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Method for Characterization of Nano-Films Mechanical Properties

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The new measuring procedure of nanosized films mechanical characteristics is proposed. The method provides laying of an explored material film on a surface of getter which containing gas. A film is locally deformed to bubbles formation by gassing from getter. Mechanical properties of nanofilm are calculated by measuring the sizes and the shape of the undamaged and destroyed bubbles. Mechanical properties of iron nanofilm with thickness 30 nanometers were determined by the method.

Keywords: Nano-Film, Mechanical Properties, Iron, Strain, Getter.

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1. INTRODUCTION

Increasing interest to nano-materials application demands knowledge of their mechanical properties. The particular interest to measuring of nano-films mechanical properties is due to insufficient suitability of existing methods for their precise definition. So, for example, accuracy of widely used method of nano-indentation significantly depends on substrate material and a thickness of an explored film [1]. It also does not allow to define tensile strength of a material as material test is made by hardness indentation. The purpose of the presented work was to get rid of the specified limitation.

2. METHOD AND EXPERIMENT

Procedure is based on betterment of an technique for definition of solid thin- and nano-films mechanical characteristics [2]. In a method the solid film is superimposed on a flat surface of solid getter that contains gas. Further, heating of getter results in a gassing. As a result there is the partial delamination of a film in the form of bubbles. During formation of bubbles there is an elastic-plastic deformation ε of a film material. Film mechanical properties are computed with use of geometrical parameters of bubbles at an elastic-plastic state and after removal of elastic strains. Elastic deformation removal carry out by gas diffusion through a film or as a result of bubbles fracture. Outgassing leads to elastic deformation removal. The film residual elongation is conditioned only by a plastic deformation ε_p. Elastic deformation ε_e is calculated as a difference elastic-plastic and the residual plastic deformation: $\varepsilon_e = \varepsilon - \varepsilon_p$. A stress in a film, strength and yield stress of a material is calculated as multiplication of a Young's modulus and value of a corresponding elastic strain. Use of a Young's modulus for these evaluations is correct because of insensibility of the given modulus to size effects [3]. A film state (a) according to the stress-strain diagramme (b) is schematically presented on Fig. 1.

Investigations realized for an iron film nanosized thickness. Multilayer structures MgO (7nm)/Fe (30nm) was obtained by consecutive electron-beam evaporation on polycrystalline substrates ST51 (based on Al_2O_3) in vacuum 10^{-4} torr [4]. In such conditions the higher content of impurities in films, in particular, nitrogen is provided. As a result of the forced gassing from getter there was a local delamination of explored film *Fe* and formation of numerous bubbles in places of a gas output from getter (Fig. 2).

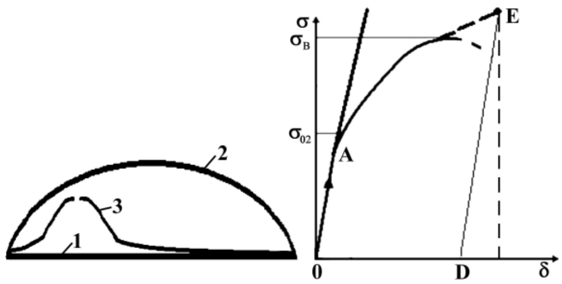

Fig. 1 – A film state *(a)* according to the stress-strain diagramme *(b)*: 1 - initial state, a point «0» on the diagramme; 2 - tension before a fracturing (a point «E»); 3 - state of a film after a relaxation of elastic stresses (a point «D»).

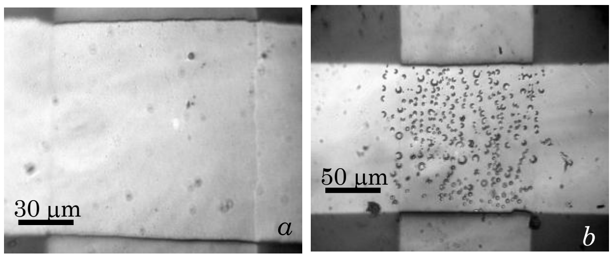

Fig. 2 – A film of iron after deposition (a) and after gassing from MgO (b)

As is obvious from Fig. 2 bubbles in different diameter are observed. Analyzing their shape it is possible to define values of elasto-plastic and elastic strains for different values of strain. It is possible to define all stress-strain diagramme for an investigated material. A material strain in bubbles was found from a relation of length of arc L of a segment of the strained film of a bubble to its chord l. In case of the spherical form of a bubbles in altitude h the arc length is defined as

$$L = \frac{l \cdot \pi}{180} \cdot \frac{\arctan \beta}{\sin(\arctan \beta)}, \text{ where } \beta = \frac{4lh}{l^2 - 4h^2},$$

Table 1 – Mechanical properties of iron

Quantity	**Bulk iron**	**Iron nano-film**	**Whiskers of iron** [5]	**Defectless crystal of iron** [6]
The limiting elastic extension, %	0,15	5	5	8
Strength (breaking stress), GPa	0,2-0,3	10	13,5	11-18

3. RESULTS AND DISCUSSION

Computing result of mechanical properties of nano-film with thickness of 30 nanometers are presented in the Table 1. As mechanical properties of bulk materials can differ considerably from such for nanosized films due to the reduced defect concentration, results of calculations compared to mechanical properties of nano-materials, such as whiskers of iron [5].

As is obvious, the obtained film of iron has mechanical properties, close to that for whiskers of iron [5] and for defectless nano-crystals of iron [6]. It is necessary to note that the film in bubbles is in planar stressed state. It should be take into consideration in the obtained data comparison to results of the uniaxial tension [5, 6].

4. CONCLUSIONS

The technique of mechanical properties determination for the iron nano-films superimposed on flat getter MgO is developed and approved. The obtained results show high mechanical strength and elasticity of nano-films, comparable to properties of defectless nano-crystals of iron. It can be due to a low defect concentration of the obtained iron film.

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