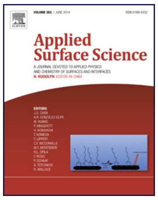
Applied Surface Science xxx (2014) xxx–xxx

Contents lists available at ScienceDirect

Applied Surface Science

journal homepage: www.elsevier.com/locate/apsusc



Sheet resistance of alumina ceramic after high energy implantation of tantalum ions☆

Konstantin P. Savkin[a,*], Alexey S. Bugaev[a], Alexey G. Nikolaev[a], Efim M. Oks[a], Maxim V. Shandrikov[a], Georgy Yu. Yushkov[a], Andrey V. Tyunkov[b], Elena V. Savruk[b]

[a] *Institute of High Current Electronics SB RAS, 2/3 Akademichesky Avenue, 634055 Tomsk, Russia*
[b] *Tomsk State University of Control Systems and Radioelectronics, 40 Lenin Avenue, 634050 Tomsk, Russia*

ARTICLE INFO

Article history:
Received 29 November 2013
Received in revised form 24 February 2014
Accepted 13 March 2014
Available online xxx

Keywords:
Metal ions
Implantation
Ceramic insulator
Sheet resistance

ABSTRACT

The results of investigation of the sheet resistance of alumina ceramic as a function of the fluence of implanted metal ions are presented. Tantalum ions with the average energy about 145 keV were used in experiments. Estimation of the sheet resistance was performed from analysis of volt–ampere characteristics by measuring the leakage current at a voltage between 100 V and several kilovolts, which was applied at a small area of the implanted surface. Energy dispersive X-ray analysis was used to determine composition of elements in the surface of the implanted ceramics. As a practical application of research results, it was shown that, after the creation of a weak conducting layer on the surface of the ceramic insulator, the electric field strength of the flashover increases by more than 25%.

Introduction

Implantation of metal ions in the surface of the dielectric is an effective tool for the synthesis of the surface layers, consisting of a composite of target material and implanted impurity. The interaction of the accelerated ions with the target body creates radiation defects, formed due to the displacement of atoms and forming vacancies. The result of the implantation process is the modification of the mechanical, optical and electrical properties of the dielectric surface, while retaining original properties throughout its volume [1]. The processes of implantation of metal ions in solid dielectrics based on Al_2O_3 have been widely investigated [2]. The most obvious phenomenon related with the modification of the electrical properties of the dielectric material is the reduction of the surface resistance with increasing implantation dose [3]. It was found that as a result of the implantation of the metal atoms, the surface layers formed a so-called matrix of conductivity, consisting of single islands or crossing clusters, which are formed by atoms of the implanted species.

Conduction electrons are transported through the surface layer under the influence of an external electric field, and, as a result of tunneling, pass directly via conducting channels, as a result of combining of both types of conductivity [4]. Heat treatment of implanted samples leads to annealing of radiation defects caused by implantation, and stabilization of the surface resistivity after processing [5]. A relatively new trend is the implantation of metal ions in organic polymers to increase the surface conductivity [6], and increase of wear resistance [7]. Also known are the works related with the implantation of metal ions in the elastic polymers, which are used for creating flexible electrodes on the basis of the dielectric electro-active polymers, such as electromechanical actuators and miniature diaphragm valve [8].

In our previous work we have shown the increasing of the dielectric strength of insulating areas of glass ceramic rods by enabling surface charge bleeding-off through the layers with surface resistance about several tens GOhm/square. Platinum was chosen as the ion implantation species because of its properties of high electrical conductivity and high chemical inertness [9].

In our work we investigated the sheet resistance of the flat alumina samples which had been implanted with tantalum ions with mean energies 145 keV, as a function of exposure dose. Element composition of implanted surfaces was performed with the energy dispersive X-ray analysis. Electrical breakdown strength of ceramic implanted by tantalum ions was investigated as a function of

---

☆ This work was supported by joint RFBR grant # 13-08-98121-r_Siberia_a.

* Corresponding author. Tel.: +7 3822491776/9138568357; fax: +7 3822492410.
E-mail addresses: savkinkp@mail2000.ru, savkin@opee.hcei.tsc.ru (K.P. Savkin), bugaev@opee.hcei.tsc.ru (A.S. Bugaev), nik@opee.hcei.tsc.ru (A.G. Nikolaev), oks@opee.hcei.tsc.ru (E.M. Oks), shandrikov@opee.hcei.tsc.ru (M.V. Shandrikov), gyushkov@mail.ru (G.Yu. Yushkov), tyunkov@opee.hcei.tsc.ru (A.V. Tyunkov), savruk@mail.ru (E.V. Savruk).

http://dx.doi.org/10.1016/j.apsusc.2014.03.080
0169-4332/

Please cite this article in press as: K.P. Savkin, et al., Sheet resistance of alumina ceramic after high energy implantation of tantalum ions, Appl. Surf. Sci. (2014), http://dx.doi.org/10.1016/j.apsusc.2014.03.080

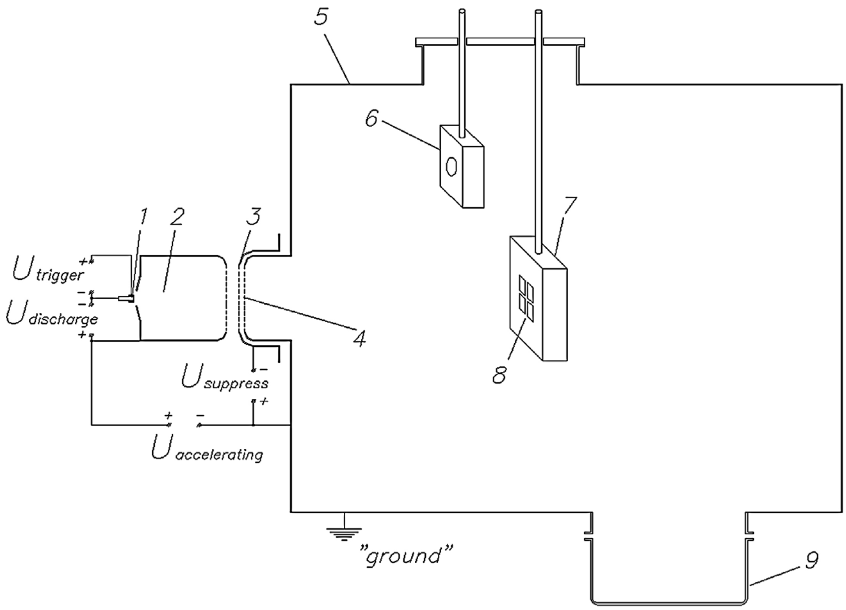


Fig. 1. Schematic of the experimental setup: 1 – cathode, 2 – hollow anode, 3 – extraction system, 4 – extracted ion beam, 5 – vacuum chamber (grounded), 6 – insulated collector, 7 – samples holder (grounded), 8 – implantation target samples, 9 – cryogenic pump.

surface conductivity. It was shown that, after the creation of a weak conducting layer on the surface of the ceramic with sheet resistance about several units 10^9 Ohm/sq insulator, the electric field strength of the flashover can be increased by more than 25%.

Experiment description

In the experiments, we used our universal test bench (Fig. 1) equipped with an ion source Mevva-5.Ru based on vacuum arc discharge [10] for generation of metal ion beams. The vacuum arc current did not exceed 300 A at a pulse duration of 250 μs and pulse repetition rate up to 10 s^{-1}. The ion beam was formed by a three-electrode multi-aperture ion-optical system of diameter 10 cm. The accelerating voltage was 50 kV in all experiments. The measurements of charge state distributions of ion beams were performed by time-of-flight mass-to-charge spectrometer [11]. The mean charge states of tantalum and platinum ions were 2.9+ and 2+ and the average energies were about 145 kV and 100 kV, respectively. For measurement of ion beam current, a movable Faraday cup was used. Typical beam current density was about 5 mA/cm^2. It corresponded to mean exposure dose rate about 3×10^{13} (cm^2 s). Ion current density distribution across the beam in the position of the implanted samples had Gaussian shape with the nonuniformity of the order ± 5% on the site with diameter 5 cm. The system was pumped to a background pressure of about 1×10^{-6} Torr by a high-vacuum cryopump.

Samples of polycrystalline alumina ceramic 8 of size about 1 cm × 1 cm and thickness about 1 mm were placed on the water-cooled grounded aluminum collector 7. Distance between the emission electrode of the ion source and the sample was about 60 cm. The samples were fixed onto the collector by fine double-sided aluminum adhesive tape. The temperature of the "collector-sample" system was about 40 °C during the implantation. Under ion beam treatment small dielectric samples were charged by ions up to positive potential not exceeded several hundred volts, as we found in our previous investigation [12], and influence of deceleration field on the ions with average energy near several tens keV was negligible. The samples were not annealed after ion beam treatment. The surface resistivity of the implanted alumina specimens was measured through direct electric bias up to several hundreds of volts. Also the surfaces of implanted samples were investigated by dispersive energy X-ray analysis for determination of elementary composition.

Results and discussion

Interaction of accelerated tantalum ions with ceramic leads to modification of surface properties of the ceramic. The first one is change of color. With increasing exposure dose, the surface colored darker (see Fig. 2). It allows visual estimates of changes relative to the original unimplanted surface. The condition of the alumina surface (color and sheet resistance) is a sensor of "implantation system cleanness". If samples are become extremely dark and have too low sheet resistance (about several kOhm/sq) and the exposure time corresponded to the implantation dose, for example, about 1015 ion/cm^2, it means that some contamination has migrated from the electrodes of the ion optical system to the ion beam target. That is why several hours operating with typical experimental parameters of ion source were required to obtain clean enough conditions for implantation.

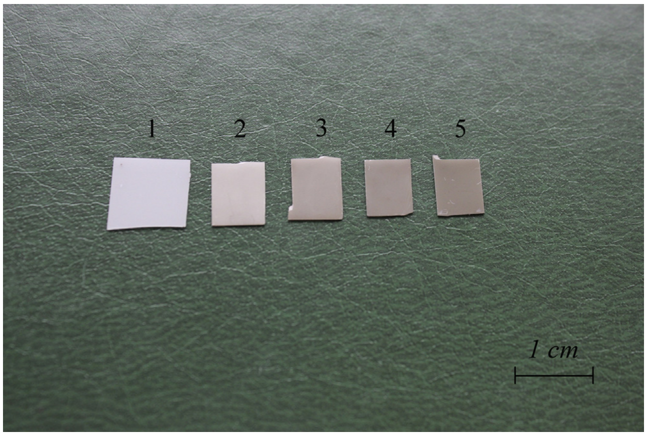


Fig. 2. View of alumina samples. From the left: original; implanted up to exposure dose 2.5×10^{16}; 5×10^{16}; 7.5×10^{16} and 1×10^{17} ion/cm^2.

Please cite this article in press as: K.P. Savkin, et al., Sheet resistance of alumina ceramic after high energy implantation of tantalum ions, Appl. Surf. Sci. (2014), http://dx.doi.org/10.1016/j.apsusc.2014.03.080