DEFORMATION PECULIARITIES IN BIDIMENSIONAL STRUCTURE ITO/n-Si UNDER CONCENTRATED LOAD ACTION

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INTRODUCTION

The development of modern technique requires new information regarding the mechanical properties of various materials having practical application, especially, bidimensional materials for micro- and optoelectronics: films, various structures of the layer/substrate type. Therefore, much attention is paid on the problem connected with the investigation of mechanical characteristics of such materials, in addition with the elucidation of deformation plastic mechanism under the action of concentrated load, and namely, under micropenetration.

The paper is aimed to the investigation of the ITO/n-Si bidimensional semiconductor structure which is a promising material for the solar cells due to its high values of optical and electrical parameters, and the simplicity of preparation of the diverse structures on their bases using alternate crystalline supports [1]. The submicronic layers studied in work are a compound of SnO_2-In_2O_3 (ITO) coating the n-Si crystals. The purpose of this work is to investigate the microhardness and the peculiarities of plastic deformation of these structures using microindentation method as one of the more suitable ones for study the mechanical properties of the dimensionally limited objects.

EXPERIMENTAL TECHNIQUE

The ITO layers are deposited on the n-Si crystal surface, (001) plane, by spraying alcoholic solution of $InCl_3$ and $SnCl_4$ in different proportion using the special designed installation containing four main units: the pulverization system, the system of displacement and rotation of the support on which the substrate is fixed, the system of heating the substrate and the system of the evacuation of the residual products of the pyrolise. The heating system consists of an electric stove and a device for automatic regulation of the substrate temperature.

The microhardness measuring was made at room temperature by Vickers method using the PMT-3 microhardness tester [2]. The interval of used loads on the indenter changed in load limit of P=10-65 g. The thin crystal structure was revealed by the methods of optical microscopy, atomic force microscopy (AFM) and scanning electron microscopy (SEM).

RESULTS AND DISCUSSION

The study of the chemical composition of the investigated samples showed that they had a complex, multicomponent structure. The spectra obtained from the cross-section of ITO/n-Si at different distance from the sample face are presented in Fig.1. It is seen that ITO layer along with basic layer elements (Sn, In и O), includes the noticeable silicon quantity (Fig.1a,b). In addition to the mentioned elements a small quantity of other ones (N, K, C, Cl, F) was found as a non-controlled impurity. The content of the mentioned elements is diminished up to zero if extending the distance from ITO layer into the structure volume. To note that thickness of main part of layer is about of t≈0,215 μm, and already on the depth of t≈0,400 μm the spectrum consists of 98,80 at.% of the Si element (Fig.1c,d).

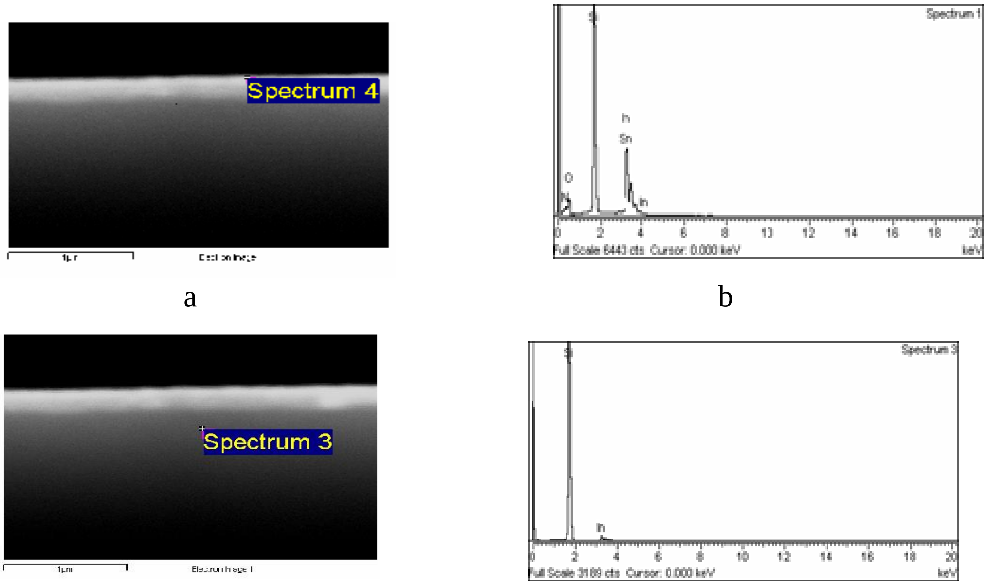

Fig.1. The ITO/n-Si structure composition in dependence of the surface distance: a,b – on the surface; c,d – on some distance of the coating.

Then it was carried out the investigation of microhardness on the ITO/n-Si structure surface as a function of load applied to the indenter (Fig.2, curve 3), and also on the substrate surface: on the Si surface after mechanical polishing (Fig.2, curve 1), and on the Si surface subjected to chemical treatment in order to remove the stratum hardened by mechanical polishing (Fig.2, curve 2). Fig.2 shows a non-constant character of hardness-load H(P) dependence for all curves which is more pronounced for loads less than 40 g; for P>40 g the curves approach essentially and show noticeable stability in the microhardness values. Non-monotonity of H(P) dependence was also marked earlier in other works [3,4] and has been explained by specificity of deformation of the material strata near the surface.

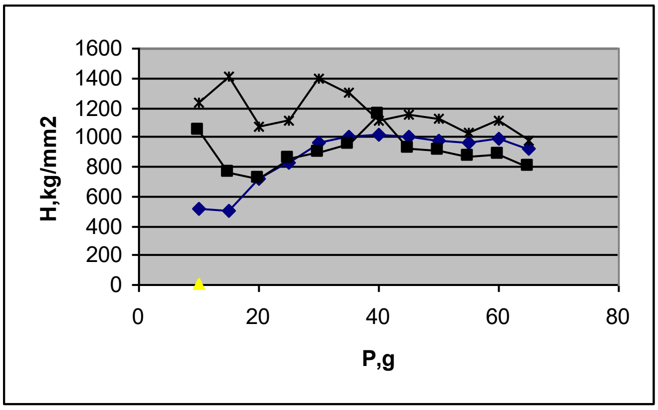

Fig.2. The dependence microhardness/load for the next samples: 1-(**x**)Si, pure, initial surface; 2 –(■) Si, pure, after the chemical treatment for surface refining; 3 –(♦) ITO/n-Si structure

To understand the shape of H(P) dependence, it was considered the interrelation between the load, diameter and depth of indentations for materials presented in Fig.2. It was found that the load of P=(35-40)g corresponds to the indentation depth of h≈(1,1-1,2)µm. It means, that if the tip of indenter penetrates into material on the depth more then 1,0 µm, the microhardness becomes less dependent on the value of applied load.

This fact correlates with the data from the literature [5,6], according to which in different materials, as a rule, it is distinguished some strata with the specific properties of strength and plasticity: 1 - t≤1,0 µm; 2 – t≈(1,0-10,0) µm; 3 – t≈(10,0-100,0) µm. To note, that namely first stratum with t≤1,0µm is characterized by the greatest instability; the hardening or softening effects can be noted in this stratum in dependence on the investigated material nature and the properties of concrete surface. Some contribution into instability effect can be introduced by the increase of measuring error at the diminution of the indentation size. In our measurements the influence of this factor was diminished due to a great number of indentations made for each load.

According to presented results it is possible to give the following explanation of the dependences, showed in Fig. 2. The curve 1 in all interval of applied loads is placed above than two other curves (2 and 3). This fact can be explained by the hardening effect as a result of mechanical polishing of the crystal surface. The curve 2 in general outline follows a course of curve 1 being a little more rounded; however on the whole curve 2 is situated below the curve 1. This fact may be explained by the removal of the Si stratum hardened by mechanical polishing. Regarding the curve 3, it is important, that it has three specific sections. The part of curve corresponding to the P=20-25g coincides with curve 2. At the same time the part for P<20g is situated beneath the curve 2 and for P>25g, on the contrary, above it.

Such a course one can be explained as follows. The indentation depths vary in limits of (0,6-1,06)µm at loads P<20g. That is slightly bigger than the ITO layer thickness (h/t≈2-2,5). Therefore the compound SnO_2-In_2O_3 being more soft and plastic materials diminishes noticeably the overall microhardness value of the ITO/n-Si structure. If the load value increases so much that indentation depth becomes essentially bigger then the ITO layer thickness, (h/t≈4-4,5), the layer has an opposite influence furthering the increase of the ITO/n-Si microhardness. This conclusion was confirmed by study the indentation shape and surface relief around them using the AFM and SEM methods.

The carried out researches let to receive some new data concerning the strength and plastic properties of the ITO/n-Si structure. They are: (i)dependence H(P) obtained for the Si and ITO/n-Si in general case has a non-monotonous character and this non-monotonity is more pronounced for small values of P; (ii) the removal of the defected layer induced by mechanical polishing from the Si surface using chemical method is followed by the Si microhardness diminution in all interval of used loads; (iii) higher plastic properties of ITO layer influence on the microhardness value of ITO/n-Si structure in the whole load interval: at small loads they diminish the microhardness, and in the range of high loads they lead to some increase of hardness in comparison with pure Si.

SUMMARY

The study of microhardness and peculiarities of plastic deformation of the bidimensional semicondustor structures of ITO/n-Si type under microindentation has been carried out in the paper. A new data regarding the strength and plastic properties of these structures testify about the dual role of the ITO layer: it has a softening role in the range of small loads on the indenter and strengthening one in the range of higher loads (P>20 g).

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REFERENCES

1. A.Simaschevici, D.Serban, L.Bruc, et al. Spray Deposited ITO-nSi Solar Cells with Enlarged Area // Abstracts of the 2nd Intern. Conference on MSCMP, Chishinau 2004, p.138

2. Iu.Boyarskaya, D.Grabco, M.Kats. Physics of Microindentation Processes // Chisinau, Stiintsa, 1986, 293p. (in Rus.)

3. Y.Y.Lim, M.M.Chaudhri. The Effect of the Indenter Load on the Nanohardness of Ductile Metals : an Experimental Study on Polycrystalline Work-Hardened and Annealed Oxygen-Free Copper // Phil.Mag. A, 1999, v.79, no.12, pp.2979-3000.

4. D.Z.Grabco, N.A.Palistrant, G.G.Zaitseva, et.al. Some Peculiarities of Mechanical Properties of the $Zn_xIn_2S_{3+x}$ Compounds // CAS-98 Proceedings, 1998, v.2, p.471-474.

5. Л.С.Раппопорт. Уровни пластической деформации поверхностных слоев и их связь с процессом изнашивания // Трение и износ, 1989, т.10, №5, с.786-792ю

6. В.П.Алехин. Физика прочности и пластичности поверхностных слоев материалов // М., Наука, 1983, 280 с.