Coefficient of Target Erosion Made of GaAs at the Influence of High-Power Pulsed Ion Beam

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Abstract – In the article the results of research on the coefficient of target erosion made of GaAs at the influence of high-power pulsed ion beam are presented. In the experiments the source of high-power ion beams was used. The beam parameters are the following: ion energy is 250 keV, current density at the target is up to 350 A/cm^2, pulse duration is 80 ns. The energy density at the target is up to 7 J/cm^2. The coefficient of target erosion and its dependence on the number of subsequent pulses were changed. The increase of surface roughness (R_z) parameter at the increase of number of subsequent current beam pulses and the formation of regular structure of surface relief at the pulse number of 20–40 were noticed.

1. Introduction

Some laboratories perform the researches on thin film deposition from target ablation plasma formed at the influence of high-power pulsed ion beam [1–5]. The pulse speed of deposition can reach 0.1 cm/s and more. The formation of directed flux of ablation plasma at the influence of high-power pulsed ion beam has mechanisms similar to the use of pulsed laser radiation with the power density of 10^8 W/cm^2 for the same purposes. The coefficient of energy absorption for the beams of charged particles is higher than for the laser radiation. It does not depend on the reflective ability of surface and formed layer of plasma. This seems to be important at the practical application of this method for film deposition. The peculiarities of this method are the invariance of stoichiometric composition of the target material in the film, narrow angle direction of ablation plasma distribution, decrease of requirements to the residual gas pressure in the chamber at the generation of films of high purity. The application of this method seems to be perspective for semi-conductor devices production and particularly the production of sun photo transformers [6].

The determination of behavior of the target pulsed erosion at high number of pulses is very important. And this is the aim of this work.

2. Experiment Setup

The scheme of the experiment id presented in Fig. 1.

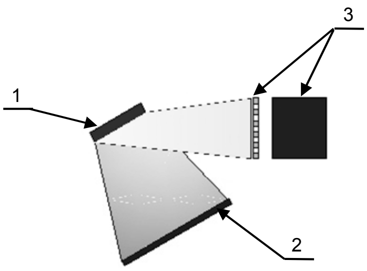

Fig. 1. Experiment Scheme: 1 – target, 2 – substrate, 3 – diode with magnetic self-isolation

In the experiments the source of high-power pulsed ion beams basing on the diode with magnetic self-isolation was used [7]. The accelerating voltage of magnetically isolated diode (MID) was 250 kV, current density at the target was up to 350 A/cm^2, current pulse duration was 80 ns. The oscillogram of current density at the target measured by the collimated Faraday cup is shown in Fig. 2. The power density in the pulse was 80–90 MW/cm^2. The parameter spread of the beam (current density and ion energy) did not exceed 20 % from pulse to pulse. The beam composition includes carbon and hydrogen ions.

Residual pressure in the chamber is 10^{-4} mm of Mercury.

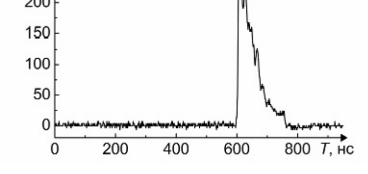

Fig. 2. Oscillogram of Ion Current Density

The sample mass was determined by the method of target weighing before and after pulse influence. The difference in these values contained the value of erosion weight. In the process of experiments the surface morphology was controlled by photographing at the optical microscope and the measurement of roughness by three-dimension noncontact profilometry.

3. Experiment Results

At the GaAs film deposition a significant spread of target erosion coefficient from pulse to pulse can be observed. The spread exceeds the beam parameter spread. The possible mechanism of such a spread can be the modification of surface layer structure of the target and the change of surface relief by the previous pulses of beam current. In this context the measurement of erosion coefficient at the change of pulse number at the target was performed.

The dependence of erosion mass of samples standardized for a pulse from the subsequent pulses of beam current to the target (N_i) is shown in Fig. 3. Each experiment point is average by several samples. The initial roughness of all samples was identical.

Even a higher spread and high value $\Delta m_i/N_i$ at initial values of N_i is typical. After approximately 40–60 pulses to the target the value of distributed mass decreases and stabilizes from shot to shot (Fig. 3). It was found out that at that the surface relief also changes obtaining more regular surface structure with the increase of pulse number, Fig. 4.

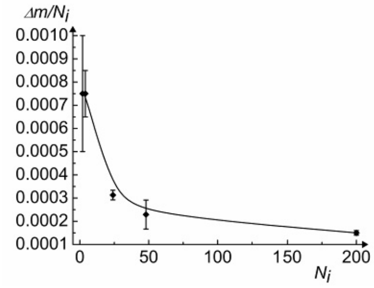

Fig. 3. Dependence of target erosion mass made of GaAs standardized for a pulse $\Delta m_i/N_i$ on the number of subsequent pulses of a current (N_i)

A regular surface structure forms at metal materials at subsequent influence of a large number of beam current pulses. In the papers [7, 8] the pictures of metal target surfaces (Cu, Fe, and Ni_3Fe) are shown with the formation of regular surface structure after the influence of several tens of beam current pulses. The target surface had a wave structure similar to the structure of GaAs target surface relief. So the picture of surface relief formation has a character similar for the material targets and semi-conductive material as GaAs.

In the paper [7] it was informed that the distribution coefficient of copper samples at the influence of high-power pulsed ion beam depends on the size of copper sample grains which in its turn forms at the influence of previous beam current pulses. So we can see that the surface roughness slowly increases with the increase of number of subsequent beam current pulses to the target, Fig. 5. At the roughness parameter value R_z about 30 μm the erosion coefficient for a pulse stabilizes and the incline angle of the curve $\Delta m_i/N_i=f(R_z)$ becomes 30 times lower (Fig. 6). So the erosion coefficient significantly depends on the surface roughness. The distribution coefficient of GaAs depends as on the size of crystals controlled by the beam influence so in the target surface relief which in its turn depends on the current pulse number at the target (Fig. 5). The spread of erosion coefficient decreases from shot to shot and stabilizes with the increase of number of beam current pulses, Fig. 3. The calculated value of erosion coefficient and beam parameters coming from the values presented in Fig. 3 is 0.2 mg/cm^2 for a pulse at $N_i\approx100$.

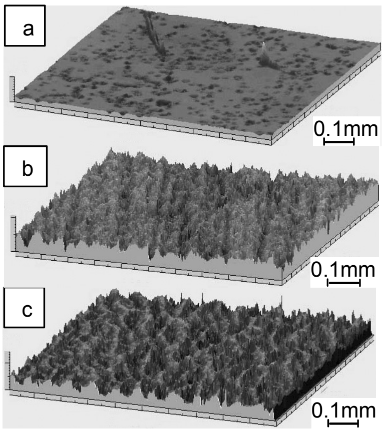

Fig. 4. Picture of initial target surface made of GaAs (a) and target surface after various quantities of current pulses: b) – 4 pulses, c) after 48 pulses

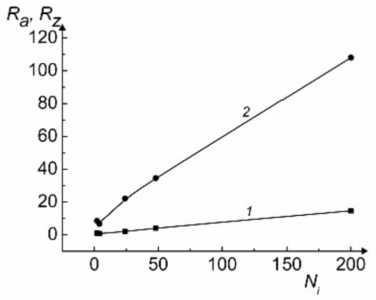

Fig. 5. Dependence of roughness parameters (R_z, R_a) on number of subsequent current pulses to the target

X-ray researches of the used GaAs targets were performed at a diffractometer Shimadzu XRD-600 at CuK(α) radiation. The initial targets represent a perfect monocrystal of GaAs with the cut flatness (111), deviation of cut plane is not more than 0.5°. At the X-ray of initial targets we can observe a reflection of the layer line (RCS)>0.5 μm. After the influence of 100 current pulses the intensity of diffraction lines decreases, integral intensities of diffraction reflections of layer line (hhh) also decreases (for 200 pulses they became ten times lower). Moreover, weak reflections which do not depend on the stated layer line can be observed. Taking into consideration that the analysis depth is 5–6 μm, the presented facts show the appearance of polycrystalline formations of GaAs phase. At that the sizes of coherent scattering area of mono crystalline GaAs decrease down to 20±10 nm, and internal stress significantly increases $\Delta d/d\approx5\cdot10^{-3}$ E.

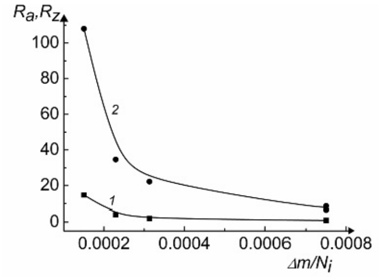

Fig. 6. Dependence of $\Delta m/N_i$ on the roughness parameters R_z, R_a

The formation of regular surface structure, Fig. 4, determines the spread decrease from pulse to pulse.

An important characteristic for practical application is an angular divergence of ablation material. It determines the coefficient of target working substance usage. In the experiments GaAs working target 30 mm in diameter was used for the deposition and study of GaAs films. For metal materials it was shown [9] that the half angle of ablation material spread stays within the range of 20–30° at the target-substrate distance 25–35 mm.

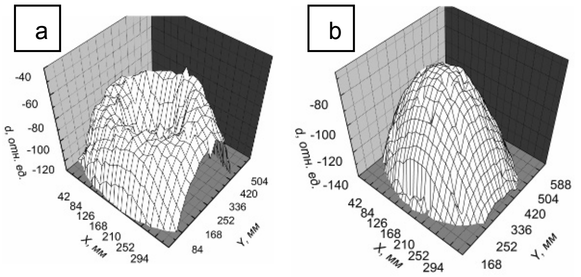

Fig. 7. Profile of film thickness distribution (d) by the substrate: a) target-substrate distance 7 cm; b) target-substrate distance 10 cm

In order to measure the angular dependence of the deposited material as the result of target erosion a lavsan film was used. The correlation dependences of film thickness and optical translucence were measured. Further the films were densitometered, and profiles with the deposited film thickness were built, Fig. 7.

The film deposited at 7 cm distance or less has the smallest thickness in the central part, Fig. 7, *a*. This is associated with the distribution of deposited film by the ablation plasma which has at close distances from the target the density of transmitted energy in the axis part of ablation material flux sufficient for erosion of already-deposited film in the previous pulses. At long distances the density of ablation plasma decreases as well as the density of transmitted energy. The optimal distance which was determined basing on these dependences is 9–12 cm when a significant erosion of film by ablation plasma does not take place (Fig. 7, *b*). A half angle of ablation material spread (Θ/2) is 12° what is significantly less than for metal materials [9]. A significant decrease of angular dependence of ablation material can be connected to the geometric factor of surface relief – deepening aperture when the material part deposits on the deepening surface decreasing a common erosion coefficient.

4. Conclusion

In the paper a special performance of GaAs ablation material spread at the influence of high-power pulsed ion beam with the current density of 300 A/cm^2 (energy density of MID at the target is 7 J/cm^2).

The half angle of ablation material spread is Θ/2=12° at the half-height of maximal film thickness at the distance from target of 10 cm. This value is significantly lower that the one for metal targets.

The coefficient of GaAs material erosion and its spread depends on the number of pulses preceded the measuring which modify the target surface layer changing the surface relief and its roughness, determining the target erosion coefficient.

The target roughness increases with the number of subsequent pulses of current at the target leading to the decrease of material erosion coefficient.

The formation of regular structure of target surface at the influence by more than 20–40 beam current pulses in it was found out. Possibly it is connected to the decrease of spread coefficient of target erosion made of GaAs. The size of crystallites in the surface target layer up to 6 μm is 20 ±10 nm.

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