AIP | Review of Scientific Instruments

Probe for studying wall charges in electrodeless discharges at 60 Hz

Rui-Lin Ma and F. L. Curzon

Citation: Review of Scientific Instruments **54**, 1767 (1983); doi: 10.1063/1.1137330
View online: http://dx.doi.org/10.1063/1.1137330
View Table of Contents: http://scitation.aip.org/content/aip/journal/rsi/54/12?ver=pdfcov
Published by the AIP Publishing

Probe for studying wall charges in electrodeless discharges at 60 Hz

Rui-Lin Ma[a] and F. L. Curzon

Physics Department, University of British Columbia, Vancouver, British Columbia, Canada V6T 1W5

(Received 4 April 1983; accepted for publication 1 August 1983)

A probe is described, which together with a high-resistance buffer and differential amplifier, has been used to study wall charge effects in a 60-Hz electrodeless discharge in neon at a pressure of 10 Torr. The device makes use of the external fields produced by the wall charges and shows that, in typical conditions, the wall charges take several milliseconds to come to an equilibrium after a breakdown has occurred. A major feature of the device is the use of the small external electrodes which localize the region where the wall charges tend to accumulate.

PACS numbers: 52.80.Dy; 51.50. + v

INTRODUCTION

The study of electrodeless breakdown of gas is of interest because of its possible application in measuring environmental electric field.[1,2] As is well known, wall charges tend to create fields which oppose the applied field inside the bulb and play a very important role in the electrodeless discharge. The most popular method used to study the wall charges is by integrating the current pulses which flow in the outside circuit at the instant of breakdown.[3,4] This method is only sensitive near the breakdown interval when the field inside the bulb and the wall charges change rapidly and hence, the external current is large enough for measurement. It cannot respond to the process of deionization. Since the deionization process lasts the order of a millisecond, the current induced in the external circuit is too small to measure and it is obscured by the noise. Recent studies of wall charge effects, relevant to plasma display panels, have been reported.[5,6]

Previous analyses of the electrodeless discharges tend to neglect the variation of wall charges during the process of deionization. However, to study the phenomena further in low-frequency electrodeless discharges it would be desirable to have an instrument which can indicate directly the time dependence of wall charges and the field inside the bulb. The above purpose has been achieved by means of a voltage measuring probe outside the bulb together with a high-input resistance buffer and a differential amplifier. The principle of this method and the practical apparatus are reported in Secs. I and II. Some new phenomena were found and a preliminary discussion appears in Sec. III.

I. THE PRINCIPLE OF THE PROBE

The principle of the probe is shown in Fig. 1. The electrodeless discharge is produced in neon contained in a 40-mm-diam Pyrex glass bulb by applying a 60-Hz alternating field to two external spherical electrodes (6.4-mm diam). The voltages applied to the electrodes are equal and opposite, so that the equatorial plane of the bulb is a ground plane. Charges produced by a breakdown in the gas will tend to migrate towards the electrodes and are therefore deposited in well defined locations. As shown in Fig. 1 a probe P and a ground plate are placed outside the bulb. P is very small and is close to the equatorial plane of the discharge gap, so that the influences of the probe and ground plate on the discharge is small and can be neglected.

We study at first the case when there are no charges on the inner surface of the glass. The charges on the upper external electrode produce an electric field which causes a potential difference between the probe and the ground plate. The influences from the lower electrode are screened by the ground plate and can, therefore, be ignored.

The potential of the probe u_p is, therefore, given by the following expressions:

$$u_P = u_s C_1/2(C_1 + C_2), \quad (1)$$

$$= AQ/2C_0, \quad (2)$$

$$A = C_1/(C_1 + C_2), \quad (3)$$

where u_s is the electrode voltage, C_1 is the coupling capacitance as shown in Fig. 1, C_2 is the total capacitance between the probe and the ground, including the lead capacitance and the input capacitance of the buffer, C_0 is the capacitance between two external electrodes, Q is the amount of charge on the external electrode. In our experiment C_1 is very small (less than 0.01 pF). It is always true that $C_0 >> C_1$, so that the feedback from the probe to charges on the electrode can be neglected. If C_0, C_1, and C_2 remain constant the signal picked by the probe is only determined by Q.

When there are charges $(-q)$ on the upper inner surface of the bulb (Fig. 1) and they are very close to the elec-

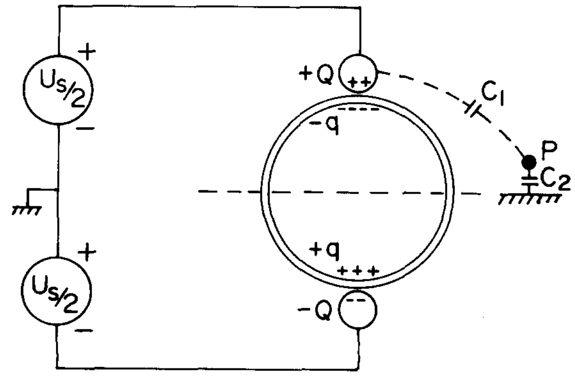

FIG. 1. Diagram illustrating the principle of the probe. u_s = applied voltage; P = probe; Q = charges on the external electrode; q = charges on the inner surface of glass.

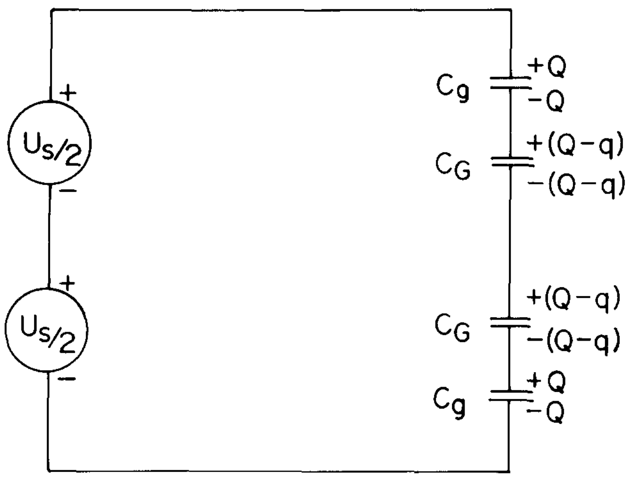

FIG. 2. Equivalent circuit of the discharge gap. C_g = capacitance between the electrode and the charged inner surface; C_G = capacitance between the charged inner surface and the middle plane of the bulb.

trode, u_p can be expressed approximately as

$$u_p = A(Q-q)/2C_0. \tag{4}$$

Since glass is a very good insulator, the leakage of $-q$ in about a 20-ms period of the applied field can be entirely neglected. This implies that once the charges have been placed on the glass surface they stay there until they are neutralized by charges of opposite sign coming from the discharge space. If the wall charges $-q$ are distributed in an equipotential plane through which the most electric flux from the external electrode passes, then Fig. 2 can be used as an equivalent circuit for Fig. 1. It is a reasonable approximation in our experiment.

In Fig. 2, C_g is the capacitance between the electrode and the charged inner surface of the bulb, C_G is the capacitance between charged inner surface and the middle plane of the discharge gap, $C_g >> C_G$.

It follows from the equivalent circuit (Fig. 2) that,

$$u_s = 2(u_g + u_G) = U_{sm}\sin\omega t, \tag{5}$$

$$u_G = (Q-q)/C_G, \tag{6}$$

$$u_g = Q/C_g, \tag{7}$$

$$C_o = 1/2[(1/C_g) + (1/C_G)], \tag{8}$$

$$Q = C_0[u_s + (2q/C_G)], \tag{9}$$

$$Q - q = C_0[u_s - (2q/C_g)], \tag{10}$$

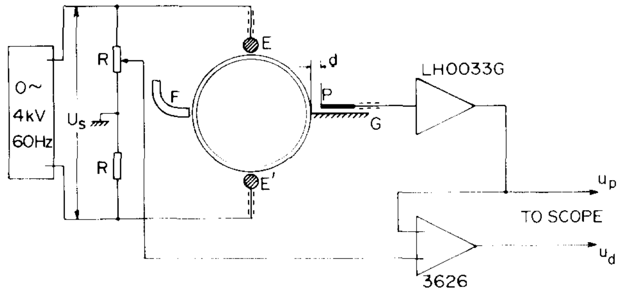

FIG. 3. Sketch of experimental apparatus. P = probe; G = ground plate; E-E' = external electrodes; B = bulb; F = optical fiber; d = distance of the probe from the bulb.

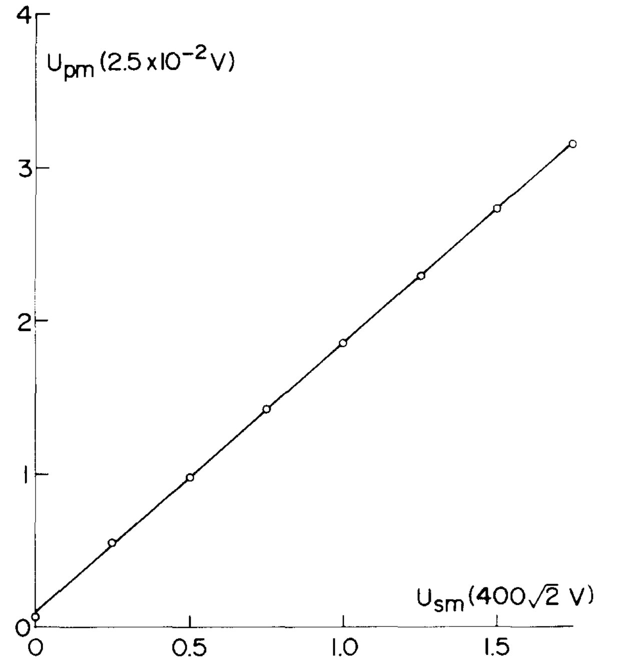

FIG. 4. Plot of u_p vs u_s. u_p = output of the buffer (signal picked by the probe); u_s = applied voltage.

where u_g and u_G are potential differences across the capacitances C_g and C_G.

From Eqs. (4), (6), and (10) and using $C_0 \approx C_G/2$, we get,

$$u_p = A(C_G/2C_0)u_G, \approx Au_G, \tag{11}$$

$$(Au_s/2) - u_P = Aq/C_g. \tag{12}$$

Two useful results can be derived from Eqs. (11) and (12). (a) The signal u_p picked up by the probe directly indicates the potential difference and, hence, the electric field inside the bulb. (b) If u_p and $Au_s/2$ are fed into a differential amplifier, then the output u_d directly indicates the amount of charges placed on the upper inner surface of the bulb

$$u_d = BAq/C_g, \tag{13}$$

where B is the gain of the differential amplifier.

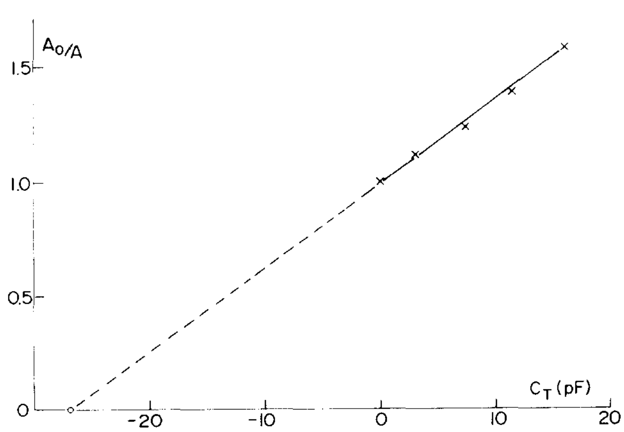

FIG. 5. Plot of A_0/A vs C_T. C_T = capacitance connected additionally across the input of the buffer; A = gain of the probe defined in Eq.(3); A_0 = value of A when $C_T = O$.

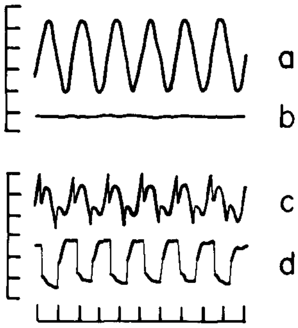

FIG. 6. Scope traces of $u_P(t)$ and $u_d(t)$ when $U_{sm} = 1130$ V. u_P = output of the buffer; u_d = output of differential amplifier; time base = 10 ms/div. a) $u_P(t)$, 50 mV/div, absence of breakdown; b) $u_d(t)$, 0.5 V/div, absence of breakdown; c) $u_P(t)$, 50 mV/div, two breakdowns per cycle; d) $u_d(t)$, 0.5 V/div, two breakdowns per cycle.

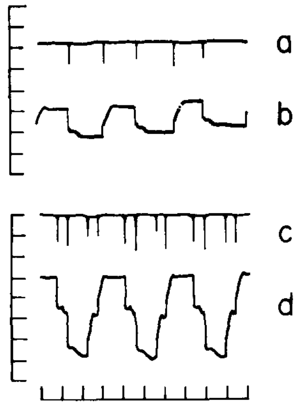

FIG. 8. Scope traces of $u_d(t)$ simultaneously with light pulses emitted by the gas. Time base = 5 ms/div. a) light pulses, 2 breakdowns per cycle; b) $u_d(t)$, 2 breakdowns per cycle; c) light pulses, 4 breakdowns per cycle; d) $u_d(t)$, 4 breakdowns per cycle.

II. DESCRIPTION OF THE EXPERIMENTAL APPARATUS

Figure 3 is a sketch of the experimental apparatus. The details of the gas-filled bulb and external electrodes have been given above. The electrodes are connected across the secondary of a transformer which has a balanced output voltage. The primary is fed from an autotransformer which permits the voltage across the electrodes to be varied from 0 to 4 kV. A copper ground plate is placed on the equatorial plane of the bulb. The probe is a copper wire with a diameter of 1.5 mm and a length of 20 mm. The distance between the probe and the ground plate is 4.5 mm. The tip of the probe is normally 7 mm from the bulb surface. The buffer is an integrated circuit chip (LH0033G) which has a high input resistance (exceeding $10^{10}\,\Omega$) and a voltage gain near one. The differential amplifier is a 3626 integrated circuit with a voltage gain of $B = 9.6$. A variable resistance is used to adjust the input of the differential amplifier to ensure zero output when there is no charge on the inner surface of glass.

All leads are screened in order to eliminate spurious signals. The noise picked by the probe is less than 3 mV which is less than 4% of the typical value of u_p.

In order to obtain more information we also observe the flashes of light emitted from the gas when breakdowns occur. The light pulses are conveyed to a photomultiplier by a glass fiber bundle. More details of the system appear in Ref. 2.

III. EXPERIMENTAL RESULTS

Two experiments were performed to verify that the probe operated as expected. In the first the probe, signal u_p was measured as a function of u_s when the breakdown is absent. As Fig. 4 shows, the plot of u_P vs u_s is a very good straight line with a slope of $A = 1.54\times10^{-4}$. In the second experiment a variable capacitor C_T was connected across the input of the buffer, and A^{-1} was determined as a function of C_T. The straight line plot (Fig. 5) is in good agreement with Eq. (1) with $C_1 = 4.2\times10^{-3}$ pF and $C_2 = 27$ pF.

Figures 6(a) and 6(b) show the waveform of u_P and u_d (the output of differential amplifier) when the breakdown is absent. u_P is a sine wave while u_d is a horizontal line (noise $<4\%$). The typical wave form of u_P and u_d when breakdowns occur are shown in Figs. 6(c) and 6(d), where $U_{sm} = 1130$ V (peak value) and there are two breakdowns per cycle of the applied voltage.

Since u_P represents the electric field inside the bulb when breakdown occurs, u_p suddenly goes to zero then tends to follow the u_s waveform again.

The waveform for u_d is roughly rectangular in shape and can be divided into three parts. First, a jump occurs in the moment of breakdown. This results from space charges which rapidly migrate to the inner surface of the glass. These charges build up an opposite field and stop the discharge. When breakdown occurs with $u_p > 0$, the jump is caused by the accumulation of electrons near the upper electrode

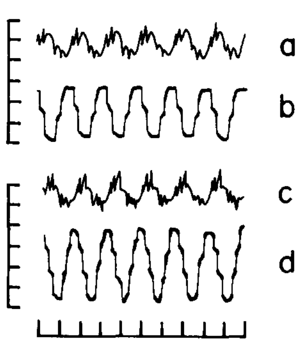

FIG. 7. Scope traces of $u_P(t)$ and $u_d(t)$ when there are 4 and 6 breakdowns in a cycle. u_P = output of the buffer; u_d = output of the differential amplifier; time base = 10 ms/div. a) $u_P(t)$, 100 mV/div, 4 breakdowns per cycle; b) $u_d(t)$, 1 V/div, 4 breakdowns per cycle; c) $u_P(t)$, 100 mV/div, 6 breakdowns per cycle; d) $u_d(t)$, 1 V/div, 6 breakdowns per cycle.

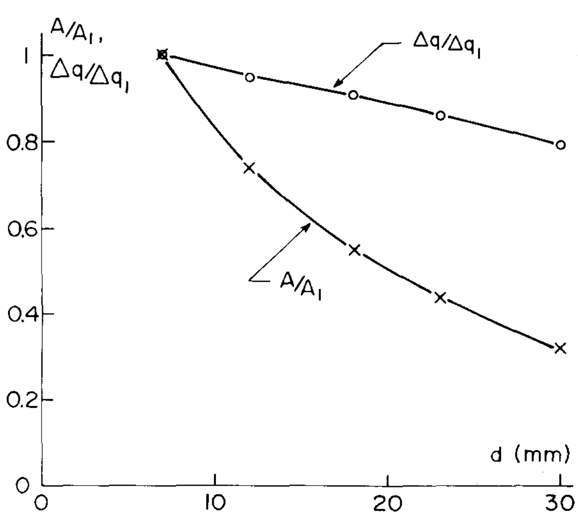

FIG. 9. Plot of $\Delta q/\Delta q_1$ and A/A_1 as the function of d. d = distance of the probe from the bulb (see FIG. 3); Δq = charges delivered by one breakdown; Δq_1 = value of Δq when d is 7 mm; A = gain factor of the probe; A_1 = value of A when d is 7 mm.

($q<0$). When $u_P<0$ ions accumulate near this electrode ($q>0$). The initial jump in u_d is larger if $q<0$ than if $q>0$. In the second part of the waveform, u_d changes continuously but with a slower rate. The duration of this stage is about 2–3 ms. The slower rate of change of u_d means that wall charges are still being altered for a rather long time after the breakdown. The amplitude of this variation is about $20\% \sim 30\%$ when $q<0$ and 50% or more when $q>0$. The third portion of the u_d waveform is flat and indicates that the wall charges are constant and that the field inside the bulb follows the applied field completely.

The total amount of the wall charges delivered by every breakdown (Δq) can be determined by the difference between two successive flat regions (Δu_d). $\Delta q = \Delta u_d C_g/(AB)$. If C_g is estimated as 1.6 pF the typical value of Δq is 1.1×10^{-9} C and it is independent of the sign of the wall charge.

Figure 7 shows the waveforms of u_P and u_d when there are four and six breakdowns in a cycle.

In Fig. 8 the light pulses are shown simultaneously with u_d. When the probe is at a distance (d, see Fig. 3) from the bulb the corresponding values of A and Δq can be written as $A(d)$ and $\Delta q(d)$. With this notation, one would expect $\Delta q(d)$ to be constant irrespective of distance d. As d is increased from 7 to 30 mm, $A(d)$ decreases by a factor of three, however, $\Delta q(d)$ decreases by 20%. If it is noted that spurious signals greatly affect the accuracy of measurement in the case of small values of A, then this result shows that the probe does indeed give a good measure of Δq, the charges deposited by successive breakdowns. Figure 9 shows a plot of $\Delta q(d)$ and $A(d)$.

The above results indicate that the voltage probe and differential detection system provides a convenient method of studying the properties of wall charges generated in electrodeless discharges. The method is particularly beneficial if the wall charges are localized by means of small external electrodes. Finally, since the probe is remote from the charged areas, it has very little influence on the properties of the quantities being measured.

ACKNOWLEDGMENTS

This work was financed by a grant from the National Science and Engineering Research Council of Canada. The authors are indebted to A. Cheuck, R. Keeler, and R. Morgan for their assistance in devising some of the apparatus.

[a]Cultural exchange visitor from South China Institute of Technology, Guangzhou, China.

[1]F. L. Curzon, D. E. Friedmann, and M. Feeley, J. Appl. Phys. **54**, 86 (1983).

[2]D. E. Friedmann, F. L. Curzon, M. Feeley, J. F. Young, and G. Auchinleck, Rev. Sci. Instrum. **53**, 1273 (1982).

[3]W. L. Harries and A. von Engel, Proc. R. Soc. London, Ser. B **64**, 951 (1951); and A **222**, 491 (1954).

[4]J. M. El-Bakkal and L. B. Loeb, J. Appl. Phys. **33**, 1567 (1962).

[5]E. Kindel and R. Arndt, Beitr. Plasmaphys. **21**, 411 (1981).

[6]E. Kindel and R. Arndt, 13th International Conference on Phenomena in Ionized Gases, Part I (Physics Society German Democratic Republic, Leipzig, Berlin, 1977), p. 219.