CHIN. PHYS. LETT. Vol. 29, No. 5 (2012) 055202

Pressure and Discharge-Voltage Dependence of Self-Sustaining Pulses in Air-Glow Discharge

A. A. Azooz, Y. A. Al-Jawaady, Z. T. Ali

Department of Physics, College of Science, Mosul University, Mosul, Iraq

(Received 16 November 2011)

The details of formation of micro discharges in air-glow discharge plasma are experimentally studied. The number of micro discharges formed per second is strongly related to both pressure and discharge voltage. This number tends to show reflections of the Patchen curve as far as its pressure dependence is concerned. The discharge-voltage dependence indicates that the transition from normal to abnormal glow discharge is not a sudden one, but has its roots during the normal glow stage and is initiated by the micro discharges which can be regarded as the early stage of abnormal glow.

PACS: 52.35.Ra DOI: 10.1088/0256-307X/29/5/055202

One common and intrinsic feature that is shared by all plasma systems is the existence of instabilities. Instabilities of all kinds are always observed in all kinds of plasmas ranging between very low-density Townsend discharges up to extreme-density plasma generated in Tokomaks. This is not surprising if one remembers that gases and fluids, whether ionized or not, are characterized by the random motion of constituents. This random motion is modulated by the effects of external and internal electromagnetic fields. Thus, the art of describing such instabilities in any plasma system is reduced to the study of the interaction of the randomness of the electrons and ion motions with the external and internal electromagnetic fields affecting the plasma. This in turn is bound to produce results that are in one way or another affected by the random nature of the constituent's motion.

As far as glow discharge plasmas are concerned, such instabilities manifest themselves in many ways. Striations seen in a simple glow-discharge tube experiment are one example. Irreproducibility of breakdown voltages in gas discharges is another example. It has been known for some time that the glow-discharge current at a fixed discharge voltage is not constant. Many studies have shown that there are continuous or damped oscillations in the discharge current. The frequencies of these oscillations are in the range between a few hertz and several kilohertz.[1,2] Such discharge current oscillations, spikes and constrictions have been observed in low-pressure glow discharges[3–5] and atmospheric-pressure discharges with micrometer and millimeter electrode gaps (microdischarges).[6,7] Similar oscillations are also reported in many discharge setups with configurations including simple parallel plate geometry,[8] hollow cathode,[9,10] micro hollow cathode[11] and plasma jets.[12,13]

One method of registering instantaneous short-time pulses in the plasma is based on detecting their electromagnetic signature. This can be carried out by attaching a small antenna to the discharge tube. This antenna can be of the dipole plate type[14] or the loop type. However, experimental study has shown that loop antennas are more suitable than dipole antennas for such purposes. This is due to the fact that in addition to the latter's large impedance, which can cause under-damped oscillations in the circuit, a dipole plate antenna will tend to pick up more noise and 50 Hz hum signals from the surroundings. Applying earthed metal shielding to the system can indeed reduce noise effects but this will result in a reduction of the heights of pulses detected. This is due to capacitive coupling between the antenna and the shield.

It was thus decided to use a loop antenna instead of the dipole antenna. This has the advantage of reducing noise. In this case, the capacitive coupling with the shield is much lower and has no significant effect on the pulses' heights. The two terminals of the loop antenna, which consist of four loops of insulated wire around the discharge tube are connected to the oscilloscope and the computer data acquisition device.

The computer soundcard is used as the data acquisition device. In addition to its availability, any computer soundcard can provide a data sampling rate of up to 44000 Hz. This sampling rate is sufficient for many purposes. One program that can interact with the soundcard for data acquisition purposes is MATLAB. The software written for this purpose was set to acquire data for one second during each run. The diagram for the experimental setup is shown in Fig. 1.

The discharge tube consists of a 15-cm long, 3.6-cm diameter soda glass cylinder. The ends of the cylinder are folded at 90° to form two rims. The two electrodes are aluminum disks machined at the outer rims to allow for O-rings to fit tightly with the discharge tube.

*Correspondence author. Email: aasimazooz1@yahoo.com

© 2012 Chinese Physical Society and IOP Publishing Ltd

The inner surfaces of the two electrodes are finely polished and cleaned. The electrodes are connected to a high-voltage dc power supply through a shunt resistor and an ammeter. The four-turn loop antenna is connected either to the oscilloscope or to the line in port of the computer's soundcard. The cable shield is properly earthed to reduce interference. It must be pointed out that the high-tension vacuum-tube voltmeter is connected to the power supply and not to the discharge tube in order to eliminate stray effects on the discharge. The actual tube voltage is calculated using the values of the discharge currents.

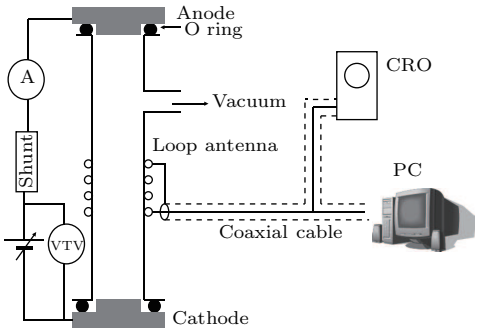


Fig. 1. Experimental setup.

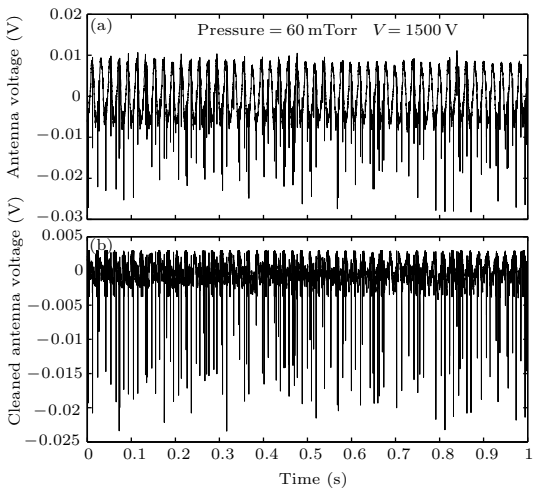


Fig. 2. Typical pulse signals acquired at pressure of 60 mTorr and discharge voltage of 3000 volts (a) raw data. (b) filtered data.

Measurements were carried out at seven discharge pressure values. These values are 30, 45, 60, 90, 120, 150, and 220 mTorr. At each pressure value, the discharge voltage is increased from the breakdown value up to the limit where the discharge begins to transform from normal to abnormal glow. Under each pressure and voltage condition, the signal induced in the loop antenna is acquired and saved on a hard disk. It may be worth mentioning that the negative polarity of the spikes obtained is of no importance. This polarity is due to the connection polarity of the loop antenna. The advantage of using a loop antenna over a probe system[8] is related to the fact that probes are only capable of detecting localized pulses. This is contrary to the response of a loop antenna which surrounds the whole discharge and can detect almost all pulses taking place within the plasma. The assignment of voltage units to the signals is rather arbitrary here. This is because although these represent actual voltage signals measured by the computer soundcard, they should be treated only as an arbitrary systematic measure of the signal. Typical signals obtained are shown in Fig. 2(a).

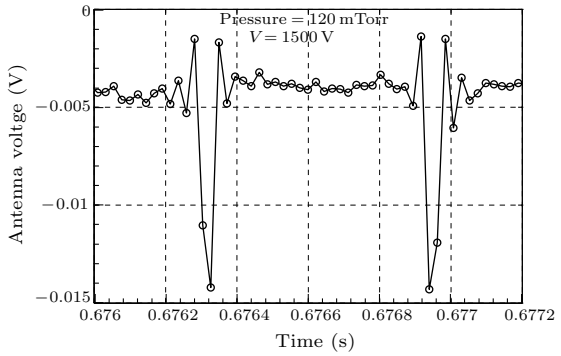


Fig. 3. Typical pulses amplified in time scale.

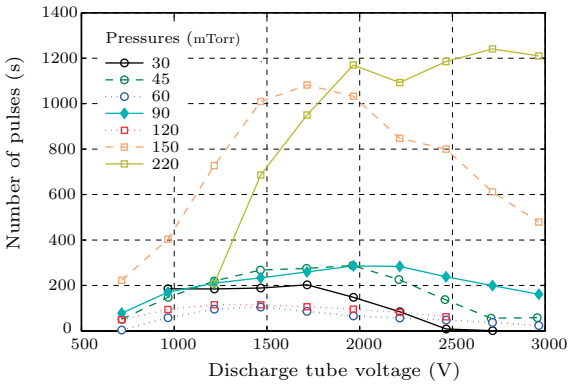


Fig. 4. Number of pulses per second against discharge-tube voltage at pressures of 30, 45 60, 90, 120, 150, and 220 mTorr.

Data similar to those in Fig. 2(a) are considered to be raw data only. This is due to the fact that the signals are contaminated by the 50 Hz main interference picked up by the antenna. Such contamination could not be avoided in spite of all the shielding techniques applied because of the high sensitivity of the computer soundcard. This interference was observed to be of constant amplitude and frequency of about 0.0083 V and 49.5 Hz, respectively, throughout the experiment. These two values were obtained by fitting the signal acquired when no discharge was taking place to the equation

$$v = a_1 \sin(2\pi a_2 t + a_3). \tag{1}$$

In Eq. (1), v represents the instantaneous voltage; a_1, a_2, and a_3 are the amplitude, frequency and phase, respectively. These fitted values of the amplitude and

frequency are further used in the signal processing of all data. All data are fitted to Eq. (1) but with only one free parameter a_3, which represents the phase. The fitted equation is subtracted from the data. Figure 2(b) shows the data in Fig. 2(a) after the application of the above signal processing procedure. It is clear that the main interference is reduced by about 80%. Other data show similar results.

It may be worth mentioning here that the data in Fig. 2 represent a discharge situation with one of the highest pulse rates obtained throughout the experiment. In order to assess the data acquisition system's capability of detecting all pulses, an amplified plot of two typical pulses is shown in Fig. 3. The circles in the figure indicate actual data samples. It is clear that the pulse duration is about 70 μs. At a data acquisition rate of 44000 Hz, each pulse will have the chance of being detected at least twice during each data acquisition trigger. Successive pulses separated in time by less than 2.3 μs may be registered as overlapping pulses. The data does not indicate the presence of many such overlapping pulses. Thus the soundcard data acquisition system can be considered to be adequate for these types of measurements.

All signals acquired were analyzed to study the pressure and discharge-tube voltage-dependence of three main parameters. These parameters are the number of pulses per second (N), the distribution of pulse heights (H) and the distributions of the time intervals between each two successive pulses (ΔT).

The variation of the number of pulses per second with pressure and discharge-tube bias voltage is shown in Fig. 4. In this figure, the curve markers are selected such that data for pressure values to the left side of the Patchen curve are circles. Data to the right of the Patchen curve are squares. At the Patchen minimum, which is about 90 mTorr, data points are solid diamonds. It is clear that for all pressure values, the number of pulses tend to start to increase with voltage up to a certain point and then start to show a slower decrease. The pressure effect, on the other hand, is slightly more complicated. Figure 5 shows the dependence of the mean pulse height as a function of the discharge voltage at different pressure values. The plots indicate that all pulses start to appear having approximately the same heights at all pressures for voltage values slightly higher than the breakdown voltages. These pulse heights start to increase with the increasing bias voltage in excess of the breakdown voltages and then assume some saturation values at very high voltages. The rate of increase and the saturation values are pressure dependent.

In order to understand this behavior, one can speculate that the pulses are produced as a result of electron bombardments of the anode. At sufficiently high voltage values, this bombardment causes extra electrons to be released from the anode surface in a way similar to what happens in a photomultiplier tube. The initial voltage increase will result in the release of more electrons such as these and with higher kinetic energies. This enables them to participate in additional inelastic collisions. The result is a temporarily localized increase in plasma density, and consequently higher electrical conductivity. This will give rise to a sharp short pulse increase in the discharge current. However, as the voltage is increased further, the anode will be better able to recapture these electrons back and the number of pulses starts to decrease slightly. This effect is more pronounced at lower pressures. Under low-pressure conditions, secondary electrons emitted from the anode surface will have a smaller chance of producing inelastic collisions with gas neutrals before they are recaptured by the anode. This explains the decrease in the number of pulses per second when the discharge voltage is high enough and the discharge is taking place at low pressures when the neutral atoms number density is small.

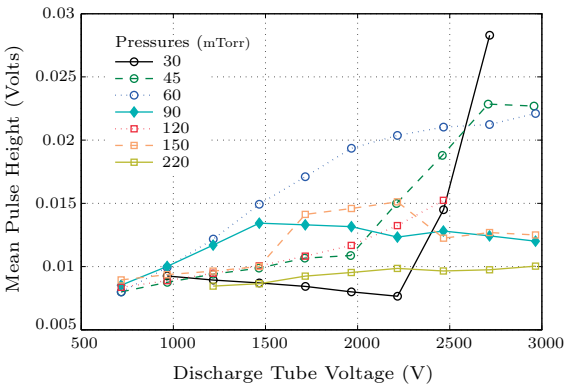


Fig. 5. Mean pulse heights against discharge tube voltage at pressures of 30, 45 60, 90, 120, 150, and 220 mTorr.

This hypothesis is further supported by the pulse height analysis in Fig. 5. It is clear that the average heights of the initial pulses are always almost the same at all pressures. These heights tend to increase at some stage approaching a saturation value. The nature and position of the saturation is pressure dependent. The behavior at pressures less than 90 mTorr, which approximately defines the left side of the Patchen curve in our system, is different from that on the right side. On the left side of the Patchen curve, the start of the increase takes place at higher voltage values as one moves away from the minimum of the Patchen curve to the left. The situation is almost reversed on the right side of the Patchen curve. The increase is delayed as one moves to the right side away from the Patchen minimum. At the minimum, the increase in pulse height starts almost immediately.

Experimental results on the pressure and voltage-dependence of very short self-sustaining pulses in glow-discharge plasma suggest that these pulses are

produced as a result of electron bombardment on the anode surface. It seems that these pulses generated during the normal glow mode tend to develop creating the abnormal glow mode. It would be interesting to study such pulses with different anode materials to further support this argument.

References

[1] Klinger T, Greiner F, Latten A, Piel A, Pierre T, Bonhomme G, Arnas Capeau C, Bachet G and Doveil F 1995 *J. Phys.* VI (Paris) **5** C6-131

[2] Sigmond R S 1997 *J. Phys.* VI (Paris) **7** C4-383

[3] Petrović Z L and Phelps A V 1997 *Phys. Rev.* E **56** 5920

[4] Maric D, Malovic G and Petrovic Z L 2009 *Plasma Sources Sci. Technol.* **18** 034009

[5] Pérès I and Pitchford L C 1995 *J. Appl. Phys.* **78** 774

[6] Hensela K 2009 *Eur. Phys. J.* D **54** 141

[7] Du B, Mohr S, Luggenhölscher D and Czarnetzki U 2011 *J. Phys. D: Appl. Phys.* **44** 125204

[8] Stefanović I, Škoro N, Marić D and Petrović Z L 2010 *20th ESCAMPIG* (Novi Sad, Serbia)

[9] Donko Z 1999 *J. Phys. D: Appl. Phys.* **32** 1657

[10] Marić D, Škoro N, Malović G, Petrović Z L, Mihailov V and Djulgerova R 2009 *J. Phys.: Conf. Ser.* **162**

[11] Rousseau A and Aubert X 2006 *J. Phys. D: Appl. Phys.* **39** 1619

[12] Walsh J L, Iza F, Janson N B, Law V J and Kong M G 2010 *J Phys. D: Appl. Phys.* **43** 075201

[13] Hong Y C and Uhm H S 2006 *Appl. Phys. Lett.* **89** 221504

[14] Balmain K G 1972 *IEEE Trans. Anten. Propagat.* **20** 400