PLASMA DYNAMICS STUDIES IN DEVELOPMENT OF IPD METHOD OF SURFACE ENGINEERING

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During the Impulse Plasma Deposition (IPD) process of surface engineering plasma is generated in the working gas due to a high-voltage high-current discharge, ignited within an interelectrode region of a coaxial accelerator. The paper presents computational studies of working medium dynamics during the IPD discharge. Plasma has been investigated with a two-dimensional two-fluid magnetohydrodynamic code. Presented analysis of discharges outside the typical exploitation parameter range increases the understanding of phenomena relevant to process of coatings deposition.

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INTRODUCTION

The impulse plasma generated by the electric discharge can be used in surface engineering for synthesizing various materials and depositing coatings as thin layers. In particular, in the beginning of 1980 s the Impulse Plasma Deposition (IPD) was developed [1, 2]. During the IPD process plasma is generated in the working gas due to a high-voltage high-current discharge, ignited between two coaxial metal electrodes (a cylinder and a rod, insulated one from the other by a ceramic material) in a gas-filled vacuum chamber connected to a capacitor bank (Fig. 1). Typical parameters of IPD process fall into the following ranges: condenser bank capacitance C = 100...200 μF, voltage U = 2...6 kV, external circuit inductance L = 1.25 μH, working gas pressure p = 20...60 Pa. At the outlet of the device, plasma consists of the ionized atoms of the working gas and the eroded electrode material. Using the IPD process coatings of a diamond-like carbon, c-BN, oxides (e.g., Al_2O_3), amorphous and nanostructured high-melting materials, the intersitial phases (e.g., the titanium nitride) and multi-component metallic alloys could be deposited on various non-heated substrates.

Plasma parameters in the region of the electrodes' front head are very important for the quality of the coatings. Thus, changes of IPD process dynamics become an important factor in facility optimization. Computer simulations [3, 4] have significantly increased the understanding of phenomena during the technological process; they also allow indicating the direction of the optimization changes in the development and application of the Impulse Plasma Deposition method of surface engineering.

COMPUTATIONAL SIMULATIONS

According to a physical model [3] of dynamic phenomena in the IPD device at the initial stage of the accelerator work a rapidly rising electric current flows across the back wall insulator, and an axially symmetric electric current sheet forms on the insulator surface. Current flowing within this layer induces an angular magnetic field behind. Plasma spreads out in the form of a dynamically moving electric current sheet which is accelerated by the Lorentz force, induced by the interaction of the current with its own magnetic field. Since the strength of magnetic field decreases proportionally to the radius, the current carrying layer acquires a paraboloidal shape causing the plasma flow toward the external electrode just as a snow plow does. The schematic pattern of the described discharge region is presented in Fig. 2. At the end of discharge the fall of current value causes the magnetic piston to vanish and reversal shocks occur.

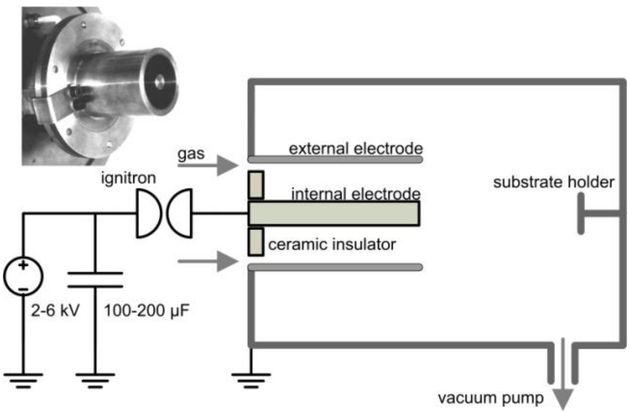

Fig. 1. Scheme of the IPD accelerator

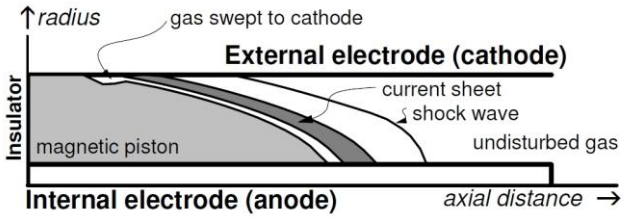

Fig. 2. Schematic pattern of the discharge region

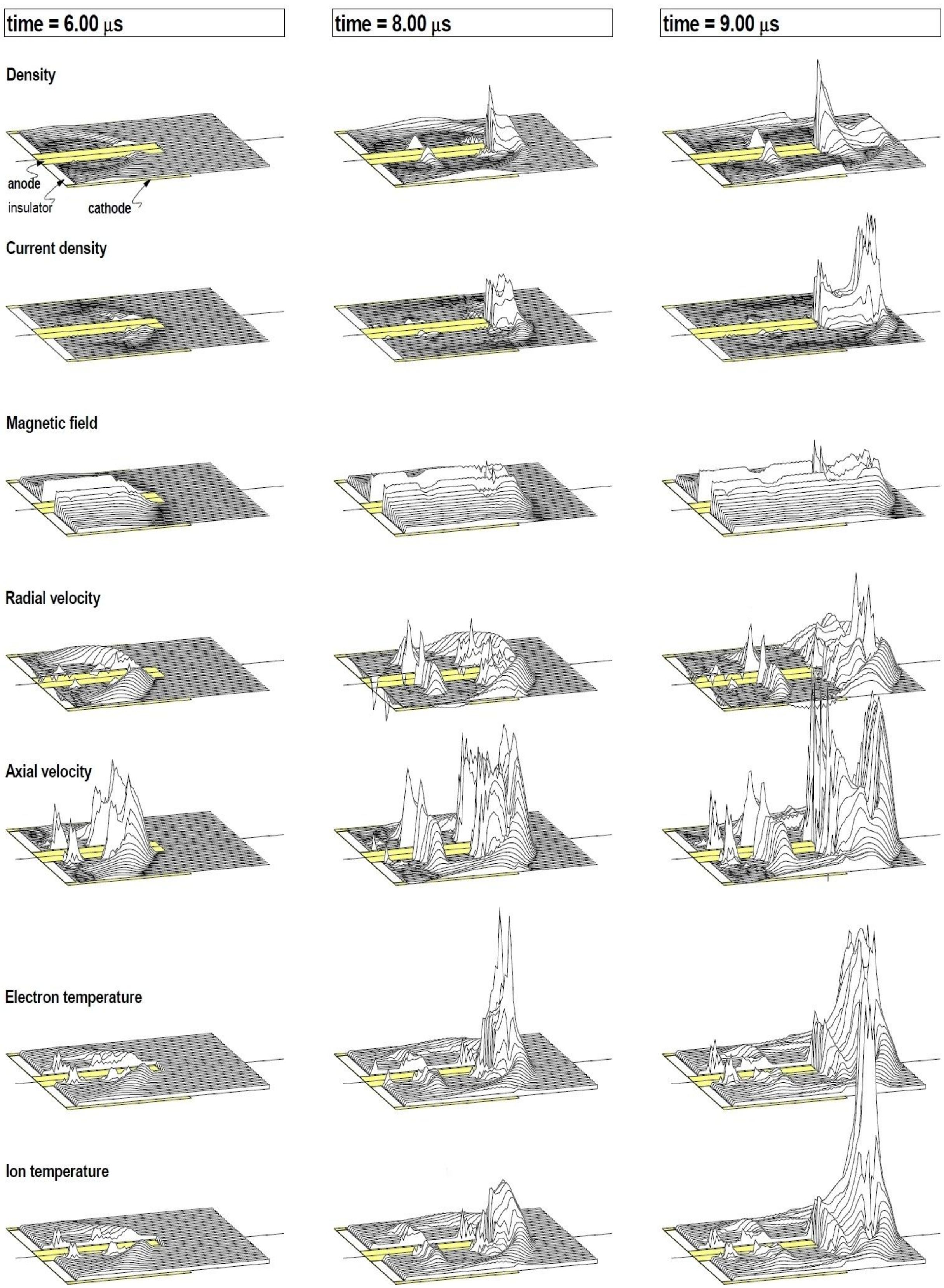

Fig. 3. Sequence of calculated plasma parameters distributions for the IPD accelerator (working gas at p = 10 Pa)

The two-dimensional magnetohydrodynamic (MHD) approach has been applied to investigate the sweeping of the working gas by the moving layer, as well as the details of phenomena that take place behind the discharge region. Mathematical model is based on a set of coupled transport equations for the medium composed of electrons and one sort of ions. Thus, plasma is described by a self-consistent system of two fully ionized fluids. The conservation equations for mass (continuity equation), momentum, magnetic flux (Faraday's law) and plasma energy densities are solved simultaneously with the Maxwell-Ohm law for the electric circuit. Cylindrical symmetry is assumed, as well as the magnetic field is restricted to the azimuthal

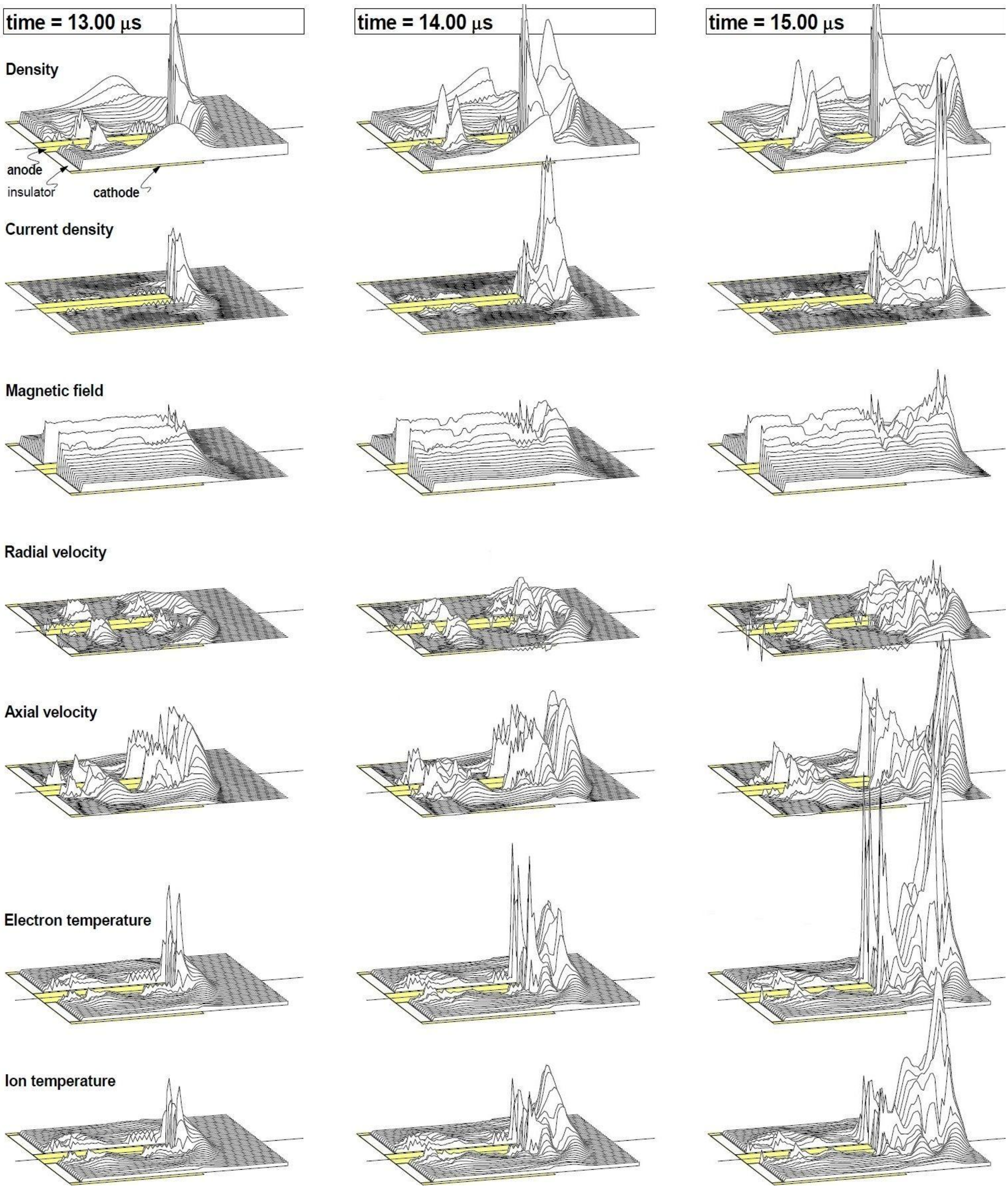

Fig. 4. Sequence of calculated plasma parameters distributions for the IPD accelerator (working gas at p = 70 Pa)

direction. The modified and extended version [4] of code [5] originally evaluated by D.E. Potter [6] for the modelling of Plasma-Focus devices has been applied.

During the computational studies the influence of different parameters was investigated for the accelerator with the positive and negative polarization of the electrode system (an internal anode vs an internal cathode) [7], as well as use of a squirrel-cage-type external electrode [8] was also analysed. The latest studies confirm significant changes of the internal structure of the discharge region caused by the application of a pulse valve for the gas injection into the IPD accelerator [9].

As an illustration of recent computational investigations, the sequences of plasma parameter distributions are presented for electrodes' length – 10 cm, the internal electrode radius – 0.7 cm and the outer electrode radius – 3.7 cm. The latest stages of plasma column formations are shown in Fig. 3 for typical condenser bank capacitance C = 200 μF and external circuit inductance L = 1.25 μH. The assigned working gas pressure p = 10 Pa was imposed at lower level than usually applied during process of coatings deposition. In the considered case time needed for snow plow structure to reach the internal electrode end is noticeable shorter (2...3 μs) than in the instance of typical IPD process. Unfortunately, plasma temperatures achieved in the pinched column are noticeable lower, which results in an unacceptable change for the worst of the deposited coating quality.

Analogous simulations (Fig. 4) have been carried out for working gas pressure of p = 70 Pa – higher than in the regular conditions. Driven by the Lorentz force, the current sheet propagates axially along the electrodes to the open end. Nevertheless, sweeping up of the noticeable higher amounts of the gas leads to significant deceleration of process dynamics. Thus the time needed to reach the internal electrode end becomes 3...4 μs longer. Calculated distributions of plasma parameters demonstrate a partition of the discharge front into two structures, separated because of the significantly different velocities within the forehead portion of plasma. Such partition jointly with the amounts of gas gathered on the snow plow layer create perfect conditions for evaluation of Rayleigh-Taylor instability on the separated surfaces. Appearance of such phenomena on whichever structure definitely destroys a whole build up discharge.

CONCLUSIONS

Plasma parameters in the region of the electrodes' front head are very important for the quality of the coatings. Presented analysis of discharges outside the typical exploitation parameter range increases the understanding of phenomena relevant to process of coatings deposition during the Impulse Plasma Deposition process of surface engineering.

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ИЗУЧЕНИЕ ДИНАМИКИ ПЛАЗМЫ В РАЗРАБОТАННОМ ИПО-МЕТОДЕ ИНЖЕНЕРИИ ПОВЕРХНОСТИ

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Во время процесса импульсного плазменного осаждения (ИПО) в рабочем газе генерируется поверхностная плазма благодаря развитию высокоточного разряда с высоким напряжением, который инициируется в межэлектродном пространстве коаксиального ускорителя. Приведены расчетные исследования динамики средних условий работы во время ИПО-разряда. Плазма исследовалась с помощью двумерного магнитогидродинамического кода для двух жидкостей. Представленный анализ разрядов за пределами типичного диапазона эксплуатации параметров увеличивает понимание явлений, имеющих отношение к процессу нанесения покрытий.

ВИВЧЕННЯ ДИНАМІКИ ПЛАЗМИ В РОЗРОБЛЕННОМУ ІПО-МЕТОДІ ІНЖЕНЕРІЇ ПОВЕРХНІ

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Під час процесу імпульсного плазмового осадження (ІПО) в робочому газі генерується поверхнева плазма, через розвиток високоточного розряду з високою напругою, який ініціюється в міжелектродному просторі коаксіального прискорювача. Приведені розрахункові дослідження динаміки середніх умов роботи під час ІПО-розряду. Плазма досліджувалась за допомогою двомірного магнітогідродинамічного коду для двох рідин. Представлений аналіз розрядів за межами типового діапазону експлуатації параметрів збільшує розуміння явищ, що мають відношення до процесу нанесення покриттів.