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EFFECT OF ELECTROLYTE VISCOSITY ON HEATING OF GROWING ANODIC OXIDE DURING ELECTROCHEMICAL ANODIZING

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I. INTRODUCTION

Electrochemical anodic oxidation of valve metals has been intensively investigated in recent years, because this process allows to create the nanoscale structures [1]. An important factor affecting the kinetic of electrochemical anodizing is temperature. Growth of metal oxides during anodizing process is caused by the migration of metal cations from an oxide/metal interface to electrolyte and of oxidant anions from an oxide/electrolyte interface toward metal through the oxide barrier layer. As the voltage of an electrochemical cell almost completely drops on the oxide layer, the Joule heating of growing oxide occurs. The heating increases with increasing of energy consumption of the anodizing process and changes the oxide growth rate. Anodizing of aluminum on high power consumption is applied for fabrication of porous alumina with high ordered hexagonal cells [1, 2].

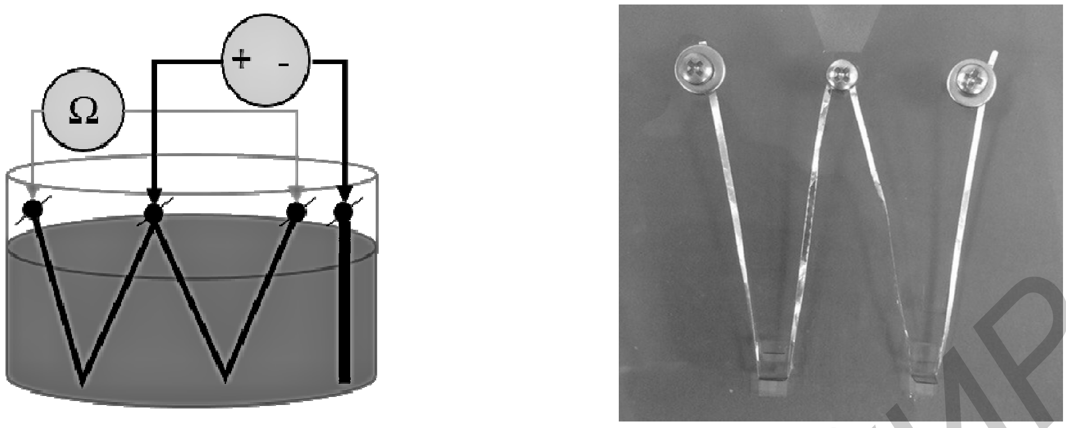
II. EXPERIMENTAL

We propose an indirect method for temperature measuring of growing oxide during the electrochemical anodizing. This method is based on the property of metals to change their resistance with rising of temperature. To implement this method, a special electrochemical cell has been designed. An anodizing sample in the cell is a tape of aluminum foil with thickness of 10 µm, length of 29 cm and width less than 0.5 mm. An anodic terminal was connected to center of the tape, while ohmmeter terminals to its ends, as shown in Figure 1. Due to the special separation of terminals, the influence of anodic voltage on the measurement chain was minimized. According to the fact that a thin conductive part of aluminum during anodizing is surrounded by growing oxide film, the temperature of aluminum is close to the anodic oxide temperature.

Experiments were carried out at the galvanostatic regime at anodic current density of 200 mA/cm^2 in aqueous (low viscous, i.e. less than 10^{-3} Pa·s at 20°C) and based on 1:1 (volume) mix of water and glycerin (high viscous, i.e. more than 10^{-3} Pa·s at 20°C) solutions of 1% citric acid. Changings in the resistance were interpreted in heating according to the formula:

$$\Delta T = T_i - T_0 = [R(T_i) - R(T_0)]/[\alpha \cdot R(T_0)] \qquad (1)$$

where T_i – the conductor temperature during anodization, K; T_0 – the conductor temperature at the beginning of anodization, K; $R(T_i)$ – the resistance of the conductor during anodizing, Ohm; $R(T_0)$ – the resistance of the conductor at the beginning of anodizing, Ohm; α – temperature coefficient of resistance ($4{,}2\cdot10^{-3}$ K^{-1} for aluminum).



a b

Figure 1 – The experimental cell to investigate oxide temperature during the electrochemical anodizing: a – the cell's scheme; b – the photo of the anode

III. RESULTS AND DISCUSSIONS

The results of experiments are shown in Figure 2. As can be seen, there is the drastic increase in resistance on high values of specific power. Presumably, it is caused by local melting of the aluminum tape inside the refractory oxide layer. During the experiments, there were cases of breakage of the aluminum tape in the meniscus region [5], which indicates that the melting temperature of aluminum (~660 °C) has been reached. To calculate the temperature variation, resistance values preceding this increase were used (Figure 3).

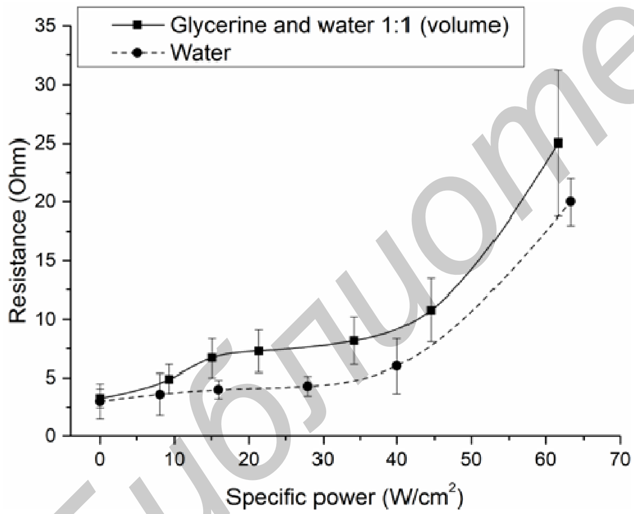


Figure 2 – An experimental dependencies of resistance on specific power during anodization in different electrolytes

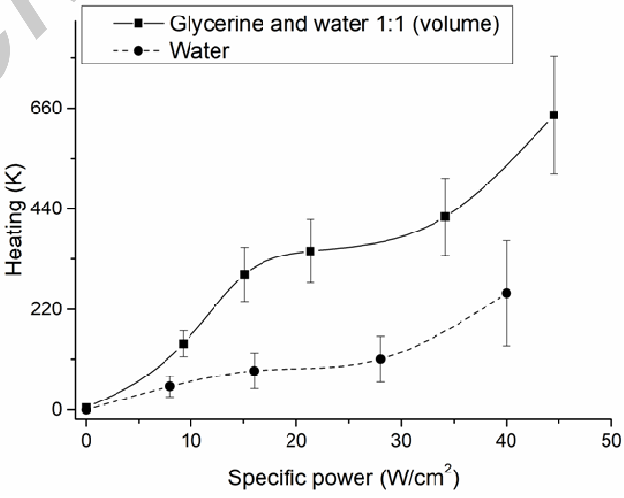


Figure 3 – The calculated dependences of heating from the specific power during anodization of aluminum in different electrolytes

In addition, the heat transfer coefficient has been calculated on the basis of experimental data [4]. The heat transfer coefficient shows how much heat is transferred per unit time from a more to less heated coolant through 1 m^2 of heat exchange surface while the temperature difference between the coolants is 1 degree. The values of the heat transfer coefficient are shown in Figure 4. According to the graphic water has the highest heat transfer coefficient.

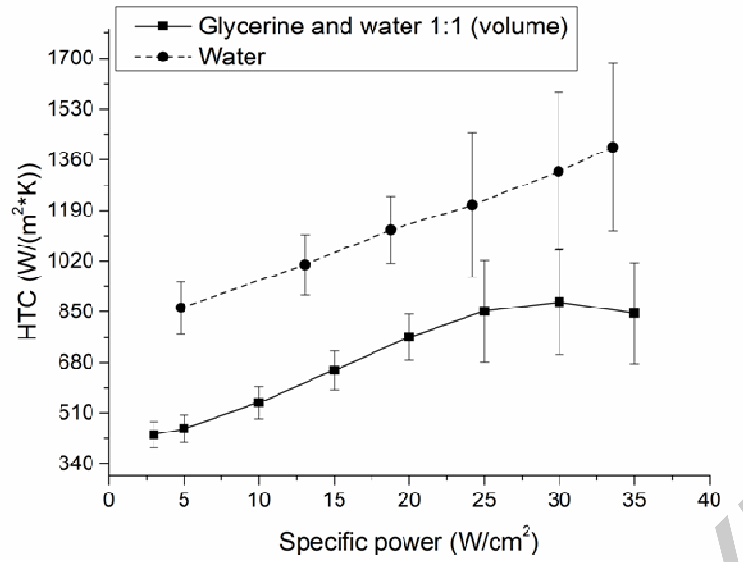


Figure 4 – The dependence of the heat transfer coefficient (HTC) from specific power during anodization of aluminum in electrolytes with different viscosity

IV. CONCLUSIONS

We have established that the increase in temperature of the growing anodic alumina during the anodizing process can reach several hundred degrees. The electrolyte composition is an important parameter that affects the heat transfer from the growing oxide. The experimental-based calculations showed that average values of heat transfer coefficient for low viscous (aqueous) electrolyte is in the range of 800-1400 W/(m^2·K) and of 400-850 W/(m^2·K) for high viscous electrolyte. HTC determines the temperature in the zone of growth of anodic oxides. Consideration of heat generation will allow to provide the stability of the anodizing and make possible to conduct controlled anodizing under extremely high temperatures.

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ACCUMULATION OF POROUS SILICON COMBUSTION ENERGY FOR MECHANICAL PULSE ENHANCEMENT IN MEMS

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I. INTRODUCTION

Microthrusters have received significant attention during the last few years, though early development in the microelectromechanical systems (MEMS) field began approximately 15 years ago. The principle applications of microthrusters are for primary propulsion and attitude control of microspacecraft and micro-, nano-, picosatellites. These small-scale satellites require efficient propulsion systems that can approach and maneuver around objects in a space orbit. Technological efforts are