Experimental investigation of discharge channel in IPA solution

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We are showed experimental results of the investigation of the spark channel created by the high voltage pulse generator in 15% IPA solution. The initial glowing in the anode region was captured with high speed camera and is considered as a result of ionization-overheating instability development. The rate of spark channel propagation is about 4 m s^{-1} and corresponds to the thermal process of current carriers generation. The side filaments of spark channel are observed propagating toward the nearest bubbles.

1. Introduction

Underwater arc discharges are of interest for various applications such as water purification, underwater welding, electrohydraulic and electrodynamic fragmentation, high power switchers [1]. Arc discharge in liquids always starts with the formation of gas regionwhere electron avalanches, slow (primary) and fast (secondary) streamers may occur [2, 3]. On the next stage if conductivity is quite high it takes some time for hot plasma channel to reach opposite electrode. On the final stage spark channel bridges the electrode gap. A number of papers on low density regions (microbubbles etc.) importance for discharge initiation have been published for the last decades. Their reviews are given in [4, 5] as well. Some of them deal with pre-existed microbubbles [6], while others report on microbubbles generation during initial stages of streamers propagation. In this paper we describe experimental observations connected with the propagation of pulse discharge in 15% IPA solution in tap water.

2. Experimental set-up and diagnostics

The main parts of the experimental setup are the pulse generator and the discharge cell. Full scheme is shown in figure 1. The pulse generator consists of DC high voltage power source, high voltage oil-filled storage capacitor which is discharged by a triggered spark gap switch. The value of capacity is 1.6 μF.

The discharge voltage could be varied in the range of (0-40) kV and has a positive polarity. A rise time could be varied in the range of (10-40) μs. The half amplitude pulse duration was typically 10 ms. The ballast resistance R_b limits current in the range of (1-5) A. The applied voltage was measured by a Tektronix P6015 probe with additional resistive divider (R1-R2), the current was measured by means of the 2 Ohm current shunt (R_s) at the cathode side. Both signals were recorded with Tektronix DPO7054C oscilloscope. The conductivity [sigma] of the solution was about 300 μS/cm. The high speed images were taken with CMOS Redlake MotionPro X3 camera which was synchronized with applied voltage pulse.

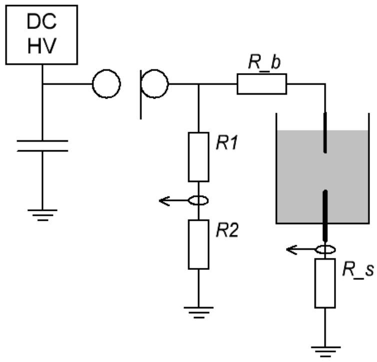

Figure 1. Experimental setup

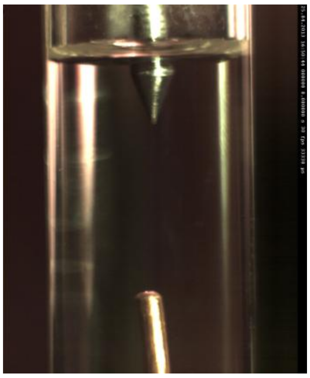

Figure 2. Electrode system: the anode at the top and the cathode at the bottom

The experiments are performed in the pin-to-pin geometry in the closed volume. The quartz tube with 16.6-mm-inner-diameter was used as the closed volume and was able to carry out OES diagnostic. The quartz tube was vertically oriented. The bottom cathode side is sealed with elastic dielectric plug. The anode is made of copper and inserted from the top side. The anode is of conical shape with an apex angle of 20º, a cone basis diameter of 3 mm, and a 100 μm radius hemispherical tip. The cathode is made of 2.5-mm-diameter copper wire with rounded borders, so it also has a hemispherical tip and placed at the center of the elastic plug. The inter-electrode gap is 15 mm. The resistance to direct current of the inter-electrode volume was about 4.5 kOhm. During the experiments, the water was replaced after each breakdown and had the same chemical composition.

3. Experimental results

The experimental results are shown in series of images and set of waveforms on discharge in 15% IPA solution in tap water. The images in figure 3 show the evolution of spark channel. At the very beginning when the voltage is applied the anode the surrounding liquid are cold and do not show light emission. After the switch is triggered the voltage has a constant value near the applied one for a short period of time (300–600) μs. A pre-breakdown current is quite large due to large conductivity of tap water and decreases while the capacitor discharges. The stored energy is spent on Joule heating of the liquid and the anode tip. After some threshold energy is deposited (about 40 J in our case) the anode and the near region glowing (figure 3(a))

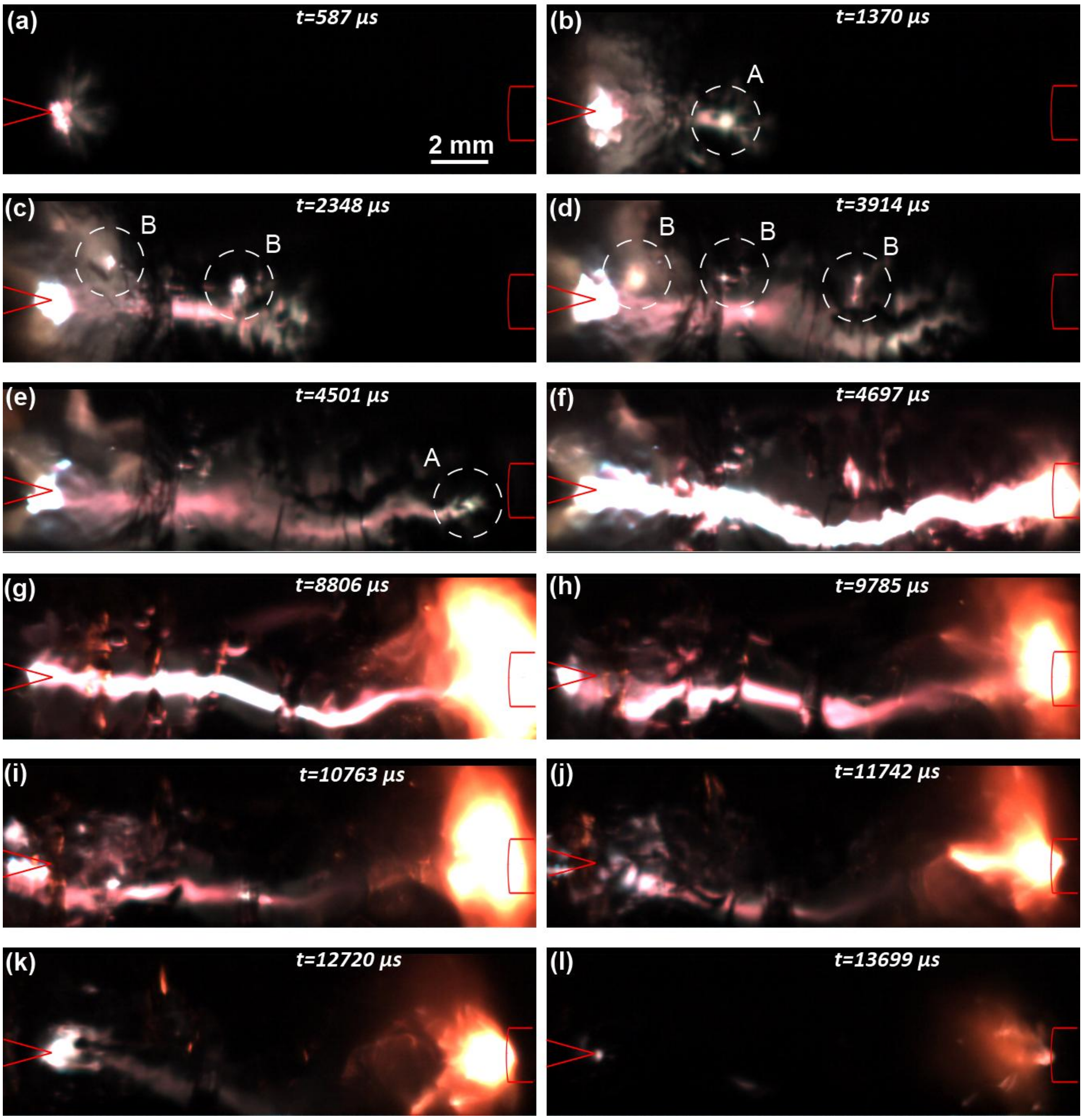

Figure 3. The evolution of spark channel in 15% IPA in tap water. Anode is at the left and cathode is at the right. Images are obtained with RedLake MotionPro X3, 5000 fps, exposure 300 μs.

appears typically in (300–600) μs after voltage applying due to ionization-overheating instability near the surface of anode. It corresponds to the point (a) on figure 4 where nonlinear growth of the current starts. Figure 3(b) shows channel developing from the anode region and denote the end of the first nonlinear part of current waveform (figure 4, point (b)). Partial discharges (figures 1(b-e), A, B) are observed in the near region along the whole channel during its evolution. They often correlate with small current peaks on the raw waveforms without smoothing. These discharges most likely occur in gas bubbles. Their formation due to vaporization during the Joule heating of highly volatile fraction with conduction currents was observed in subsidiary experiment without electrical breakdown of the electrode gap.

Bubble breakdowns are observed both in front of channel tip and on the side. Bubble breakdowns in front of the channel tip are showed in figures 3(b,e)-A. Side discharges (B) are presented in figure 3(c) and (d). The full set of images shows that generated bubbles can lead to additional side channels developing. Their propagation is stopped by side bubbles. Even the main discharge channel can change its propagation towards the bubbles. The flash of lightning (figure 3(f)) bridges the electrode gap in 4 ms after the anode glowing appearance. The propagation velocity is about 4 m/s. After the gap is bridged the discharge channel heats up. During the next 4 ms the most of energy deposits in the cathode region, intensive cathode heating occur which leads to growing of the cathode spot (figure 3(g)). Images in figures 3(h-j) show dehomogenization of the discharge channel and decrease in glowing intensity. The hydrodynamic destruction of spark channel takes about 2 ms. After the discharge current drops anode glowing almost disappears in contrast to cathode glowing with additional (4–5) ms life-time (figures 3(j–l)).

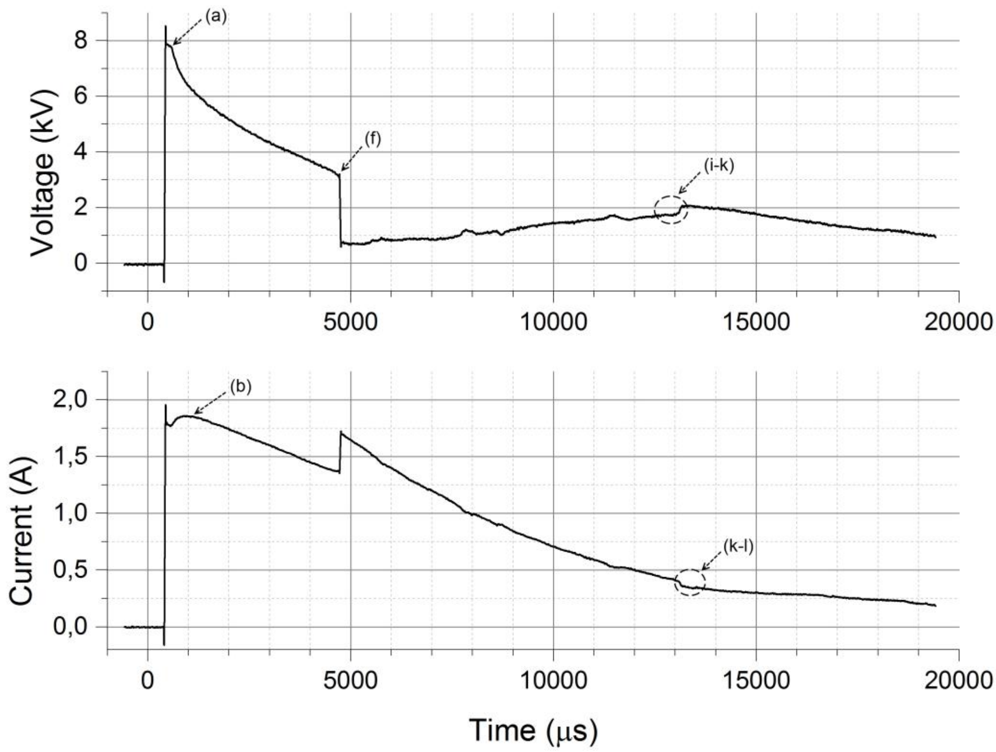

Figure 4. Current and voltage of the electrical discharge in 15% IPA solution in tap water.

4. Conclusion

High-speed images of discharge channel evolution in IPA solution recorded by a CMOS fast camera and set of waveforms are presented. The spark channel develops due to ionization-overheating instability near the surface of anode. Partial discharges in bubbles occur in the near region along the whole channel during its evolution. The generated bubbles lead to additional side channels developing. The main discharge channel can change its propagation towards the bubbles. The cathode glowing disappears much later than anode one after the destruction of the channel. The most part of energy during discharge deposits in the cathode region.

4. Conclusion

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