PULSED LASER DEPOSITION METHOD USED IN THE DEPOSITION OF THIN LAYERS ON THE SURFACE OF METALLIC MATERIALS

Mihut Nicoleta-Maria, *Constantin Brâncuși University of Târgu Jiu, ROMANIA*
Tătar Adina Milena, *Constantin Brâncuși University of Târgu Jiu, ROMANIA*
Georgi VELEV, *Tehnical University of Gabrovo, Bulgaria*

Abstract: The Pulsed Laser Deposition (PLD) method is widely used in the field of producing thin layers in particular from materials and combinations of materials that can only be processed with great difficulty by other methods, especially in medicine and dental medicine. In the field of implantology, the functionalization of the implant surface is currently a current approach. The lifespan of implants is determined by the quality of the bone-implant interaction, which is characterized by a close integration of the bone with the implant surface, aiming to obtain an active interfacial bio connection. The realization of such an interface involves complex processes and depends on many factors, in addition to surgical and patient-related. Moreover, the interfacial reaction of the bone in the case of medical and dental implants depends both on the topography and chemistry of the surface, as well as on the mechanical properties of the implant biomaterials used.

Key words: thin layers, Pulsed Laser Deposition, laser radiation

1. INTRODUCTION

Pulsed Laser Deposition (PLD) is a modern thin layer deposition technique often used today. In this method, a laser beam is used which acts in pulsed mode on a target. For an incident energy higher than a threshold value characteristic of each substance, the result is a local heating and evaporation (ablation) of the irradiated material. A plasma is formed, containing species such as atoms, ions and possibly molecules. This plasma is called ablation plasma and it extends in the direction perpendicular to the target, thus transferring the material to a properly placed support [1,2]. The PLD method offers the possibility of working with a wide range of materials and has multiple applications. In this method lasers with different wavelengths and pulse duration of the order of nanoseconds or femtoseconds can be used. The PLD technique allows the deposition of elements, compounds and even polymers [3,4,5,9]. There is also the possibility of synthesizing materials by using a deposition atmosphere that influences the final composition of the layer or by simultaneous deposition of two targets.

2. CREATION OF A SECONDARY X-RADIATION. FLUORESCENT PHOTON

The process of growing the thin layer by the PLD method takes place in four stages:
1. The action of laser radiation on the target.
2. Dynamics of ablated material - plasma expansion.
3. Interaction of the ablated material with a substrate (at a controllable temperature).
4. Nucleation and layer growth on the collector surface.

Each step is important for controlling the parameters of coatings such as stoichiometry, density, crystallinity, uniformity and roughness. In the first stage, the laser beam is focused on the target surface. For a sufficiently high value of the incident laser intensity, all elements in the target are rapidly heated above their evaporation temperature. This value is defined as the ablation threshold. The ablation rate is dependent on the laser flux incident on the target. The ablation mechanism involves several physical phenomena such as collisions, electrical and thermal excitations, exfoliation and hydrodnamics.

During the second stage, the expelled material moves to the substrate and deposits on the collector surface. An important role in the geometry of the deposition and its thickness distribution is played by the size and shape of the spot, as well as the energy of the species contained in the plasma and the target-collector separation distance.

Plasma species energy and target-collector distance (d) are important parameters that determine the quality of coatings. If d is not large enough then the plasma is much too energetic and will produce a large distribution of defects even the destruction of the deposited structure. Plasma species that have sufficient energy condense on the surface of the substrate producing nucleation and increased coating. These will depend on several factors: energy density, degree of ionization, nature of the condensed material, temperature and physico-chemical properties of the collector. Two very important parameters for the growth mechanism are temperature and super saturation Dm.

They are described by the relation:

$$D_m = kT \cdot \ln\left(R / R_e \right) \tag{3}$$

where: k - Boltzmann constant; R - deposit rate; Re - equilibrium value at temperature T.

The crystallinity of the coatings depends on the mobility of the atoms [6]. Initially, the atoms diffuse into the coating through several atomic layers of the coating before establishing their position in the newly formed layer. The temperature of the substrate surface has a decisive role in the diffusion ability of atoms.

High temperatures favor the rapid growth of crystals while low or high supersaturation temperatures can disrupt the growth of crystals due to too energetic species resulting in increased disorder or amorphous structures.

In PLD, due to the duration of the pulses of the order of ns, a short temporal spread of the ablated material and the high frequency of pulse repetition, high deposition rates can be achieved. Consequently, a layer-by-layer nucleation will favor the production of very thin and smooth coatings.

Due to the possibility of independent variation of a large number of parameters, PLD is a versatile technique for obtaining thin layers with a wide variety of morphological and structural characteristics. All parameters can be controlled and varied in order to identify the optimal regime for obtaining structures and thin layers [10]. The main deposition parameters are: wavelength, fluence, laser frequency, pulse duration, energy, target preparation, target-collector distance, substrate temperature, laser spot area, deposition geometry, nature and ambient gas pressure in the deposition chamber.

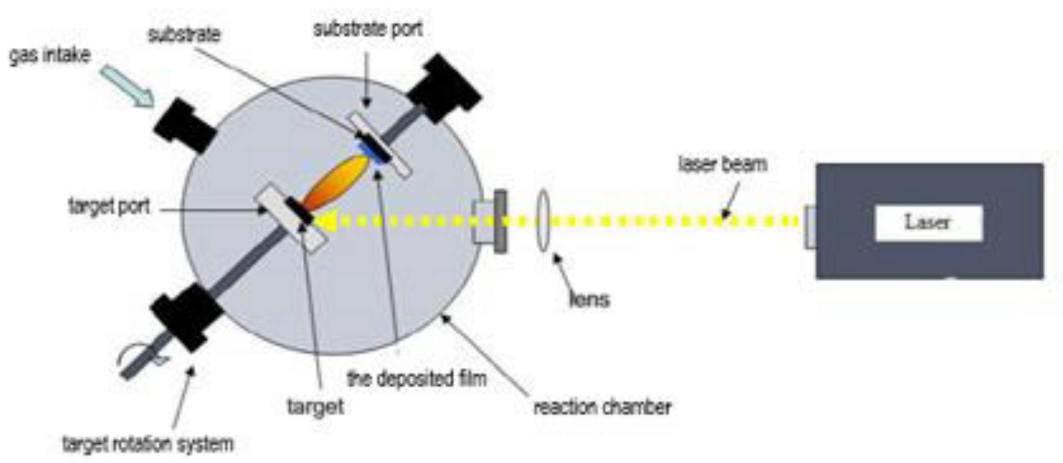

Fig.1. General PLD assembly [1]

The PLD deposition plant consists mainly of a laser source and a stainless steel enclosure, coupled with a pumping system and a gas supply system.

Advantages of the PLD method

The PLD technique has two major advantages: versatility and simplicity of the experiment. The film can be obtained very easily, without the need for further processing, in a reactive gas by using a vacuum chamber and high-intensity UV laser pulses. Any type of material can be removed by the PLD method once adequate irradiation conditions have been established [11]. A key element of the PLD method is the preservation of the stoichiometry of the material in the deposited films. This leads to congruent evaporation of the target regardless of the point of evaporation of each constituent or compound of the target composition.

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This leads to congruent evaporation of the target regardless of the point of evaporation of each constituent or compound of the target composition. Due to the high rate of laser-induced heating, films made by PLD require a much lower substrate temperature than other film deposition techniques. It is therefore necessary to control several important parameters during the PLD deposition process such as: deposition geometry, incident laser radiation flux, substrate cleaning and heating procedure, nature of ambient gas and pressure, possible application of electric fields and / or external magnetic.

In many field of activities are used different types of materials which need to be covered with thin layers for better resistance in use and superior mechanical properties [7,8]. In this way, multilayer films of different materials can be easily obtained by ablation of different types of materials. Using a carousel-type system, where targets of different compositions are loaded, multilayer films can be obtained without opening the deposition chamber.

The thickness of the deposited layer is very precisely controlled by the sequential nature of the process and the number of pulses. It can be specified whether the ablated substance is deposited in the form of nanoparticles or in the form of a thin film. The method has the ability to make an atomic monolayer. Laser processing of materials does not contaminate the receiving substrate and the target during deposition as opposed to spraying. By varying the deposition parameters, micro and macroscopic films with different physico-chemical properties can be obtained.

Disadvantages of the PLD method

The presence of particles or droplets on the surface or embedded in the film is the main problem of this method. The main physical mechanisms that lead to these inconveniences are:

• explosion of the liquid at the interface of the solid;
• condensation of evaporated material;
• hydrodynamic instability on the target surface;
• expulsion of the liquid phase under the action of the recoil pressure of the ablated substance;
• dislocation of the explosive substance caused by the local underground overheating of the target.

The micrometric size of the particles can affect the growth and can damage the quality of the layers deposited later, as well as the optical and electrical properties of the films. Despite this, for some applications, the presence of particles is not considered a disadvantage because it can improve the quality of the films due to the large surface areas. One of the ways to significantly reduce the presence of droplets in films is to reduce the liquid phase content inside the crater and / or choose the appropriate laser wavelength.

Regarding the uniformity of the films on larger substrates, by rotating and translating the target and the substrate, uniform and larger films can be obtained. Because intense laser pulses can break long organic chains and the stored material is irreversibly damaged or altered, the PLD method cannot be extended to the deposition of complex organic molecules. Because of this, a complementary method of PLD has been developed, a matrix-assisted pulsed laser evaporation (MAPLE) that can be applied to more delicate biomaterials.

CONCLUSIONS

Pulsed Laser Deposition (PLD) method is a relatively simple variant of obtaining thin layers on the surface of metallic materials, used in implantology. This is possible because the PLD technique has two major advantages: versatility and simplicity of the experiment, and laser processing of materials does not contaminate the receiving substrate and the target during deposition, which is extremely important because it is known that certain nanoparticles used (eg silver nanoparticles) provides antimicrobial properties for surfaces.

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