Study Waves through the Production and Development Electrical Discharge Pulse Size of Helium at Atmospheric Pressure

Emad A. Salman, Ali G. Al-Shatravi
Department of Physics, Collage of Science, University of Thi-Qar
e-mail: emadrazaq@yahoo.com

Abstract

The transition of a diffuse volume discharge in a centimeter long gap into a high current diffuse mode, when the gas pressure increased from 1 to 5 atm and the applied voltage rose from the statistical breakdown voltage to a 100% over voltage was investigated in atmospheric pressure for helium were studied by analyzing the emission spectra of the cathode plasma and the spatiotemporal behavior of the plasma glow.. Analytical expressions for the radius of the cathode spot and its expansion velocity obtained in the framework of a spherically symmetric model agree satisfactorily with the experimental data.

Introduction

The transition of a self- sustained discharge with gas preionization into a high – current mode by instabilities developing near the cathode. The development of a spark channel from the cathode is preceded by either explosions of micro points on the cathode surface or initiation of emission centers during the breakdown of dielectric inclusions [1,2].

High-current diffuse discharge (HCDD) in noble gases and their mixtures with a small amount of halogen -containing compounds (such as SF_6 ,CCL, and NF_6) takes place at specific energies deposited in the discharge of higher than 0.1 J/cm^2 [3 - 4]. In the intermediate stage of the discharge, diffuse channels arise and bridge the gap. Later on, the diffuse channels merge to from a homogeneous highly conductive discharge column-a high-current diffuse discharge. In [3], this phenomenon was explained as follows:

The current flowing in the gas volume under the conditions of electron-impact ionization is unstable, which leads to the formation of a diffuse channel. After the formation of a diffuse channel, the energy stored in a capacitor is spent on the formation of new diffuse channels, rather than on the further development of the channel and its conversion into a spark.

In spite of external (a three - dimensional homogeneous glow), the properties of the discharge in the volume and HCDD stage are very different. These are two types of volumetric current flow. In contrast to the volume discharge (VD), there is actually no current constriction in the HCDD. However, the reasons for the occurrence of diffuse channels attached to cathode spots (CS_s) and the nature of HCDD ignition still remain poorly studied in the literature.

Experimental Setup and Diagnostic Technique

The experiment setup is similar to that described in [4]. The 1cm long gap under study was irradiated by either a spark discharge through the grid anode or a UV source placed in the same gas at a distance of 5-7 cm from the axis of the main gap. We used 4cm diameter electrodes having various shapes and made of different materials: plane and hemispherical (R= 30 cm) aluminum electrodes, plane steel and copper electrodes, and stainless-steel electrodes (a solid cathode and a grid anode).

The pulsed voltage source generated voltage pulses with a variable amplitude of up to 30 kV and front duration ~ 10 ns. The discharge voltage and current were measured using a resistive divider and a 2Ω low inductance shunt, respectively. Frame photographs of the discharge glow starting from a plasma density of about 10^{12} cm^{-3} were obtained using an FER-2 streak camera with an UMI-92 image tube. When photographing the discharge in the frame mode, the scanning voltage of the FER-2 was switched off. The frame photographs of the discharge glow were synchronized with the electrical characteristics of the discharge by simultaneously supplying of the triggering voltage pulse to the FER-2 and the signal of the discharge current (or voltage) pulse to an S8-14 double-beam storage oscilloscope. Streak images of the discharge glow were synchronized with the discharge current (or voltage) pulse to within 2-3 ns by applying the signal of the current (or voltage) pulse to the deflecting plates of the UMI-92 image tube simultaneously with the scanning of the discharge . In this case, the time shift between the glow and electrical signals was taken into account.

Time integrated photographs of the discharge glow with a high spatial resolution were taken using a digital camera. The emission spectrum of the cathode using an MDPS-3 diffraction-grating monochromator with a linear dispersion of 0.2 - 0.3 nm/mm. The time delay of CS formation was determined from both the occurrence of spectral lines of atoms and ions of the cathode material and streak images of the discharge glow.(In some experiments, a system of slits combined with photomultipliers was used to study the time evolution of the glow in the near-electrode zones and determine the expansion velocity of the CS plasma). The plasma density in the low-current stage was determined from the current density, while that in the high-current stage, from the Stark broadening of helium spectral lines. The plasma temperature was determined from the relative intensities of spectral lines and was also estimated from the plasma conductivity. The spatiotemporal distribution of the radiation intensity between the electrodes was recorded using microphotometry and then processed by a PC.

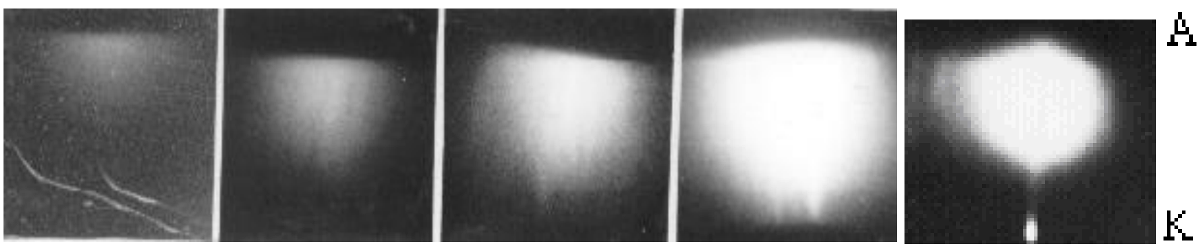
Experimental Results and Discussion

Figure (1) shows frame photographs illustration the dynamics of a VD with external preionization (the preionization source is aside) in He at discharge voltages of U_0=15kV

3 kv **11 kv** **13 kv** **3 kv**

(frames 1-4) and 18kV (frames 5). Aluminum electrodes with a curvature radius of 30 cm ,the gap length is d=1 cm , and the gas pressure is p=1 atm .Under the condition of intense preionization ,the discharge operates in the VD mode until the CS forms, after which the discharge current increases abruptly. This is confirmed by both FER-2 frames (fig.1) and the presence of spectral lines of atoms of the plasma torch at the cathode.

1 2 3 4 5



75 **100** **125** **140** **(нс)**

Fig (1): Frame photographs illustrating the formation of a VD with external preionization (the preionization source is aside) in He discharge voltages of U_0 = 15 kV (frames 1 – 4), U_0 = 18 kV (frames – 5) (aluminum electrodes with a curvature radius of 30 cm, the gap length is d=1 cm and p=1 atm).

The experimental studies of the transformation of a diffusive VD into a constricted discharge or an HCDD as the gas pressure increases from 1 to 5 atm and the applied voltage rises from the static breakdown voltage (for a pressure of p=1 atm, the static breakdown voltage of a 1cm long gas is U_S=3kV) up to a 100% overage show that the constriction of a VD into a spark channel with increasing energy deposited in the discharge occurs a E/P≈13 kV/atm cm (Fig 2, fram3). In other time –integrated photographs (taken at pressures of 2 and 3 atm), the discharge remains homogeneous and diffuse. Because the values of the ratio E/P at the same electric field remain substantially smaller than the critical value E/P≈13 kV/atm cm (Fig.2 in which the upper electrode is the cathode).

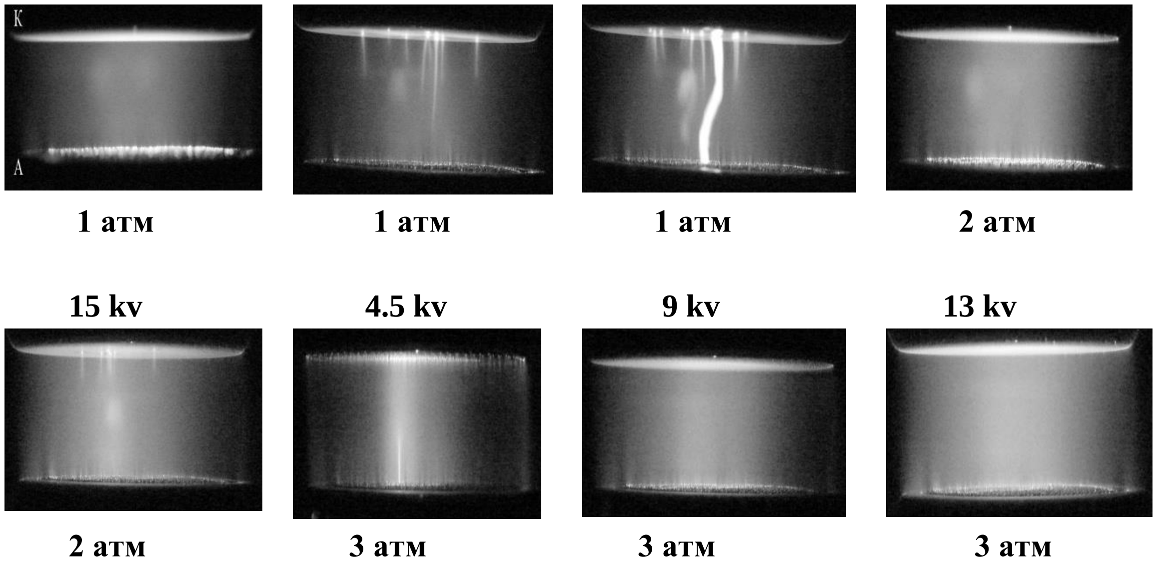
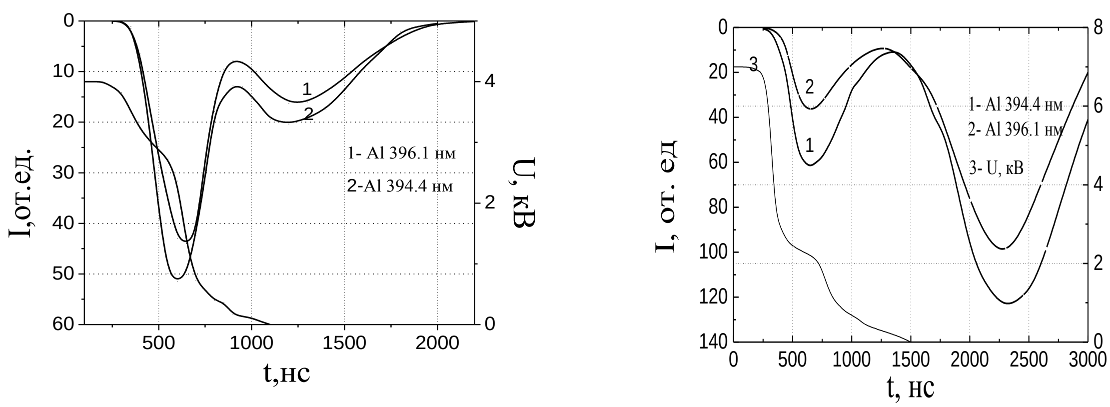


Fig (2): Time –integral photographs of the glow under different initial condition plane stainless –still electrodes (the solid cathode, and the grid anode). The gap length d=1 cm.

The emission spectrum of the CS plasma is characterized by intense atomic lines of the cathode material, AL 396.1 and 394.4 nm, having high excitation energies. Figure (3) shows the time dependences of the intensities of the AL 396.1 and 394.4 nm lines measured near the cathode at discharge voltages of 4 and 7 kV (aluminum electrodes with a curvature radius of R=20 cm, d=1cm and p=1 atm).



(a) **(b)**

Fig (3): Typical time dependences of the intensities of aluminum spectral lines emitted from the cathode at discharge voltage of (a) 4 and (b) 7 kV Hemispherical aluminum electrodes with a curvature radius of R=30 cm, the gap length is d=1 cm ,and the gas pressure is p=1 atm.

In the emission spectrum of the cathode plasma, the AL lines appear simultaneously with the beginning of the abrupt growth of the discharge current (or the drop in the voltage) and their intensities reach their maxima in 20 - 30 ns. Direct measurements of the temperature and density at the instant of CS formation are impossible, but they can be estimated indirectly in the later stages of the discharge. About 30 ns after the abrupt increase in the current, the half –width of the He II 468.6nm line is ≈0.5 nm, which corresponds to an electron density of about 10^{19} cm^{-3} , 20 ns later, the density decreases to 2×10^{18} cm^{-3} . After 30-40 ns, the CS plasma temperature estimated from the relative intensity of helium spectral lines is 4-5 eV, the cathode plasma torch begins to extend along the external field, and a spark channel starts to grow from the CS into the gap (Fig.4). The spark channel propagates with a velocity of about 3×10^{6}cm/s and bridges the gap in 280-300 ns.

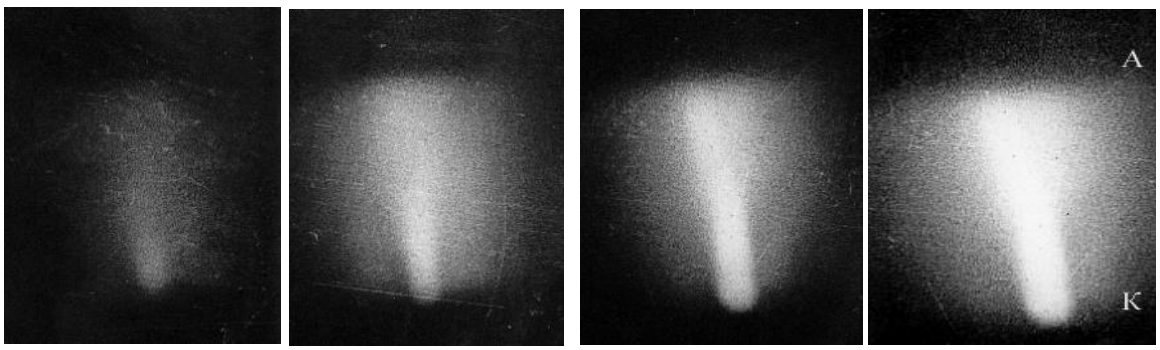


Fig (4): Frame photographs illustrating the formation and growth of the spark channel U_0 = 9kV, p=3 atm, d=1 cm.

The explosive model of CS development assumes the release of a large amount of energy in the emission center, followed by the heating and explosion of the micropoint. The specific energy released over a very short time interval ($\leq10^{-8}$s) is $6X10^{7}$J/kg. As the CS plasma expands (ν -2×10^{6} cm/s), its density decreases. The time during which energy is released is much shorter than the stage of CS expansion. Hence, when the plasma radius becomes much larger than the CS initial size, the energy conservation law in the plasma volume takes the form $W_0 \approx \rho v^2/2$. In the course of expansion, the initial energy is transformed into the kinetic energy of directed motion of plasma particles. The density ρ behind the shock front is related to the unperturbed density ρ_0 as [5]:

$$\frac{\rho_0}{\rho} = \frac{M^2(\gamma+1)}{2+(\gamma-1)M^2} \qquad (1)$$

Where M is the Mach number and (ɣ) is the adiabatic exponent. The expansion velocity in early stages is ν≫c (where c is the speed of sound) hence, the energy conservation law can be rewritten as:

$$W_0 \approx \rho_0 \frac{\gamma+1}{2(\gamma-1)} \upsilon^2 \approx 10^9 \frac{J}{M^3} \qquad (2)$$

The condition relation the unperturbed values of parameters ahead of the shock front (ρ_0 ,P_0 ,V_0, and ε_0, where ε is the internal gas energy) to their values behind the shock front (ρ_1 ,P_1, V_1 ,and ε_1) have the form[5].

$$\rho_0\upsilon_0 = \rho_1\upsilon_1 \ , \ \rho^2\upsilon_0^2 + p_0 = \rho_1\upsilon_1^2 + p_2 ,$$

$$\varepsilon_0 + \frac{p_0}{\rho_0} + \frac{\upsilon_0^2}{2} = \varepsilon_1 + \frac{p_1}{\rho_1} + \frac{\upsilon_1^2}{2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

The equation of state for an ideal gas withe the adiabatic exponent γ , $\varepsilon = p/(\gamma-1)\rho$ yield the following equation of the shok adiabat

$$\frac{p_1}{p_0} = \frac{(\gamma+1)\rho_1 - (\gamma-1)\rho_0}{(\gamma+1)\rho_0 - (\gamma-1)\rho_1} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

Solving Eqs. (3) and (4), we obtain the following expressions for the jumps in the quantities across the shock front in terms of the shock wave intensity given by the Mach number M [6].

$$\frac{\rho_1}{\rho_0} = \frac{M^2(\gamma+1)}{2+(\gamma-1)M^2}; \quad \frac{p_1}{p_0} = \frac{2\gamma M^2 - (\gamma-1)}{\gamma+1}; \qquad \frac{T_1}{T_0} = \frac{[2+(\gamma-1)M^2][2\gamma M^2 - (\gamma-1)]}{M^2(\gamma+1)^2}$$

.

Hence, for a storing shock wave with M>>1, we have

$$\frac{\rho_1}{\rho_0} \approx \frac{(\gamma+1)}{(\gamma-1)} \ ; \quad \frac{p_1}{p_0} \approx \frac{2\gamma}{\gamma+1}M^2; \quad \frac{T_1}{T_0} \approx \frac{2\gamma(\gamma-1)]}{(\gamma+1)^2}M^2$$

……………………..(5) CS expansion lasts for 40 - 50 ns, after which the CS dimensions change insignificantly. The temperature at the shock front of the expanding plasma can be estimated from condition (5) for a strong shock wave. For example, for $\upsilon=10^4$ м/c, γ=1.5, the temperature of the perturbed gas is 6-7 ev.

Since the expansion velocity of the CS plasma is much higher than the speed of sound, the temperature at the shock front increases substantially; as a result, the ionization front also propagates with the velocity of the shock wave. The characteristic time of CS formation at high over voltages (W≥300%) is about $\sim10^{-9}$ s, which is much shorter than the time of CS expansion; hence, the initial energy estimated from the above expression seems to be quite reasonable.

The propagation of the shock wave initiated by the CS along the weakly ionized discharge column increases the degree of ionization and lead to the formation of a diffuse discharge channel ,along which the spark channel then grow. At sufficiently high over voltages (W≥300%), the VD in He transforms into an HCDD.

Rapid termination of radial plasma expansion indicates the explosive nature of the CS formation, i.e. a very short time of energy release in plasma. If energy release in the CS plasma wouid continue, then the expansion would last much longer .The propagation velocity of the shock wave along the plasma column is higher than that in the unperturbed gas (in the radial direction); i.e. the wave front is spherically asymmetric .This is because the gas temperature in the weakly ionized column is higher than the temperature of the ambient gas. The shock wave is an additional source of gas heating in the diffuse channel.

Conclusions

The shock wave propagating along the electric field is an additional source of gas heating in the diffuse channel. We have studied the condition under which the VD in a centimeter –long gas gap transforms into a spark channel and an HCDD when the gas pressure increases from 1 to 5 atm and the applied voltage rises from the statistical breakdown voltage to a 100% over voltage. Analytical expressions for the radius and expansion velocity of the CS obtained in the framework of a spherically symmetric model agree satisfactorily with the experimental data.

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دراسة الامواج من خلال انتاج وتطوير حجم نبضة التفريغ الكهربائي للهليوم عند الضغط الجوي

عماد عبد الرزاق سلمان علي جهاد الشطروي

قسم الفيزياء، كلية العلوم، جامعة ذي قار

الخلاصة

توليد الامواج من خلال انتاج وتطوير حجم نبضة التفريغ لغاز الهيليوم تحت الضغط الجوي بواسطة تحليل طيف الانبعاث لكاثود البلازما المتولدة من هذا الغاز ودراسة سلوك التوهج البلازمي المتولد من الانهيارالنبضي (التفريغ التام) للغاز. ان الانتقال الحجمي (الانتشار) لموجة التفريغ على طول سينتمتر من فجوة التفريغ للغاز (سريان التيار العالي) عند زيادة ضغط الغاز من 1 الى 5 ضغط جوي بتسليط فولتية عالية جدا تكون 100% فولتية انهيار لذلك الغاز. وتبين من الدراسة تطابق النتائج النظرية والعملية بالنسبة لنصف قطر بقعة الكاثود المتولدة وسرعتها.