NUMERICAL MODELLING OF PLASMA IN IPD PROCESS

Marek Rabiński[1] and Krzysztof Zdunek[2]

[1]*Dept. of Plasma Physics and Technology, The Andrzej Sołtan Institute for Nuclear Studies 05-400 Otwock-Świerk, Poland; e-mail: rabinski@cx1.cyf.gov.pl*

[2]*Faculty of Materials Science, Warsaw University of Technology, 85 Narbutta, 02-524 Warsaw, Poland; e-mail: zdunek@inmat.pw.edu.pl*

1. Introduction

In surface engineering plasma can be used as an efficient source of mass and energy for the synthesis and deposition of various materials as layers. During the IPD (Impulse Plasma Deposition) process [1] metallic plasma is generated within the working gas due to a high-voltage high-current discharge, ignited within an interelectrode region of a coaxial accelerator [1-3]. Throughout such a discharge the internal electrode undergoes electroerosion, and as a result the plasma is enriched with products of the erosion. At the outlet of the accelerator, the plasma consists of ionised atoms of the working gas and the electrode material. In addition, these products may react chemically, including the phase nucleation.

A short lifetime (100 μsec) of the plasma and its high ionisation are the characteristic features of this technique. Coatings made of diamond, titanium nitride, multicomponent metallic alloys and aluminium oxide adhere well to the substrate, although no external source heats them during the process. The IPD has been implemented on the industrial scale at the Steel Works of STALOWA WOLA (Poland) for depositing TiN coatings on cutting tools.

2. Structure of discharge region

The plasma is generated and accelerated in a coaxial accelerator discharge chamber containing two electrodes - internal (a rod) and external (a tube), insulated one from another by a ceramic insulator. When the capacitor bank is discharged through the gas, an axially symmetric current sheet forms at the surface of the insulator. The current flow causes an azimuthal magnetic field behind the current carrying sheet. Driven by the Lorentz force the sheet propagates axially along the electrodes to the open end, sweeps up the ionised gas and leaves behind a vacuum region in its wake. Magnetic field in the vacuum behind the current sheet acts much like a piston. The sheet advancing rapidly along the electrodes creates a shock ahead of it.

One can distinguish the three regions in the discharge space between the electrodes [4]: undisturbed gas in the front, intermediate plasma region of discharge and magnetic piston next to the insulator. The discharge region is confined within the front edge of the magnetic piston, which is also the back end of the preceding current sheet. The ordinary gasdynamic shock wave separates the plasma in the intermediate region from the undisturbed gas ahead.

Magnetic field intensity increases with decreasing radius, so that the magnetic pressure at the internal electrode exceeds significantly its value at the outside electrode. It causes a paraboloidal shape of current carrying interface and induces plasma flow along the sheet to the outside, much like the snow plow. Interface shape results from the balance of the magnetic and fluid pressures. Upon reaching the front end of the central electrode, the sheet diffracts around it and pinches on the axis.

3. Snow plow model

The details of the phenomena that take place in the region between shock and magnetic piston can only be described by the solution of a complete magnetohydrodynamic model. Simplified two-dimensional snow plow model [5] assumes that all the swept up mass is compressed into an infinitely thin layer immediately behind the shock. Thus the magnetic piston edge, the current sheet and the shock form the same interface. The intermediate plasma region is reduced into an infinitely thin surface.

The advantage of the snow plow theory lies in that it allows a relatively simple but accurate calculation of the current sheet dynamics. Numerous studies proved that, despite the simplifications, the discrepancy between the snow plow model and the full magnetohydrodynamic description is surprisingly small [6].

4. Dynamic phenomena in coaxial accelerator

Computer simulations with the snow plow code show that the time needed for plasma discharge to reach the electrode end and pinch on the axis is about 15-20 μsec, that is one fourth of the current half-period. During the rest of time massive erosion of the anode front end occurs. At the end of this phase, a rapid decrease of current value destroys the magnetic field supported interface between the vacuum and the swept up gas mixed with metallic plasma.

Even phases of accelerator work (second and fourth half-period) occur with the change of electrodes polarisation. Experiments [7] carried out in plasma devices with central cathode prove significant differences in the discharge pattern caused by polarity change. The current sheet is more then twice as thick as that formed with internal anode. The sheet is also not so well defined and is almost perpendicular to the channel walls. Actually its shape is concave, which causes plasma to gather on the moving interface and the motion to decelerate significantly. Therefore, the current sheet cannot approach the end of the cathode. At the end of each phase the fall of current value causes the magnetic piston to vanish and reversal shocks occur.

The lowering current amplitudes in the consecutive half-periods are an additional reason for the plasma approaching nearer and nearer range along the electrodes. At the end of each phase the weakening magnetic piston slows the current sheet motion, stops it or even causes its reverse movement. This leads to massive electroerosion of the electrode material at the sheet foot. As a result after many discharges one can observe a characteristic form of eroded central rod. Moreover, the alternating direction of the current flow during the end of consecutive discharges leads to alternate the direction of central electrode magnetisation [2].

5. Numerical modelling of IPD dynamics

Computational model of plasma dynamics during the IPD has been worked out on the basis of a snow plow description of current sheet motion [4]. The evidence of favourable conditions for the Raleigh-Taylor instability evaluation on the current sheet surface has been proved during the recent studies. Appearance of these phenomena explains observations of a toroidal ring of dense plasma in the front of the central electrode. The influence of discharge conditions on instability formation has been found (see Fig. 1). The electrode geometry also has been analysed. When the current sheet could migrate towards the chamber wall (electrode joined with the chamber) plasma is distributed over a larger volume and its concentration is lower. In the case of electrode isolation from the wall plasmoid density is much higher, which results in the intense heating of a substrate and obtaining $\alpha-Al_2O_3$ coatings instead of common $\gamma-Al_2O_3$.

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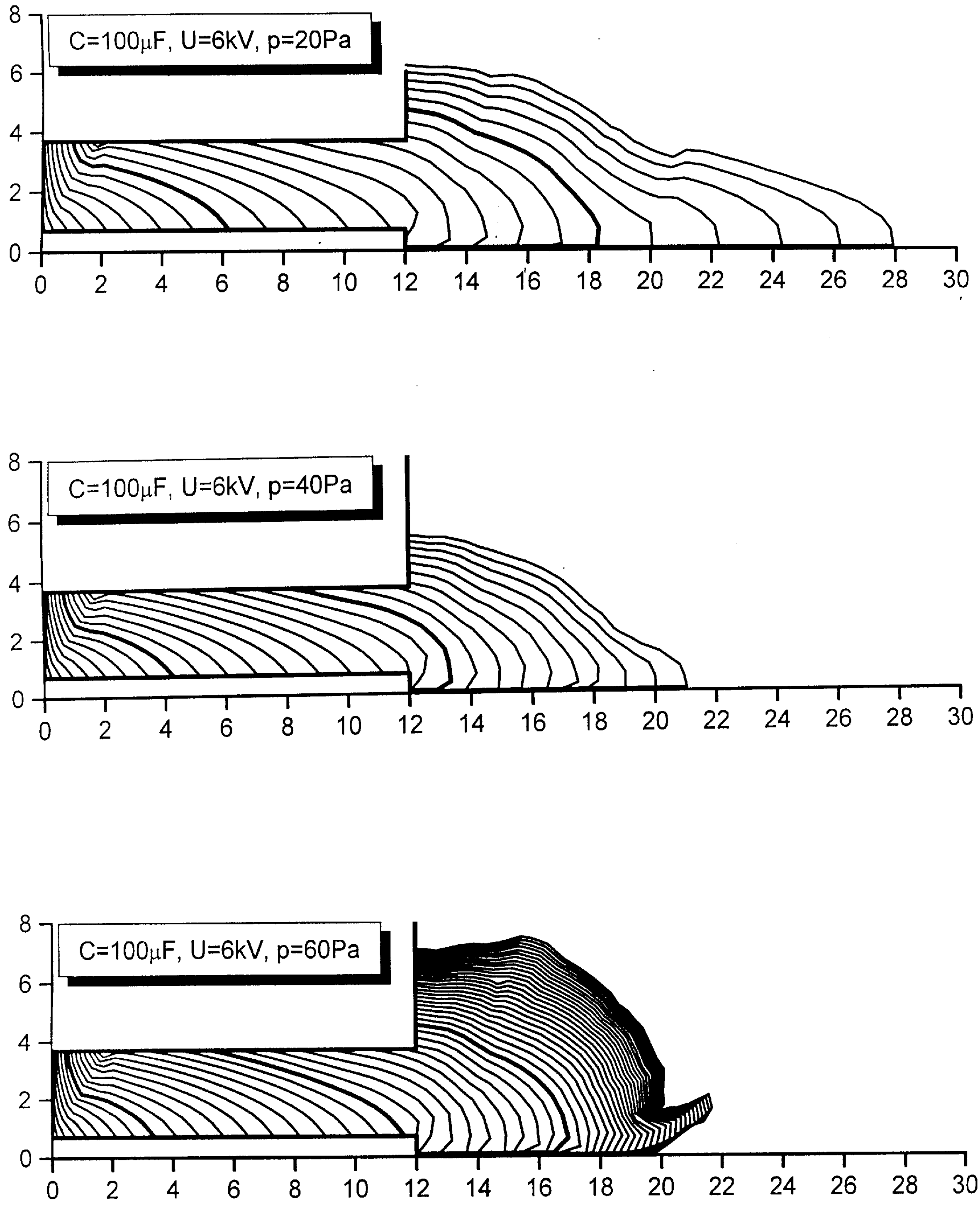

Fig. 1. Current sheet dynamics in the IPD accelerator
for several discharge conditions
(plotted with *1 μsec* interval).