Modification of an aluminum electrode in a surface dielectric barrier discharge plasma

A V Lazukin 1,3, I V Selivonin1,2, I A Moralev3 and S A Krivov4.

1 National Research University “Moscow Power Engineering Institute” Krasnokazarmennaya 14, Moscow 111250, Russia
2 Joint Institute for High Temperatures of the Russian Academy of Sciences, Izhorskaya 13 Bldg 2, Moscow 125412, Russia
3 JSC «SPA «CNIITMASH», Sharikopodsibnikovskaja 4, Moscow 115088, Russia
E-mail: morler@mail.ru

Abstract. The paper is devoted to the phenomenological study of the aluminium electrode modification in the surface dielectric barrier discharge in ambient air. The morphological changes found on the electrode edge after discharge treatment include the formation and pit-wise erosion of the relatively thick oxide film and redeposition of the oxide vapor in the form of the dendrite structures. These formations are obtained independently on the thickness of the electrode in the range 10-80 µm, with minor changes of the structures morphology. It is shown that in the case of thin foils, intense oxidation of the electrode edge leads to the mechanical separation of the oxidized region from the electrode.

1. Introduction

In the experimental studies of surface dielectric barrier discharge (SDBD) and in a variety of technological problems two basic types of electrode configurations are used: with a pair of dielectric-covered electrodes (coplanar surface discharge) and with one electrode exposed directly to the discharge. The latter class of systems is characterized by higher electric field strengths in the discharge formation region, lower operating voltages amplitudes and assembling simplicity.

Although thin aluminum foils are one of the most common materials used for electrode manufacturing in SDBD, erosion of the aluminum electrodes in SDBD is not described in the literature. Most of the work devoted to changes in electrodes geometry, cell parameters during SDBD operation are devoted to modification of the dielectric barrier [1,2].

Atmospheric pressure SDBD develops as a set of separate pulsed microdischarges, each having its own electrode spot at the edge of the exposed electrode. The parameters of the microdischarge pulses are close to ones obtained for the pulsed corona discharge in air. In this regard, one can expect some similarity of electrode processes in SDBD and corona discharges.

The erosion of the pin electrodes in the corona discharge was studied in [3-7], in particular, works [3,4,8] describe to the morphological changes that occur on aluminum electrodes. It is shown that in the case of aluminum, the formation of an oxide film on the electrode has a significant effect on both the erosion process and the dynamics of the discharge. The main processes responsible for changing the shape and morphology of the pin electrode was shown to be the formation of breakdowns and cracks in the oxide film, as well as redeposition of the electrode material to the surface.
Besides the fact that the morphological processes on the electrodes have a significant effect on the discharge cell lifetime, they can have an unexpected effect on other applied aspects of the SDBD-based devices. Thus, in the plasma biological applications, in cases when the object of influence is directly in the discharge zone, the formation of a cloud of charged particles of the nanometer range near the aluminum electrode can affect the results and variability of biological studies. Significant thermal loadings on a limited part of an electrode, in presence of an intensely oxidizing atmosphere, may be interesting from the point of view of fast tests to reveal local defects in metals intended for work under aggressive conditions.

2. Experiment details and analysis techniques

In a present study an asymmetric barrier discharge cell with a linear strip electrode was used [8]. The pair of electrodes, one connected to the high voltage and other grounded, were separated by a 1 mm thick ceramic barrier (alumina ceramics 94% Al2O3, ε=10). The thickness of the foil electrodes used in the study was 10, 20, 35, and 80 μm. Foils were glued onto the surface of the cleaned ceramic surface with an alcohol-based adhesive with a thickness of the order of 2-4 μm. The electrode was exposed in the SDBD for 40 hours. The discharge was created by a sinusoidal voltage of 3 kV RMS at a frequency of 25 kHz. The shape and amplitude of the voltage were controlled by an oscilloscope TDS 2014 (Tektronix) with a high-voltage divider P6015A (Tektronix).

At the end of the electrode exposure (5 iterations for 8 hours), the discharge cell was examined by various microscopy methods. Evaluation of changes in the shape of the electrode edge was carried out on a scanning confocal laser microscope Olympus LEXT OLS4000 with a resolution of at least 200 nm, and also with an electron microscope Nova NanoSem 650 with a resolution of up to 2 nm. The length of the electrode edge exposed in the discharge was 40 mm. The studied region with a typical size of 1.8 x 1.8 mm was chosen in the middle of this span. Before exposure, the electrode was marked at some distance from the edge, that allowed for accurate positioning of the inspection zone during the whole test and examination cycle.

3. Results and discussion

It is found that during the discharge operation the structure of the electrode edge changes is subjected to strong morphological changes. The edge of the electrode is covered with a porous oxide layer; in the immediate region where the electrode spots are observed, a black band is formed, consisting of groups of bound grains. The formation of the black band is supposed to be associated with the transition of aluminum oxide from alpha to gamma state. As a result of return of the erosion material, dendrit-like structures are formed on the electrode surface. The greatest density these deposits reach at some distance from the edge, where a "wall" with a height of up to 20 μm is formed. Detailed structure of the oxide layer was studied using an electron microscope. It was found that the surface of the oxide layer in the region directly exposed to the microdischarges electrode spots is covered by small holes (200 nm in diameter and less) (Fig. 1).

Similar structures were observed in a negative corona discharge, where their formation was associated with the breakdown of the dielectric film at the time of the formation of the next Trichel pulse. Discharge operation at long exposures leads to the significant stresses appearing in the oxidized strip. As a result, in the case of thin foils (10 μm) by the end of 40 hours of the discharge operation, the oxidized part of the electrode is detached from its bulk.

The images of the electrode edge for 20 μm, 35 μm and 80 μm thicknesses are shown in Fig. 2. For the comparison, the left fragment shows a 35 μm electrode before discharge operation. The size of the imaged field is 250 to 650 μm. With respect to the difference in the electrodes height, the total length of the modification zone (the total linear length of the black band and oxide side) remains practically unchanged and is equal to nearly 280 μm.
Figure 1. SEM images of 10 μm electrode edge

Figure 2. Left to right: 35 μm electrode prior to the exposure; electrodes after 40 hours exposure at 25kHz, 3kV RMS: 20 μm; 35 μm; 80 μm;

Modifications of the electrodes that arise in the process of the surface discharge operation should cause significant changes in the characteristics of the surface discharge. These changes are assumed to be an object of further studies.
4. Conclusions
Aluminum foil electrodes, regardless of thickness, are subject to considerable modification under the influence of a surface dielectric barrier discharge. The nature of these modifications is similar to the erosion damage that occurs in the negative corona discharge: the formation and point-like breakdown of an oxide film, the formation of craters and local erosion, the redeposition of erosion material onto the electrode. At long exposures, the destruction of the electrode on the form of oxidized layer was detected (separation of the black strip).

Acknowledgments
This work was partially funded by the Russian Federation Ministry of Education and Science as part of agreement to provide subsidies for the implementation of applied scientific research (Unique identificator RFMEFI57915X0114) and partly by RFBR grant #17-58-16004 as a part of Associated International Laboratory “Kinetics and Physics of pulsed Plasmas and their Afterglow” activity.
Authors would like to acknowledge Dr. Alexey Petrov for the fruitful discussion of the results.

References
[1] Sokolova M, Kozlov K, Mitin, A, Tatarenko P 2013 EPJ Applied Physics 61, 2, 24312
[2] Ngo A, Pai K, Jacob J 2017 48th AIAA Plasma dynamics and Lasers Conf (Denver; United States) K192609
[3] Laan M, Paris P and Repän V, Le J. Phys. IV 1997 7 C4-259-C4-270
[4] Weissler G L and Schindler M 1952 J. Appl. Phys. 23 844
[5] Amirov R H, Petrov A A and Samoylov I S 2009 International Journal of Plasma Environmental Science and Technology 3 35
[6] Petrov A A, Amirov R H, Asinovskii E I and Samoylov I S 2009 Journal of Plasma Fusion Research Serie. 8 780
[7] Amirov R H, Petrov A A and Samoylov I S 2013 J. Phys. Conf. Ser. 418 12064
[8] Gibalov V I and Pietsch G J 2012 Plasma Sources Sci. Technol. 21 2 24010