Surface Resistivity Tailoring of Ceramic Accelerator Components*

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Abstract

Metal plasma deposition and metal ion implantation techniques have been developed that could provide a good tool for the surface modification of insulating materials for accelerator applications such as ceramics and that could provide a method for tailoring the surface resistivity over a range of many orders of magnitude. The methods make use of the metal plasma that is produced by the cathodic arc discharge; the plasma itself can be deposited onto the surface at an energy of order 100 eV so as to form an adherent thin film, or an energetic metal ion beam can be formed for deep implantation of the metal species below the surface so as to incorporate a controllable amount of metallic composition into the ceramic.

I. INTRODUCTION

High voltage insulators for accelerator application need to be of very high resistance for good voltage hold-off and the resistivity needs to be uniform so that the electric field is uniformly distributed along the insulator length. The insulator bulk material normally has a higher voltage holdoff capability than a vacuum gap of the same size; the weak point of the insulator is its surface and in particular the triple junction (the interface of insulator, vacuum and electrode). It has been found that surface coatings which are more conductive than the bulk material are useful, and surface treatments which penetrate into the outer layers of the insulator are particularly resistant to surface damage caused by surface flashover (for an excellent review see [1]).

In other applications, for example for beam deflectors, it would be advantageous to be able to form a conducting coating on an insulating component to define an electric potential and also allow rapid penetration of a magnetic field.

Metal plasma deposition and implantation techniques provide a means to modify the surface and the first few hundred angstroms of many materials, including ceramics and other insulators. The surface conductivity can be changed continuously from a value typical for ceramics to a value typical for metals by depositing metal films of various thickness.

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Essential for this purpose is a very good adhesion of the metal films. By implanting the metal ions deep into the material, the modification of the conductivity can be extended to a layer of several hundred angstroms. Here we outline the plasma and ion beam tools that we've developed and describe their applications for this function.

II. VACUUM ARC PLASMA DEPOSITION

A. The Vacuum Arc Plasma Sources

Plasma sources based on vacuum arc discharges have been used for the production of the metal plasmas. The plasma source consists of a rod cathode and a cylindrical anode (Fig. 1); the arc discharge is triggered by a high voltage spark. The arc current is typically 50-300 A, and the arc duration and repetition rate can be varied in the range of 10 μs - 10 ms and from single shot to 10 Hz, respectively.

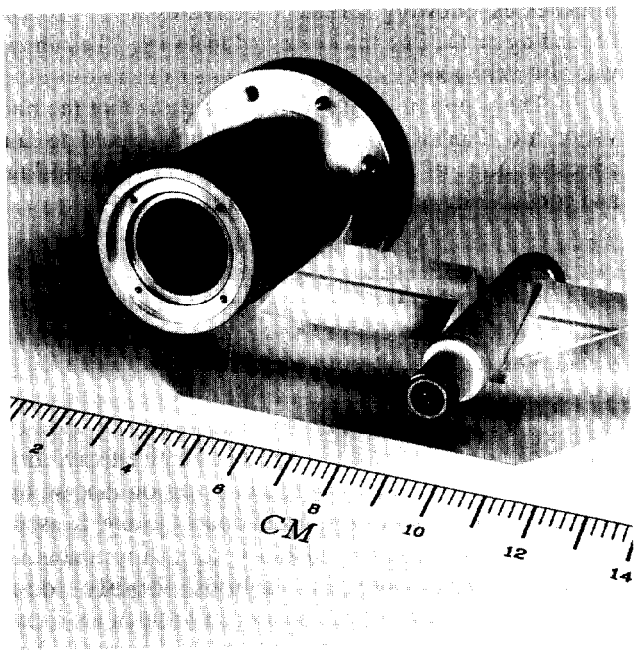

Figure 1: Plasma gun (dismantled) of the type used for the deposition of metal on the inside of ceramics tubes. Left - anode, right - cathode holder with cathode.

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Fully ionized metal plasma with mean ion charge states between 1 and 3 [2] for the different metals is produced and streams away from the plasma source with a directed kinetic energy of the ions of typically 100 eV [3]. The plasma stream can be focused by an axial magnetic field around the electrodes, providing a dense directed plasma stream with a density of order 10^{18} m^{-3}. By adjusting the arc current, pulse length and the distance between plasma source and substrate, films of thickness between a monolayer and many micrometers can be produced. Due to the possible small dimensions of the plasma sources (we have developed a micro-version with a length of 7 cm and a diameter of 2 cm [4]) the application is very flexible, e.g. the plasma sources can be moved inside of tubes or around samples with complex shapes. Vacuum arc plasma sources can also be scaled up to large facilities [5] with kiloamperes of arc current and very high deposition rates, up to hundreds of micrometers per second.

B. Experiments and Results

A number of experiments have been done to show the relevance of this method. A gold film was deposited on an alumina surface with a thickness of about 1 μm and a resistivity of 0.5 Ω/sq. The adhesion of the film was tested by the usual "scotch tape test" and found to be very good. This is a consequence of the high ion energy.

The insides of several alumina tubes of 4 cm diameter were covered by titanium and gold films of various thicknesses, showing surface resistivities of 1 - 10 Ω/sq depending on the film thickness and material. The adhesion was also very good.

These preliminary experiments show that the metal vapor arc deposition technique is well suited to form adhesive films of various metals of the desired thickness and conductivity on ceramic materials.

III. METAL ION IMPLANTATION

A. The Vacuum Arc Ion Source

The ions of a vacuum arc plasma can be extracted and accelerated to form an ion beam of high energy. In the multicathode, broad beam ion source version that we have developed [6], a three grid accel-decel system is used to accelerate ions to energies up to 300 keV. Any conducting, solid material (metals, alloys, highly doped semiconductors, carbon) can be used as vacuum arc cathode material, and an ion beam of up to several amperes during the arc pulse and up to several tens of mA time-averaged is produced. The substrates can be mounted on a fixed or rotating water-cooled sample holder. The beam diameter (FWHM) can be as large as 33 cm [7] thus allowing metal ion implantation on an almost industrial scale.

B. Experiments and Results

We have used our vacuum arc ion implantation facility to implant Ti ions with an energy of 100 keV and a dose of 10^{16} cm^{-2} into alumina ceramic pieces. The ceramic pieces had a cylindrical shape, a diameter of 40 mm and a height of 5 mm; they were polished to a micro-roughness of about 20 μm. During the implantation, the samples were continuously rotated to ensure a uniform implantation. After implantation the end faces were covered with a 1 μm thick gold film using the vacuum arc plasma sources described in section II in order to provide contacts for subsequent resistance measurements and breakdown tests. These tests showed that the relatively low dose implantation decreases the resistance of our samples to about 10 GΩ, which is rather low for electric field control purposes. Further experiments are planned with lower implantation doses.

To compare the results of metal ion implantation into ceramics with calculations, and to predict the implanted depth profile and retained doses, we have measured the implanted depth profiles for an Ti implantation into Al_2O_3 with an ion energy of 100 keV and a dose of $6x10^{16}$ cm^{-2} by Rutherford Backscattering Spectrometry (RBS). Fig. 2 shows the implantation depth profile calculated with the T-DYN 4.0 computer code [8] in comparison with the measured data.

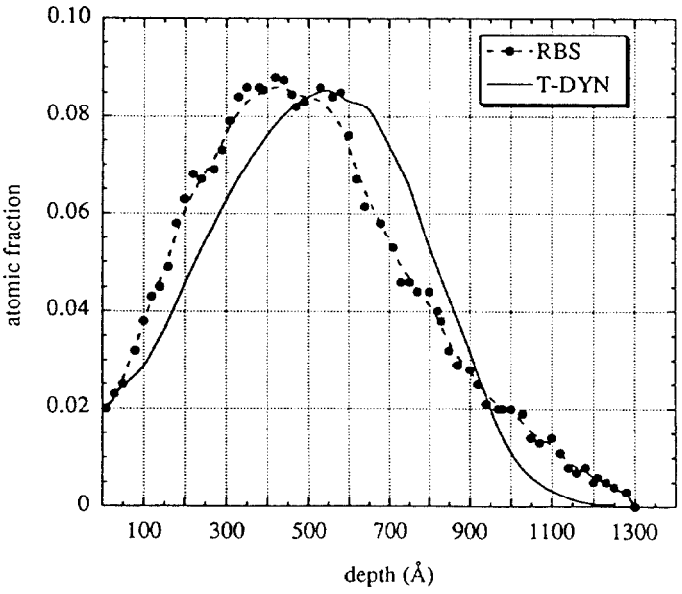

Fig. 2: Implantation depth profile for a Ti implantation into Al_2O_3 with an ion energy of 100 keV and a dose of $6x10^{16}$ cm^{-2}. Comparison between experiment (RBS profile) and calculation using the T-DYN 4.0 code [8].

The maximum fraction of Ti was 9 % at a depth of about 500 Å; the substrate was modified by the implantation up to a depth of almost 1500 Å. The agreement between calculation and experiment is good.

IV. CONCLUSIONS

It has been shown that vacuum arc deposition techniques provide a useful means for the formation of well-bonded conducting metal films to ceramics. The method is very flexible with respect to deposited material, film thickness and substrate shape.

Ion implantation based on plasma formation by vacuum arcs is a further tool for modification not only of the ceramic surface but to a depth below the surface of a few thousand angstroms. By implanting metal ions with a defined dose and energy, the conductivity of the insulator surface can be tailored as desired, either homogeneous or with gradients over the insulator surface. A combination of both techniques widens further the possible fields of applications.

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