microwire crystals on tin concentration.

As can see from figure 3, the deformation dependences of critical bending radius from of thin doped Bi microwire crystals on thin concentration are substantially monotonit character.

These results imply that wire crystals doped with tin exhibit an appreciable scale effect of strength; that is, the reduction in both internal and external diameters of the samples leads to the decrease in the critical bending radius, i.e., to the increase in their flexibility for all studied concentrations of tin.

It should be noted that the wire crystals of bismuth doped with tin are much more elastic than wire crystals of pure bismuth. For example, the critical radius of the wire crystal of bismuth doped with 0.01 at % tin with the internal diameter d = 2.9 µm is 0.253 mm, whereas the critical radius of the wire crystal of pure bismuth with the internal diameter d = 2.5 µm is 0.543 mm.

Table 1 shows that a wire spread of data is observed for the critical bending radius of wire crystals of pure bismuth; r_{cr} ranges within 0.496-0.572 mm. Note that this behavior has not been observed by us earlier [4,5] in the course of the bending test of both wire crystals of pure bismuth and wire crystals in a glass coating of germanium, nichrome, and tin.

TABLE I. CRITICAL BENDING RADIUS OF GLASS-COATED WIRE CRYTALS OFPURE BISMUTH

d, µm	**D, µm**	**D/d**	**r_{cr}, mm**
2.0	29.0	14.5	0.520
2.3	20.5	8.9	0.563
2.5	39.2	15.8	0.543
5.0	40.0	8.0	0.514
10.2	46.6	4.6	0.520
10.6	36.5	3.5	0.584
11.0	39.4	3.6	0.572
11.7	32.9	2.8	0.560
12.4	46.6	3.7	0.542
13.1	42.3	3.2	0.519
14.1	41.1	2.9	0.496
14.2	39.4	2.8	0.570

The wide spread of data of the critical radius of the pure-bismuth wire crystals under study can be a consequence of large diameters of the glass coating; the main role in bending is played by the glass coating. As one can see from Table 1, the ratio of the glass coating diameter to the pure-bismuth wire diameter D/d is very high and ranges with 2.8-14.5 for internal diameters of 14.2-2.0 μm.

It is found that for very thin bismuth wires (d ≤ 2 μm) doped with 0.01 and 0.05 at % tin, in some cases, samples did not rupture even at the critical bending radius (tab.2).

TABLE II . CRITICAL BENDING RADIUS OF GLASS-COATED WIRE CRYTAL OFPURE BISMUTH DOPED WITH TIN

Sn, at %	**d, μm**	**D, μm**	**D/d**	**r_{cr} mm**
0.01	2.9	10.2	3.5	0.253
	3.2	9.1	2.8	0.314
	3.3	10.9	3.3	0.317
0.05	6.2	13.8	2.2	0.339
	6.9	14.6	2.1	0.362
	6.9	15.3	2.2	0.376
0.075	1.5	22.6	15.0	0.403
	10.9	55.5	5.1	0.874
	15.3	60.6	4.0	1.176

This phenomenon has been observed earlier by the authors of [6] while studying the critical bending radius of manganin microwire; they explained it as a possible plastic deformation of the wire. To explain this phenomenon in the case of the samples under study, additional researchers are required.

Thus, as a result of testing of glass-coated wire crystals doped with tin, we found that they are more flexible (elastic) (~1.5-fold) as compared with wire crystals of pure bismuth. The reduction in both internal and external diameters of wire crystals of bismuth doped with tin leads to the decrease in the bending radius, i.e., to the increase in their flexibility for all studied concentrations of tin.

The results obtained by the bending test show that wire crystals of bismuth doped with tin exhibit high elasticity, which enables their practical use as sensitive elements of miniature strain gauges.

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REFERENCES

[1] A. Nikolaeva, A. Burchakov , D. Gitsu, J.Materials Science and engineering, A288, pp. 298, 2000.

[2] N.B. Brant, D.V. Gitsu , A.A. Nikolaeva and Ya. G. Ponomareov, Zh.Eksp.Teor.Fiz. 24, pp. 304, 1976.

[3] I.A. Oding, I.M. Kopiev, “Prochnostnie svoistva nitevidnih kristallov”, Metalovedenie I termicheskaia obrabotka materialov vol. 9, 1961.

[4] M. Dyntu, D. Meglei, S. Donu, A. Rusu, “Mechanical Properties of Iron Doped Bismuth Wire Crystals in Glass Isolation”, 4-rd International Conference on Materials Science and Condensed Physics , Abstracts, Chisinau, pp.74, September 2008.

[5] D. Grabco, M. Dyntu, D. Meglei, O. Shikimaka, “Microstructure and Strength Properties of Germanium Microwires for medical Devices”, Nanostructured Materials and Coatings for Biomedical and Sensor Applications, Kluwer Academic Publishers, Printed in the Netherlands, pp.71, 2003.

[6] N.R. Berman, M.V. Gibelibert, V.G. Ceban, “Prochnostnie svoistva microprovoda pri izghibe (Mechanical properties of microwire at bending)”, Izvestiya AN MSSR, vol. 3, pp. 65, 1969.