ISSN 1330–0008
CODEN FIZAE4

MEASUREMENTS OF THE TRANSITION CURRENT FROM NORMAL TO ABNORMAL NEON GLOW DISCHARGE

EMIL BARNA, VANIA COVLEA, COSTEL BILOIU and EMIL TOADER

The Bucharest University, Faculty of Physics, P.O.B. MG-11,
76900 Bucharest - Magurele, Romania

Received 28 March 1997

Revised manuscript received 27 October 1997

UDC 531.742

PACS number: 52.35Fp

A simple technique based on a non-linear effect of self-excited ionization waves is used to measure the transition current I_t from normal glow discharge to an abnormal glow discharge in neon. The experimental results are used further to calculate the similarity parameter j_n/p^2, where j_n is the normal current density and p is the neon gas pressure. The D.C. neon glow discharge is sustained in a large-diameter cylindrical glass tube ($D = 10$ cm) over the pressure range from 13 to 133 Pa (0.1 to 1.0 Torr). The results show that I_t has a quadratic dependence on p, and the average value of the similarity parameter j_n/p^2 is 453 pA/(cm^{2}Pa^2) (i.e. 8.05 μA/(cm^{2}Torr^2)).

1. Introduction

An oscillatory non-linear effect observed as an onset of the self-excited ionization wave frequencies has been reported relatively recently in a neon diffuse glow discharge [1], and in the aureole of a neon glow discharge [2]. There are two essential characteristics of this effect that make it attractive for developing a high sensitivity technique to measure the transition parameters from normal to abnormal D.C. neon glow discharge. First, the effect occurs only for the discharge current level that corresponds to the transition regime. Second, the effect is very sensitive to very small traces of impurities.

It is the intent of this work to suggest the use of the new technique relying on such oscillatory non-linear effect for the measurements of parameters which characterize the transition regime in a neon glow discharge. Experimental values of high accuracy are obtained for the transition current I_t which are used further to calculate the similarity parameter j_n/p^2. Here we investigate low-pressure (13 to 133 Pa, i.e., 0.1 to 1.0 Torr, as 1 Torr corresponds to 133.3 Pa) and low-current (1 to 600 μA) D.C. neon glow discharge obtained in a large-diameter cylindrical glass tube ($D = 10$ cm). Because of the high sensitivity of this particular measuring technique, we expect that the data of this paper will be useful to supplement those reported by Francis [3] and Engel [4].

2. Apparatus and method

Figure 1 is a schematic of the experimental set-up. The low pressure and low D.C. current neon glow discharge is obtained in a 10 cm inside diameter and 40 cm long cylindrical glass tube, using two identical nickel electrodes having the form of 9.6 cm diameter plane discs of Rogowsky profile. The main glass tube has two 2.2 cm inside diameter and 25 cm long cylindrical extensions. Each electrode is connected to the corresponding extension end via a nickel spiral, a stainless steel rod and a massive nickel cylinder, so as to be independently displaceable using external magnets. A plane probe is placed on the axis of the discharge tube and can be placed at any distance from the cathode.

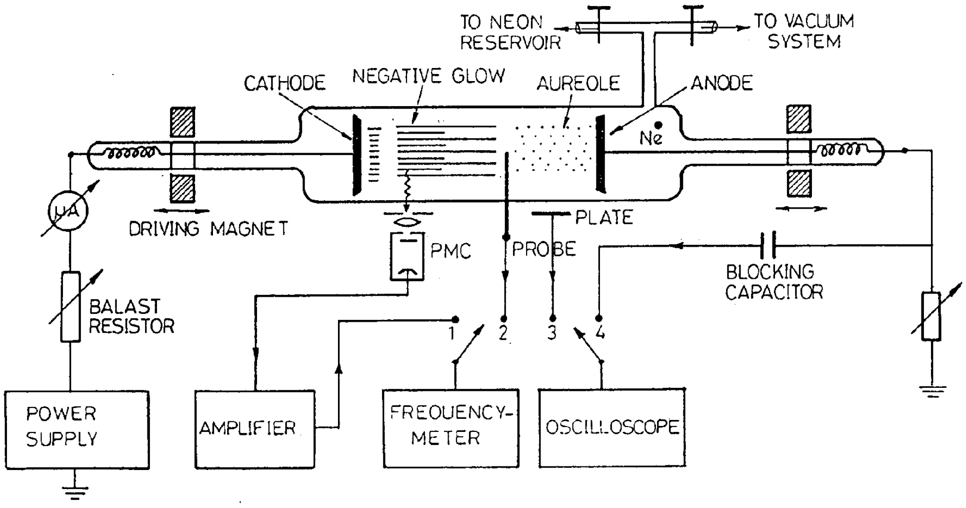

Fig. 1. A schematic of the experimetal set-up showing the neon glow discharge operation and its diagnostic by four different methods.

A diffusion pump with a liquid nitrogen trap evacuates the tube to $5.3 \cdot 10^{-6}$ Pa, and the glass tube is degassed under a vacuum of about $1.3 \cdot 10^{-5}$ Pa, while baked several days in an oven. The surface of the nickel electrodes is cleaned by running neon discharge at high current levels; neon is quite effective for sputtering most metals, including nickel. A carefully prepared cathode provides volt-ampere characteristics which are stable to less than one percent over a period of time of a few weeks. The leak-rate into the sealed tube is approximately 0.8 Pa/day. For the discharge operation, ultra-high purity (99.99%) neon is used. A capacitive manometer monitors the pressure in the range from 13 to 133 Pa. Experiments were carried out over a range of discharge currents from 1 to 600 μA. To study the neon glow discharges under the simplest and most easily controlled conditions, and to avoid the anode fall region and positive column as possible sources of oscillations, the anode is placed in the aureole of the neon glow discharges.

As shown in Fig. 1, four different recording techniques were used to record the appearance of the ionization wave signals and the onset of instability by observing the time variation of the discharge voltage, the plasma potential, the light intensity and the signals emitted by the glow discharge. These four techniques are complementary and were detailed in our papers, Refs. 5, 6, 1 and 7. Therefore, one can use the technique that is the most appropriate in the chosen experimental conditions for recording the oscillatory signals, instability onset and transition current. The simplest is the technique relying on recording of the time variation of the discharge voltage, while the most complex is the technique of measuring the light intensity with the photomultiplier in a housing with a slit, placed at a distance of a few centimeters from the tube, which was viewing the light passing through another slit placed on the discharge tube wall.

3. Results and discussion

The self-excited oscillations of the D.C. low-pressure and low-current neon glow discharges are systematically recorded using the four techniques presented above. Though in this paper we are not concerned with the origin of the oscillatory signals recorded experimentally, it is worth saying that the form of the oscillatory signals is independent on the recording method. This means that the observed oscillations are different manifestations of the same phenomenon, i.e., of the ionization waves. However, there is a very substantial difference between the oscillations of the discharge voltage and of the light intensity; the amplitude of the discharge-voltage oscillations represents a modulation of a few percent of the D.C. discharge voltage, while the modulation of the light intensity is almost 100%. The external circuit has no influence upon the oscillations. An extensive bibliography on the appearance, origin, type and parameters of the ionization waves is given in more comprehensive papers due to Donahue and Dieke [8], Nedospasov [9], Pekarek [10], Pfau, Rutscher and Wojaczek [11] and Garscadden [12].

Figure 2 shows the measured values of the frequency of oscillations, ν, as a function of the discharge current I, for a neon gas pressure of 53 Pa. The forms of the two curves are typical for the whole range of pressures used in our experiment. The most striking feature of such dispersion curves is the occurrence of a frequency onset, which, for a constant pressure, takes place invariably at the same discharge current level I, which is the transition current from the normal mode to the abnormal mode of the neon glow discharge. When the discharge current level equals I_t, the glow discharge bounces back and forth between two values of the oscillation frequency, and it is accompanied by radial expansion and contraction of the glow. The upper part of the curve in Fig. 2 corresponds to the normal glow discharge, while the lower part corresponds to the abnormal glow discharge. Consequently, the onset of the frequency of the self excited waves takes place exactly at the value I_t of the discharge current.

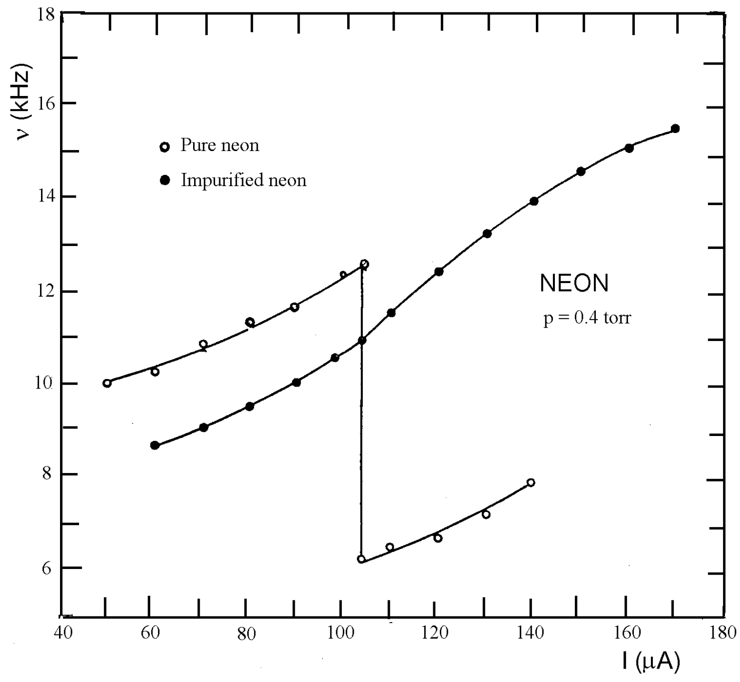

Fig. 2. The oscillatory frequency ν *as a function of the discharge current* I *for neon gas pressure of 533* Pa *showing the instability onset and the influence of impurities.*

In Table 1 are given the experimetal values obtained for the transition discharge current I_t and the values of the similarity parameter j_n/p^2 as functions of the neon gas pressure p. The transition current has a quadratic dependence on the neon gas pressure, while the similarity parameter remains constant over the whole pressure range. The fact that j_n/p^2 is a constant of the glow discharge is another proof that I_t corresponds indeed to the transition discharge current. Using the data of Table 1, an average value of 453 pA/(cm^{2}Pa^2) (i.e., 8.05 μA/(cm^{2}Torr^2) is obtained for the similarity parameter. As can be seen from the data of Fig. 2, small traces of impurities destroy the frequency onset. Consequently, this new technique may also be used to control in situ the purity of the neon gas.

TABLE 1. The values of the transition discharge current I_t and the similarity parameter j_n/p^2 as a function of the neon gas pressure p.

p (Pa)	13	27	40	53	66	80	93	106	120	133
I_t (μA)	6.4	25	58	104	158	227	310	400	506	620
j_n/p^2 (pA/(cm^2 Pa^2))	459	448	462	466	453	452	454	448	447	444

4. Conclusions

The neon glow discharges sustained in a large-diameter discharge glass tube have an oscillatory behaviour in the pressure range from 13 Pa to 133 Pa (0.1 to 1.0 Torr), and in the discharge current range from 1 to 600 μA. An oscillatory non-linear effect appears for a discharge current level which corresponds to the transition from the normal to abnormal neon glow discharge. Relying on this onset, an innovative technique is used to measure the transition discharge current I_t and to calculate the similarity parameter j_n/p^2. As impurities of neon destroy the frequency onset, this technique allows, in principle, to elaborate a very sensitive technique for detecting small traces of impurities in neon.

References

1) E. I. Toader and V. E. Kuncser, Rev. Roum. Phys. **33** (1988) 1185;
2) E. I. Toader and V. Covlea, Proc. ICPIG, Tom I, University of Belgrade (1989), p. 44;
3) G. Francis, *The Glow Discharge at Low Pressure* in *Gas Discharge II*, Vol. **22** of *Handbuch der Physik*, edited by S. Flüge, Springer-Verlag, Berlin (1956), p. 53;
4) A. von Engel, *Electric Plasma*, Taylor & Francis Ltd., London (1983), p. 133;
5) E. I. Toader, Ann. Univ. Buc. XVIII (1969) 118;
6) E. I. Toader, Rev. Roum. Phys. **14** (1969) 37;
7) E. I. Toader, Stud. Cerc. Fiz. **41** (1989) 11;
8) T. Donahue and G. H. Dieke, Phys. Rev. **81** (1951) 248;
9) A. V. Nedospasov, Usp. Fiz. Nauk (Russian) **94** (1968) 439;
10) L. Pekarek, Usp. Fiz. Nauk (Russian) **94** (1968) 463;
11) S. Pfau, A. Rutscher and Wojaczek, Beitrage Plasmaphys. **9** (1969) 333;
12) A. Garscadden, *Ionization Waves* in *Glow Discharges in Gaseous Electronics*, Tom 1, edited by M. M. Hirsh and H. J. Osean, Academic Press, New York (1978), p. 65.

MJERENJE PRIJELAZNE STRUJE OD NORMALNOG NA KAOTIČAN TINJAV IZBOJ U NEONU

Primijenili smo jednostavnu metodu mjerenja prijelazne struje I_t iz normalnog u kaotičan tinjav izboj u neonu, zasnovanu na nelinearnom učinku samo-uzbuđenih ionizacijskih valova. Na osnovi mjernih rezultata izračunali smo parametar sličnosti j_n/p^2, gdje je j_n

normalna gustoća struje, a p tlak neona. Istosmjerni tinjav izboj u neonu se održavao u cilindričnoj staklenoj cijevi velikog promjera (10 cm), za tlakove 13 do 133 Pa. Rezultati pokazuju da prijelazna struja ima kvadratičnu ovisnost o tlaku neona, a prosječna vrijednost parametra sličnosti iznosi 453 pA/(cm^{2}Pa^2).