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# Electrophysical Properties of Nanodimentional Pt Thin Films

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The results of research structural and phase state, electrophysical properties (resistivity, temperature coefficient of resistance (TCR), strain gauge) of Pt thin films in the range of thicknesses from 7 to 50 nm were presented. Thin films Pt have fcc structure with lattice parameter $\bar{a}$ = 0,390 nm after annealing. The temperature dependences characterized by relative large value of resistivity ($\rho \sim 10^{-6}$ Ohm m) and relative small value of TCR ($\beta \sim 10^{-4}$ K$^{-1}$) respectively. Strain properties characterized by a wide interval of elastic deformation (more than 1 %), relatively low value of gauge factor (1,5 – 3 units).

**Keywords:** Thin film Pt, Structure and phase state, Temperature coefficient of resistance, Gauge factor, Elastic deformation.

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## 1. INTRODUCTION

Research activity on nanodimentional materials has seen a tremendous growth in the last decade. Investigation of nanometer-sized materials has attracted considerable attention because of their unique chemical/physical properties when compared to solid-state bulk materials as well as their potential in nanoscale devices as contacts [1-3], buffer layers [4] in the fabrication of high-T$_c$ superconducting tapes, electrochemical and catalytic applications [5].

However, literary data which describe the electrical properties of thin films of noble metals like Au, Pd or Pt not enough. As well-known electorphysical properties of thin film materials (resistivity, TCR and gauge factor) depend on film thickness, crystalline size, concentration and type of defects crystal structure and external field.

The purpose of this paper is studying correlation between structural phase state and electrophysical properties (resistivity, temperature coefficient of resistance (TCR), strain gauge) of Pt thin films which has wide practical application.

## 2. EXPERIMENT

Thin films Pt were prepared by method of thermal evaporation in vacuum chamber (the base pressure was $10^{-4}$ Pa) at the substrate temperature $T_s = 300$ K. The thickness of the films was measured during deposition by the method of quartz resonator, according to the recommendation of work [6], which ensured the thickness measurement error within ±0,1 nm. For investigation electophysical properties (resistivity and TCR) thin film Pt were annealing in vacuum during two cycles in temperature interval 300 – 630 K. Strain properties were investigation during seven cycles "load – unload" using modern devices of physical experiment automatization (computerized system for data acquisition and experiment control) which described at work [7].

The TCR was calculated from the equation:

$$\beta = \frac{1}{\rho_0}\frac{\Delta\rho}{\Delta T}$$

where $\rho_0$ is initial value of resistivity, $\Delta T = 5$ K.

The mean and instantaneous gauge factors were calculated from the equations:

$$\gamma_l = \frac{1}{R}\frac{\Delta R}{\Delta\varepsilon_l}, \quad \gamma_{li} = \frac{1}{R_i}\frac{\Delta R_i}{\Delta\varepsilon_{li}},$$

where $R$ and $R_i$ are resistances at strain $\varepsilon_l = 0$ and $\varepsilon_l = \varepsilon_{li}$ respectively.

The investigation of strain properties carrying out in the range of deformation $\Delta\varepsilon_{l1} = 0 - 1$ % and $\Delta\varepsilon_{l2} = 0 -$ 2 %. The value of $\gamma_l$ was calculated as angular coefficient of dependence $\Delta R/R$ vs. $\varepsilon_l$, $\gamma_{li}$ – as graphical differentiation of this dependence.

The phase state and crystalline structure were investigated by electron diffraction and electron microscopy methods (high resolution transmission electron microscope TEM-125K).

## 3. RESULT

### 3.1 Structural and phase state

Fig. 1 shows an overview of typical diffraction and TEM-image of thin film Pt(50)/S (S – substrate, the value of thickness is in nm) after annealing during two cycles cycles in temperature interval 300-630 K. The results of diffraction data analysis are presented in Table 1.

The Pt film after annealing to 630 K has polycrystalline structure and consists of nanodimentional grains with the size between 5-7 nm (Fig. 1b). The phase state of Pt film after annealing to 630 K could be clearly assigned as fcc (see Fig. 1a and Tabl. 1). The mean value of the lattice parameter $\bar{a}$ (fcc-Pt) is 0,390 nm. The value agrees well with the tabulated data $a_0$(fcc-Pt) = 0,392 nm [8].

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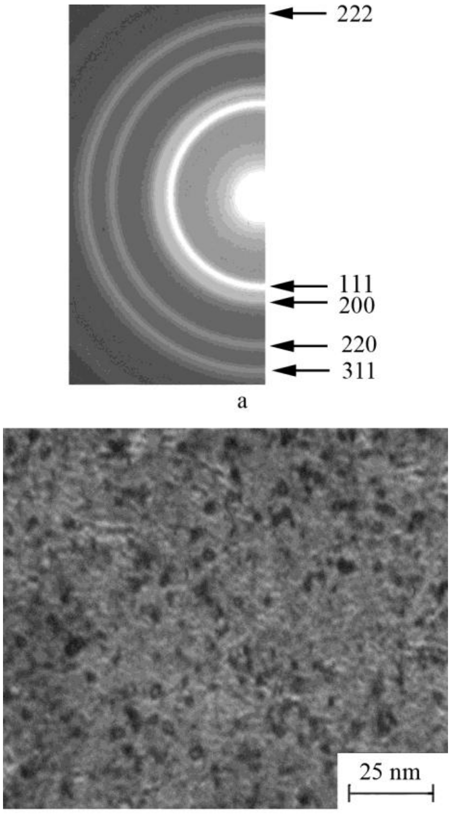


a

b

**Fig. 1** – Diffraction pattern (a) and crystalline structure (b) of thin film Pt(50)/S after annealing to $T_a$ = 630 K

**Table 1** – The interpretation of diffraction pattern for Pt(50)/S after annealing to $T_a$ = 630 K

| № | After annealing to 630 K | | | | | $d_0$, nm, [8] |
|---|---|---|---|---|---|---|
| | I, a.u. | d, nm | Phase | hkl | a, nm | |
| 1 | V H | 0,225 | fcc-Pt | 111 | 0,390 | 0,225 |
| 2 | H | 0,194 | fcc-Pt | 200 | 0,389 | 0,195 |
| 3 | m | 0,138 | fcc-Pt | 220 | 0,390 | 0,138 |
| 4 | m | 0,118 | fcc-Pt | 311 | 0,391 | 0,117 |
| 5 | l | 0,112 | fcc-Pt | 222 | 0,390 | 0,112 |
| $\bar{a}$ = 0,390 nm; $a_0$ = 0,392 nm | | | | | | |

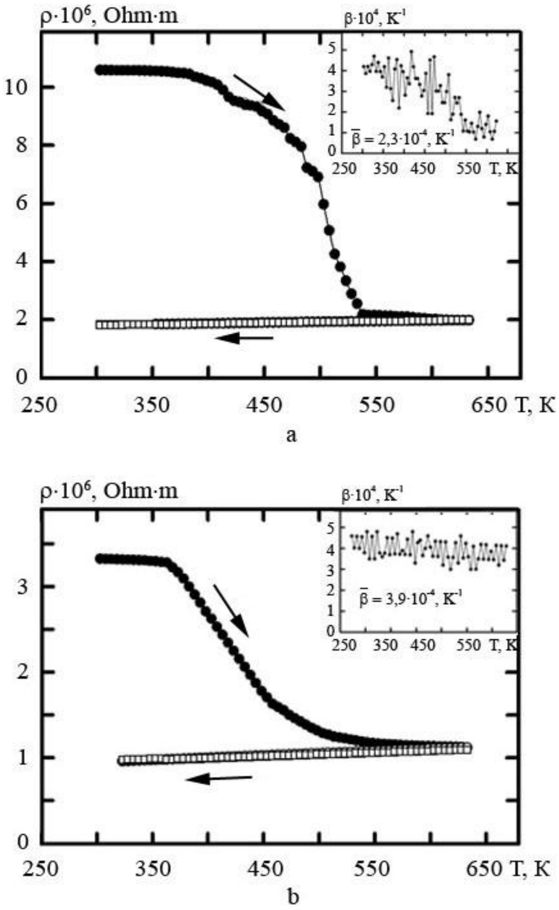
V H – very high, H – high, m – medium, l – low.

### 3.2 Resistivity and TCR

The typical temperature dependences of resistivity and TCR for thin film Pt for two termostabilization cycles in the range of temperature 300 – 630 K are shown in Fig. 2. During first cycles of heating take place healing of defects and after cooling and during second cycle of annealing the dependence has behavior typical for metal films (at increase of temperature the resistivity is increases too). Besides, the characteristic of temperature dependences are relative large value of resistivity ($\rho \sim 10^{-6}$ Ohm m) and relative small value of TCR ($\beta \sim 10^{-4}$ K$^{-1}$) respectively. These results agreed with results of work [9].

### 3.3 Strain properties

Investigation of strain properties of Pt thin films were carried out during VII cycles "load-unload" at two deformation interval: $\Delta\varepsilon_{l1} = 0 - 1$ % and $\Delta\varepsilon_{l2} = 0 - 2$ %. Fig. 3 shows typical dependences $\Delta R/R$, $R$ and $\gamma_{li}$ versus $\varepsilon_l$ for thin films Pt for two deformation interval.



a

b

**Fig. 2** – Temperature dependence of resistivity and TCR (in the insert) for two thermostabilization cycles for Pt(15)/S (a) and Pt (50)/S (b)

According to work [5, 6] the value of $\gamma_l$ dependence on number deformation cycles and starting from V – VII deformation cycles saturates, that's why dependence $\gamma_{li}$ vs. $\varepsilon_l$ for I, V and VII cycles are presented. First deformation cycle discriminated from another by reason of different recrystallization processes. The next cycles are stabilized strain properties of thin films Pt.

The linear character of dependences $\Delta R/R$ and $R$ vs. $\varepsilon_l$ for II – VII cycles could be sequestered with elastic or quasielastic deformation. Notes, Pt thin films characterized by a wide interval of elastic deformation (more than 1 %), relatively low value of gauge factor (near 1,5 – 3 units). The repeatability of results at II-VII cycles and linear character of dependences $\Delta R/R$ vs. $\varepsilon_l$ allows to create based on it strain sensors with stable characteristics.

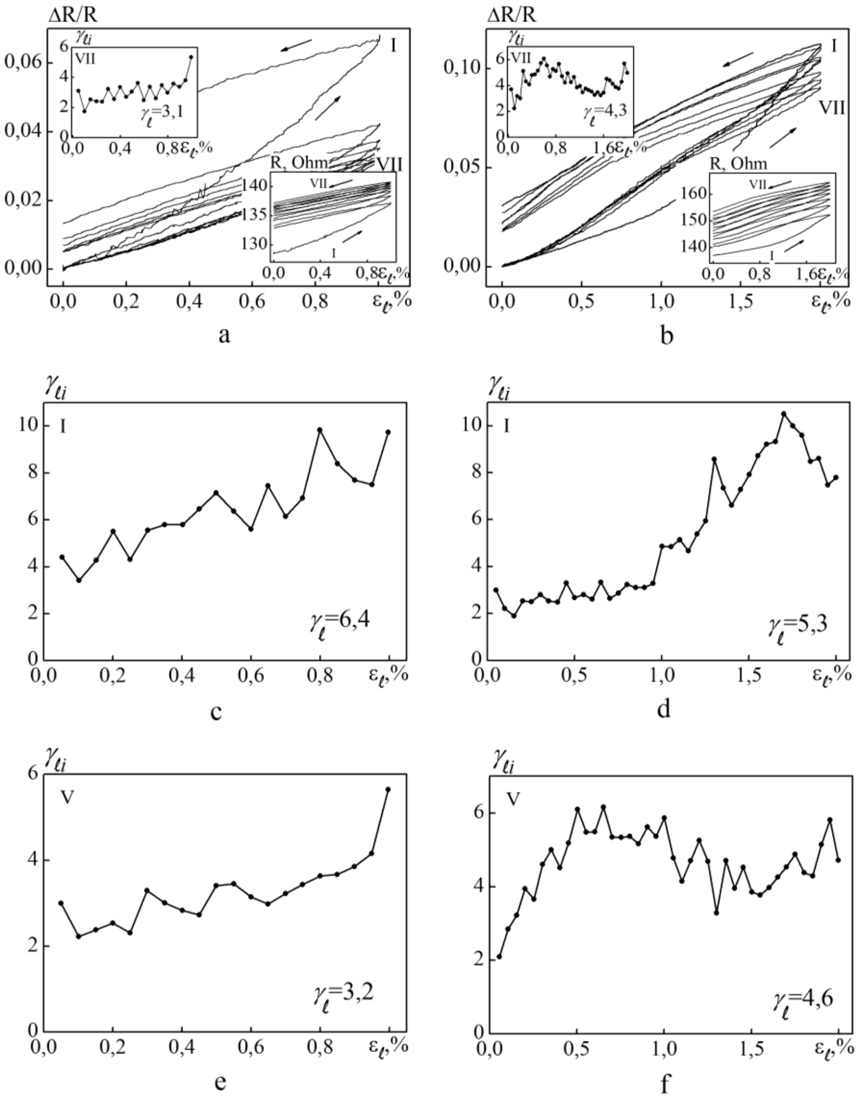


**Fig. 3** – Dependences Δ*R*/*R*, *R* and $\gamma_{li}$ vs. $\varepsilon_l$ (a, b) and dependence $\gamma_{li}$ vs. $\varepsilon_l$ for I (c, d) and V (e, f) deformation cycle for thin film Pt(20)/S at two interval: $\Delta\varepsilon_{l1} = 0 - 1$ % (f, c, e) and $\Delta\varepsilon_{l2} = 0 - 2$ % (b, d, f). I, V, VII – number of deformation cycles “load – unload”

## 4. CONCLUSION

Thin film Pt are polycrystalline with mean value of grains size 3 – 5 nm after condensation and 5 – 7 nm after annealing to 630 K. As a result temperature dependences of resistivity characterized by relative large value of resistivity ($\rho \sim 10^{-6}$ Ohm m) and, respectively, – relative small value of TCR ($\beta \sim 10^{-4}$ K$^{-1}$). Dependences Δ*R*/*R*, *R* vs. $\varepsilon_l$ characterized wide range of strain deformation and low value of gauge factor. The linearity of temperature and deformation (at V – VII cycles) leads to use Pt thin films in nanoscale sensors and devises.

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