Influence of plasma-electrolyte discharge to the glass surface

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Abstract. Gas discharges with liquid electrodes are known more than a hundred years. For these discharges typical is the fact that one of the electrodes is a conductive solution of electrolyte. The research resulted in found that the mechanisms of removal of glass for anodic and cathodic regimes differ. At cathodic regime occurs mainly thermal effect from the discharge. And at anodic regime occurs mainly glass etching by plasma of discharge.

1. Introduction

Gas discharges with liquid electrodes are known more than a hundred years. For these discharges typical is the fact that one of the electrodes is a conductive solution of electrolyte. To initiate the discharge electrode (at which combustion will take place) and the "counter-electrode" (larger area than first) omitted in the electrolyte solution. Further a voltage is applied to them and occurs an ignition of the discharge. This type of discharges has been widely used in various branches of science and engineering. One of the branches of the active application is the processing of metals and their alloys, as well as infliction of functional coating. Treatment of non-conductive materials was considered, in principle, not feasible. This problem was partially solved in 1968, by team of Japanese scientists [1]. This treatment has been called chemical-spark engraving. In recent years this theme has been actively developed by Canadian scientists [2, 3, 4]. In all of these studies research conducted from the viewpoint of the effects of thermal flux which generated by the discharge in the treatment area. It does not investigate the influence on parameters of discharge burning on treatment process and have not been studied parameters of low-temperature plasma.

Therefore the purpose of this work is to study the parameters of the discharge in the process of plasma-electrolytic engraving glass.

2. Experimental

To achieve this purpose has been developed the experimental setup on the basis of 3D-printer Picaso Builder. Schematic diagram of the setup is shown in Figure 1.

To control the coordination system of the 3D printer was used program Polygon. This system was chosen based on the simplicity of design and handling. Also in the event of failure of any node, it is easily replaced. Instead of the standard print head was manufactured device for mounting the electrode on which the generations of plasma-electrolyte discharge (Fig. 1B). Processing was conducted in an electrolytic bath (h=30 mm, l=215 mm, d=215 mm) Bath fixed on the surface of the platform 3D-printer. In the bath were located dielectric pillars on which processed glass are fixed. Also in the bath been two holes for pumping the electrolyte.
Fig. 1. The experimental setup of engraving glass (A), the head of the generation of plasma-electrolyte discharge (B).

One at the bottom and the second at the top. Thus, the hot electrolyte used in plasma-electrolytic process is gradually replaced by a new cold. For pumping of the electrolyte used a peristaltic pump.

On the two sides of the electrolytic cell installed copper counter-electrode with dimensions 20×100×1.5 mm. As a electrode, at which the occurs initiation of plasma-electrolyte discharge, was used cylinder made of steel 12X18H10T sharpened by a cone with an angle of 3.5 degrees and a radius of the top 30 microns. Electrolytic bath filled by researched electrolytes with necessary concentration and composition. The working fluid used a 5% aqueous solution of alkali NaOH.

The whole complex is consisted of a system of electric power, the electrode system, an oscilloscope, a shunt, the electrolytic bath, thermometer and two digital multimeters.

The system power supply is a DC power source with continuously variable voltage. The power supply consists of the diode bridge and laboratory autotransformer adjustment type 1M with a voltage range from 1 to 240 V, 50 Hz frequency. The main operating parameters of the electrode system: the voltage across the electrodes, the magnitude of the discharge current, the current density at the electrodes.

Used a pulsating current source obtained after full-wave rectification. Changing the form of voltage and current at the time of discharge ignition was determined by the oscilloscope FLUKE 105 SCOPEMETER SERIES II, time base varied from 5 ns to 60 s. The relative measurement error did not exceed 0.025%.

Measurement of the voltage at the anode is made through digital multimeter APPA 207, the relative measurement error is 0.2%. With a DMM APPA 305 we measured current of plasma-electrolyte discharge. The temperature distribution near the surface of the active electrode was measured by an infrared thermometer Fluke 62 Max. The principle of operation in the infrared pyrometer is based on measuring the thermal energy of objects, its main body is a sensor which detects the radiation from a heated body in the infrared range and converts it into an electrical signal proportional to temperature. Further this signal is processed, the result is displayed on the built-in display. Treatment of the obtained results was performed taking into account the measurement uncertainty.

3. Results

Figure 2 shows the current-voltage characteristic of the plasma-electrolytic process without contact with the glass and in contact with the glass.
In this case, the discharge initiation performed on the metal anode, when the cathode was the electrolyte. Consider a more detailed view of the current-voltage characteristics. They have a maximum which characterizes the phenomenon of transition from the electrolysis process to the formation of steam-shell and discharge burning. In considering the CVC process without contact with the glass surface shows that discharge burning in the vapor-sheath occurs at a voltage of 70 V and a current of 1.1 A and a further increase in voltage leads to a decrease in current. Reducing the current associated with a decrease in amount of charge carriers, and it may be due to increasing thickness of the steam-shell (the length of the electrode gap). The second curve describes CVC of plasma-electrolytic process, when the tip of the metal anode in contact with the surface of the glass. The shape of the curve remains the same, but the steam-shell formation and initiation of discharge burning was observed at higher values of voltage and current. This CVC coincides with the curve of CVC of plasma-electrolytic process by using full-wave rectification mode without smoothing capacitor filters [5]. This coincidence suggests about the same effect on formation of steam-shell electrode shape and form of the applied voltage. In [6], studies have been conducted of the transition from the regime of electrolysis to discharge burning in steam-shell, which showed that increase the steam-shell starts from the tip of the electrode. In our case, in contact electrode with the surface of the glass, increase steam-shells from the electrode impossible. As a result, was observed instability discharge burning due to failure of the steam-formed shell. A similar course of plasma-electrolytic process takes place by using the pulsating voltage. It showed the need for discharge ignition with no contact with the glass and the successive approximations of electrode to the glass surface.

By using the above arguments, experiments were conducted to glass treatment and polyethylene at the anodic and cathodic polarization of the electrode.

Experiments with a metal cathode showed that there are two modes of processing the glass. These modes differ in terms of removal rate of the glass surface, the first mode is characterized by a speed of 100 microns/s was observed near the surface to a depth of 350 - 400 microns. The second mode is characterized by a decrease in the rate of removal of the glass material to 10 microns/sec is observed at a depth of 400 microns. This observation coincides with research presented in [7]. Removal mechanism proposed in this work is based on two phenomena of melting glass under the action of thermal energy of the discharge and etching glass with sodium hydroxide. It is assumed that the heat from the discharge locally increases the surface temperature of the glass, thereby causing it to melt and to evaporate the water from the treatment zone. In the processing zone remains NaOH as the salt melt. It is assumed that the OH radicals are etched glass with the following reaction:

\[
2 \text{NaOH} + \text{SiO}_2 \rightarrow \text{Na}_2\text{SiO}_3 + \text{H}_2\text{O}
\]
NaSiO$_3$ should be washed away due to the electrolyte. But this is contradicts the previous approval of the evaporation of fluid from the treatment area. Analysis of the resulting glass surface after of plasma-electrolytic treatment showed that at the edges of the hole there are the remnants of molten glass material, which speaks in favor of the thermal melting glass and extruded products from the treatment zone melting electrode-cathode under the influence of mechanical loading. In the case of treatment discharge with the metal anode was found that, in contact vapor-gas envelope with surface of the glass discharge burning at the boundary of three phases: glass - electrolyte - vapor-shell. Gradual approximation metal anode to the glass has resulted in discharge burning between the anode and glass in vapor-shell what is not observed in the cathode regime. Discharge burning between the anode and the glass was accompanied by an intense glow. In this case, destruction of the glass surface occurs under the influence of plasma etching. The etching rate was 140 microns/s. Investigations on the treatment of polyethylene showed a completely different picture. Discharge burning occurs only between the metal anode and the electrolyte cathode. Figure 3 shows a photograph of the slice the interelectrode gap. It clearly shows that the streamers appear at the tip of the electrode and evolve on the electrolyte surface (steam-border membranes). Since the thermal capacity of of plasma-electrolytic discharge with metal anode ten times less than with a metal cathode, and consequently the processing performance of polyethylene was very low.

Fig. 3 Slice of the interelectrode gap at plasma-electrolyte discharge with metal anode.

The research resulted in found that the mechanisms of removal of glass for anodic and cathodic regimes differ. At cathodic regime occurs mainly thermal effect from the discharge. And at anodic regime occurs mainly glass etching by plasma of discharge.

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