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CONDITIONS OF EFFECTIVE DEPOSITION OF SUPERHARD MATERIALS IN MEDICINE

Abstract. *In order to obtain qualitative heterogeneous and superlattice structures we developed a method of formation of periodic structures by irradiating with a train of laser pulses. The theoretical and experimental study of the authors in the field of depositing films can be implemented in devices designed for superhard wear-resistant superlattice structures and be used in forming surfaces for implants.*

Key words: *superhard materials, irradiating, implants.*

Introduction. Obtaining superhard and high-strength material layers on the surfaces of implants, crowns and other structures is one of the major problems in Dentistry and Implantology. As a result of applying these layers, service properties of implants substantially improve, especially their wear resistance, fatigue strength and resistance to aggressive environments, which directly affect their operation life and use in tougher conditions.

To optimize the process of applying superhard layers of materials on implants and dental crowns we need information on basic parameters of vapor condensing on the substrate (base of the implant). However, those few previous papers [1,2], which had studied the properties of films obtained by sputtering the target with nanosecond laser pulses, had not practically studied the properties of the vapor phase At the same time, mass spectrometer and probe studies of the vapor phase allow identifying several important parameters of the condensation, optimizing the process of deposition and clarifying the understanding of the physics of evaporation in complicated targets.

Objective: To develop a method of forming periodic structures in irradiation with a train of laser pulses, which ensures qualitative heterogeneous and superlattice structures.

Materials and methods. Techniques for obtaining periodic thin-film structures based on liquid-phase, gas phase and molecular beam epitaxy occupy an important place in modern microelectronics. We have obtained periodic structures (mirrors of the soft X-ray band) in a multiphase laser deposition of films at a speed of 5-10/pulse. In this case the structures are formed over a long time, which imposes strict requirements to the vacuum in the working plants p≤10-9-10-10 torrs. To enhance the technological process of obtaining multilayer structures, to reduce requirements for vacuum conditions, we have proposed and implemented a way to create such periodic structures using a train of laser pulses [2].

Results and discussion. The most acceptable practical realization of the proposed method [1] is a deposition of the periodic structure with a train of pulses of nanosecond duration with the inter-pulse interval 10^{-5}-10^{-4} c. To achieve this goal we use both serial modified solid-state lasers (ruby, neodymium ones) operating in the self-oscillating mode and a CVL with average power P_{aver}=100 Вт.

In the condition when the descending part (slow of thecomponent) of the plasma bunch of the less remote target gets condenced on the substrate before the atoms from the rising edge (fast of the component) of the plasma bunch from a remoter target. This condition can be written down as

$$K = \frac{l_1}{l_2} \le \sqrt{\frac{m_2}{m_1}} \cdot \sqrt{\frac{E_{1\min}}{E_{2\max}}}, \qquad (1)$$

where l_1, l_2 are distances to the target, m_1 i m_2 – mass of the deposited material, $E_{1\min}$ and $E_{2\max}$ – minimum and maximum energy of laser plasma components.

This excludes interaction of plasma bunches with different targets during their transit to the substrate, providing an alternate deposition of layers with sharp borders. The total heads, emerging in this case, as well as energy activation of the substrate and, consequently, lower temperatures of oriented growth [2], reduce the diffusion process between the layers, which helps to ensure sharp boundaries between the layers.

For the proposed technique of deposition the requirements for vacuum conditions reduce dramatically. When the excess pressure in the vacuum chamber $p \approx 10^{-5}$ torrs during the layers deposition $\Delta t = 10^{-5}$-10^{-4} c on100 mm^2 of the surface will be deposited with residual gas molecules not more

$$\sigma = \frac{1}{4} nV\Delta t = \frac{p\Delta t}{\sqrt{2\pi mkT}} = 4 \cdot 10^{7} - 4 \cdot 10^{8} \text{ см}^{-2}, \quad (2)$$

where n – vapor density, V – speed of vapor components in a stream of plasma, m – molecular mass of the component, k – Boltzmann constant, T – plasma temperature.

This is 10^{-7}-10^{-6} of the monolayer, i.e. the requirements for vacuum conditions are only determined by the conditions of transit of plasma bunches through the target-substrate distance without collision with residual gas molecules. The condition (2) can be written down in an easy to use practical form $\gamma = P\Delta t \le 2{,}5 \cdot 10^{-9}$ (torrs·s).

This method was implemented in the diposition of two-component periodic structure Si-SiC. We used a laser on neodymium glass, working in regular pulsations mode with τ=30 ns and an interpulse interval t=9-11μs (5-6 pulses in a train with energy of 0,5 J), and a laser LTY PT-7 with 12.5 Hz repetition rate. Targets (Si, SiC), and the substrate (cleavage KC1) were placed in a high-vacuum chamber, connected to transit time mass spectrometer (residual pressure in the system $5 \cdot 10^{-6}$-10^{-5} torrs). Working laser power density $q = 1{,}5 \cdot 10^{8}$ Вт/cm^2 $E_{1\min} = E_{2\min} = 10$ eВ, $E_{1\max} = E_{2\max} = 200$ eВ.

In our experiments (for the best mode) by (2) the distance substrate- target Si was L1 = 16 mm and the distance substrate –SiC- target - L1 = 50 mm. Radiation was divided by means of a light diffusing wedge so that 0.1 of total energy of the laser pulse fell on the Si-target, and 0.9 - on SiC-target. We also followed the criteria of periodic structure purity.

We have also carried out experiments to check the possibility of obtaining periodic structures both while holding the optimal conditions and violating them. The results are shown in Table.

Implementation of the discussed methods of laser deposition of films from synchronous torches can result into devices for heterogeneous [1] and superlattice [2] structures. The quality of a periodic structure was controlled by ion-photon spectroscopy. The resulting structures were bombed by Ar + ions, and their etching and purity of deposited layers was controlled by glow of the spectral line SiIλ288,2 and by lines of impurities in the

Table

Results of experimental deposition

Order №	$K = \frac{l_1}{l_2}$	p, torr	Δt, c	$\gamma = p \cdot \Delta t$ $\gamma_{опт} = 2{,}5 \cdot 10^{-9}$, torr·c	Positive effect	Note
1	0,32 (optimum)	10^{-5}	10^{-5}	10^{-10} $\gamma < \gamma_{опт}$	+	–
2	1	10^{-5}	10^{-5}	10^{-10}	–	overlapping plasma bunches

	$K > K_{опт}$			$\gamma<\gamma_{опт}$		
3	0,32 (optimum)	10^{-5}	$8\cdot10^{-2}$	10^{-6} $\gamma>\gamma_{опт}$	–	rooting impurities of residual gas in the spectrum of available lines N, C, O

spectrum. When the criteria (1) and (2) were fulfilled, as shown in the table. 1 № 1, we received a periodic structure of 6 Si layers and 6 SiC layers (optimal mode of deposition).

Failure to comply with condition (2), as shown in the table. 1 № 2, leads to overlapping plasma bunches and, consequently, the erosion of the periodic structure (mode of overlapping plasma bunches).

Conclusions. The results of theoretical and experimental studies indicate the possibility to obtain periodic superhard structures by irradiating laser pulses with a train in case of complying with elaborated conditions, the violation of which leads to no positive effect. Deposition of films from synchronous torches and development of devices designed to obtain superhard wear-resistant superlattice structures is one of the ways of embodiment of these theoretical and experimental studies. Such structures of previously modeled properties can be formed on the surfaces of the implants, dental crowns, prosthetic elements.

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