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Influence of negative bias pulse parameters on accumulation of macroparticles on the substrate immersed in titanium vacuum arc plasma

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A B S T R A C T

The paper presents the results of an experimental study of the influence of a substrate negative bias with various pulse lengths and pulse repetition rates ranging from several pulses per second to 10^5 pulses per second on the macroparticle accumulation on the substrate immersed in DC titanium vacuum arc plasma. It was found that the increase of the bias pulse frequency from 10 up to 10^5 pulses per second at pulse length 7 μs, as well as bias pulse lengths from 5 μs to 25 μs at fixed frequency of 30 pulses per second at bias pulse amplitude -2 kV and ion-plasma substrate treatment time 30 s led to gradual almost linear up to 3-fold decrease of the surface number density of MPs on the substrate immersed in titanium vacuum arc plasma at plasma ion saturation current density of 10 mA/cm^2. The decrease of ion current density down to 3.5 mA/cm^2 leads to the reduction of the macroparticle suppression efficiency. The influence of multiple recharging of the macroparticles in plasma and the sheath on the reflection of these macroparticles in the sheath electric field is discussed. It was experimentally found that the shape of MPs and their adhesion to the substrate surface strongly depends on bias pulse, plasma and substrate parameters. It was shown that cooled vacuum arc MPs can be melted in high-voltage plasma sheath.

1. Introduction

The active integration of non-biological materials into living tissues has emerged as a novel approach in the field of biocompatible materials. Such integration is highly desirable for the implantation of artificial joints, which must maintain long-term and reliable contact with body tissues. The creation of micropores and exuberant microstructures on the surface of a non-biological material combined with biocoating can improve the integration of biocompatible coatings [1–4].

Stainless steel is one of the widespread materials for implants that must sustain heavy mechanical loads. In this case, the technology for the long-term fixation of the implant can be developed through the deposition of a titanium coating to form a surface structure [5–7]. The adhesion is one of the most important mechanical properties of such coatings. The ability to create controllable exuberant microstructures on the coating surface is also very important. In this regard, there is a substantial practical interest in seeking the possibility of controlling the surface number density of macroparticles (MPs) and their adhesion on the biased substrate.

Several different methods for physical vapor deposition, including thermal plasma spraying as well as vacuum arc and magnetron discharge techniques, are commonly used for such applications [8]. Vacuum arcs found application in different techniques of thin coating deposition and ion-implantation. The advantage of vacuum arc discharge is based on the possibility of coating adhesion improvement using ion-assisted highly ionised metal plasma deposition [9–12]. Arc discharge generates a great amount of macroparticles [13–15], which can be used for surface morphology modification.

The possibility of directly controlling the surface number density of macroparticles on a sample during vacuum-arc plasma deposition was presented in Refs. [16–20]. It was demonstrated that the surface number density of MPs can be reduced by a factor of a few orders by increasing the negative DC bias amplitude and by using repetitively pulsed bias. This paper addresses the study of the surface number density of titanium MPs, their shape transformation and adhesion enhancement depending on negative bias parameters including pulse repetition rate and pulse length.

2. Experimental details

The experimental setup scheme is presented in Fig. 1. The vacuum-arc plasma source with water-cooled cathode and random cathode

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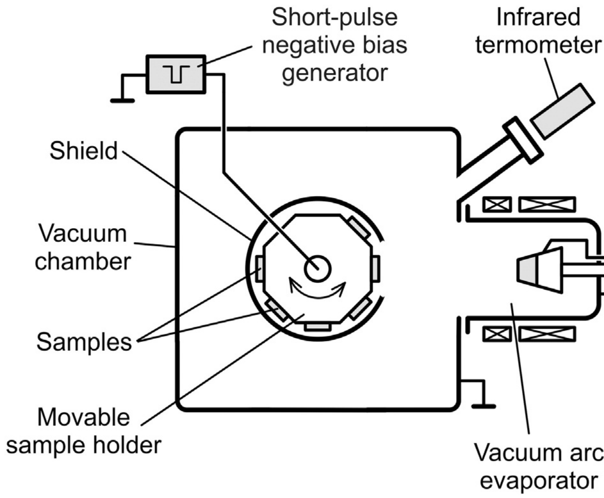

Fig. 1. Scheme of experimental installation.

spot movement was installed on the side flange of the experimental setup. Titanium alloy VT-1 was used as the cathode material. The vacuum-arc discharge current was 100 A. The variation of plasma density near the substrate surface from 33 to 3.5 mA/cm^2 was realized by controlling the distance between the sample and the cathode in the range of 15 to 44 cm. The substrate was preheated by a tungsten heater located beside the sample. For substrate temperature measurements an infrared thermometer was used.

The experimental investigations were carried out by using two short-pulse negative bias generators. The first generator had fixed pulse length of 7 μs. The pulse repetition rate of this generator could be varied from 10 to 10^5 pulses per second (pps).

The second generator had fixed pulse frequency of 3 · 10^4 pps with a possibility to control the pulse length from 1 to 25 μs. The negative bias pulse amplitude of the generators could be varied from 0.5 to 3.5 kV. Stainless steel has been used as the substrate material. The surface of samples was polished ($R_a = 0.035$ μm). The substrates were chemically precleaned using gasoline, acetone and alcohol and located on a movable massive holder, which allows processing several samples in one batch. Each substrate after ion-plasma treatment was investigated using Hitachi TM–1000 electron microscope. Experimental data on the change in the surface number density of MPs are presented in the figures in absolute units. For each experimental point, the total area of the MP counting region—for the sake of statistically adequate results—amounted to 6 × 10^4 μm^2.

3. Experimental results and discussion

3.1. Influence of the frequency and duration of the bias pulse on the content of MPs on the substrate immersed in vacuum arc plasma

The influence of bias pulse frequency on a MP accumulation was carried out at the bias voltage (U_b) of −2 kV and pulse length (τ) of 7 μs. Pulse frequency (f) of the bias potential was varied from 10 to 10^5 pps. Characteristic waveforms of pulsed bias voltage and substrate current at different frequencies (1.4 · 10^4, 2.5 · 10^4 and 5 · 10^4 pps) are presented in Fig. 2.

Stainless steel samples of 2 × 2 × 0.3 cm^3 in size were installed at three distances from the cathode of arc plasma source (15 cm, 24 cm and 44 cm). By increasing the distance between the cathode surface and the substrate, we decreased plasma ion saturation current density (j_i) from 33 down to 3.5 mA/cm^2. In these experiments, the processing time was 30 s. The experimental data of the MP amount on the steel sample versus pulse frequency are presented in Fig. 3. In all cases, increasing the bias pulse frequency from 10 to 10^5 pps led to a gradual reduction in the number of MPs deposited on the substrate immersed in vacuum arc titanium plasma. Near-linear dependences of the number density (n) of MPs versus bias pulse repetition rate were observed for

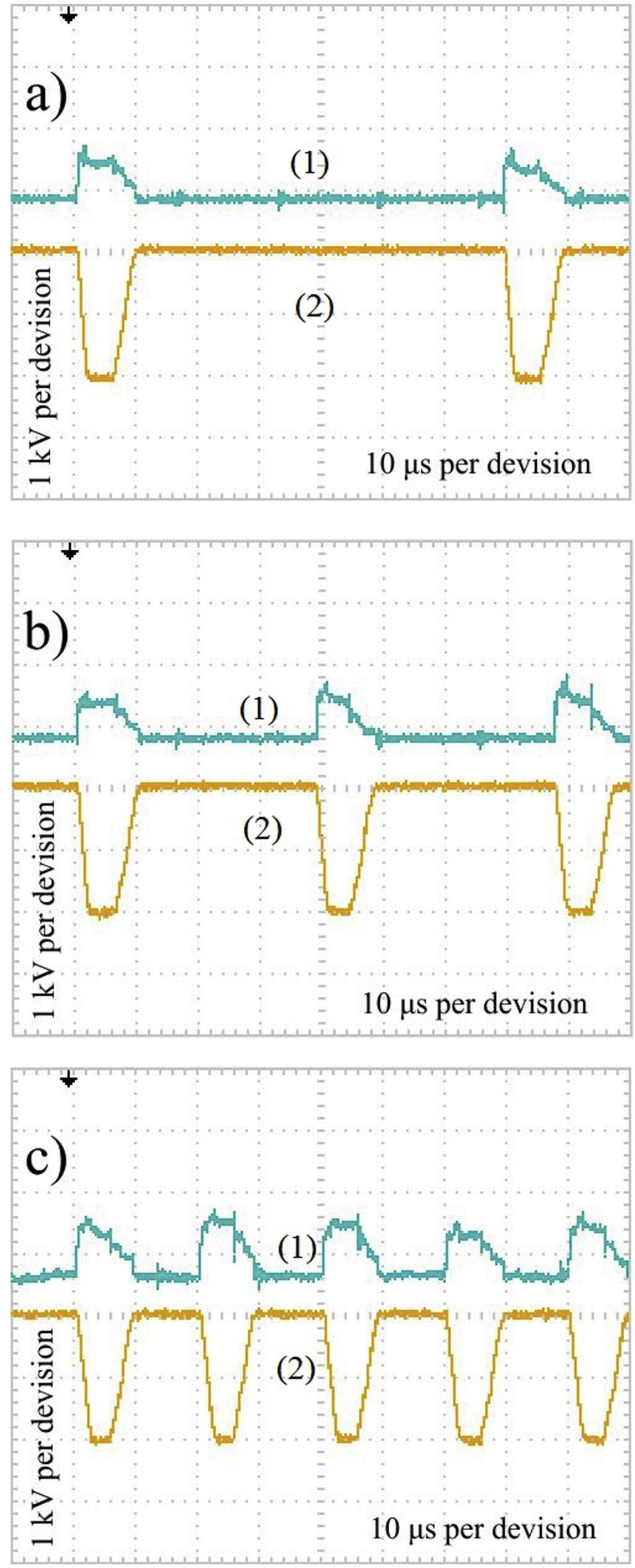

Fig. 2. Oscillograms of negative bias pulses (1) and substrate currents (2) at different frequencies: a – 1.4 · 10^4 pps; b – 2.5 · 10^4 pps; c – 5 · 10^4 pps.

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