A MICROWAVE STUDY OF MOVING STRIATIONS

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A microwave method has been used to measure the electron density n_e in moving striations in He, Ne, and Ar. The distribution of the emission S along the column (x coordinate) is found to coincide with that of n_e; $n_e(x)$ and S(x) are found to depend on the nature of the gas.

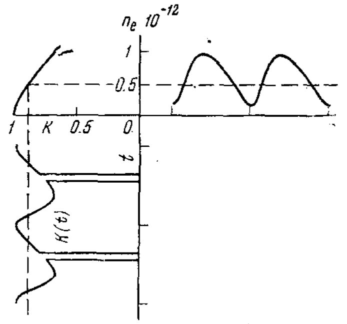

Fig. 1

The discharge tube was passed through the wide side of a rectangular waveguide parallel to the electric field of a TE_{10} wave. The ratio of guide height b to striation length l was made as small as possible, while b/R (R is tube radius) should not be substantially less than unity, since otherwise the field penetrates beyond the limits of the waveguide [1]. We used b = 1 cm, R = 1.4 cm, and l of 8-15 cm with three identical sealed tubes having electrodes 70 cm apart. One tube was filled with He at 0.7 mm Hg; the others contained Ne and Ar at 0.5 mm Hg. The measurements were made at 10 cm with a low power level. The klystron was gated by 10-μsec pulses applied to the reflector.

The motion of the striations caused the UHF power at a fixed point to vary periodically. The transmission coefficient K is dependent on the electron density n_e and collision frequency ν_e, which itself is dependent on the electron temperature U_e, which varies by a factor 1.5-2 along a striation [2-4].

However, if $\nu_e^2 \ll \omega^2$, in which ω is the angular frequency of the field, the resistive component of the admittance can be neglected [1,5], and in that case the variation in K is determined solely by the variation in n_e along the column, so n_e can readily be deduced from oscillograms if $K(n_e)$ is known.

Standard formulas [5] for a dielectric rod in a waveguide are not applicable here, because the depth of the skin layer is comparable to the radius of the tube, and n_e is not constant over the cross-section. The $K(n_e)$ curve was found by experiment from the measured K and n_e for a uniform column as a function of discharge current. A uniform column was produced in the first tube (0.7 mm Hg of He). Striations arose spontaneously in this case at 280 mA, and they slowly become stronger toward the anode over a wide range in i [6], whereas toward the cathode there is a reasonably uniform part of sufficient extent. The $K(n_e)$ curve derived from this part was then used to deduce n_e along the striations in the rest of the positive column and in discharges in Ne and Ar, on the assumption that the distribution of n_e in a cross-section of a striated column did not differ from that in a uniform column [3].

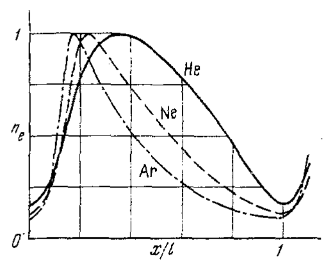

Fig. 2

The $n_e(x)$ curve was recorded as follows. The K(t) curve was recorded as shown in Fig. 1, the scale of the $K(n_e)$ curve on the K-axis being normalized to the transmitted signal in the absence of the discharge current. Then the corresponding point in coordinates n_e and x was deduced for each point on K(t). Adjustment of the tube allowed n_e to be determined throughout the region of the striations. As the scale of the variations increased (away from the cathode), the shape of $n_e(x)$ changed from sinusoidal (scale of variations 0.1 of the saturation level) to the form shown in Fig. 1. Figure 2 shows $n_e(x)$ in the region of maximum sharpness for discharges in He, Ne, and Ar, the curves being normalized to the maximum value. These curves show that n_e changes by factors of 6, 8, and 10, respectively, over the length of a striation.

The shape of $n_e(x)$ is almost exactly that of S(x) in all these cases. The shape of a striation is dependent on the nature of the gas.

No systematic study has previously been made on traveling striations, and $n_e(x)$ has been recorded only for Ar [2,7]. Figure 2 shows that the falling branch of $n_e(x)$ for He is clearly convex over much of its length, the ratio of l_1 to l_2 (lengths for rise and fall) being 2:3. At about the same pressure of Ar, the falling branch of $n_e(x)$ is concave, while $l_1 : l_2$ as 1:6. The region $n_e > 0.7n_{e.max}$ takes up about half the length of a striation for He, but only 1/6 for Ar; Ne gives a shape for $n_e(x)$ intermediate between those for He and Ar. Increase in pressure causes the shape to tend toward that found for the heavy gas, but there was no deformation of striations of maximum sharpness as i was altered. This indicates that the shape is determined by longitudinal ion diffusion. The results for $n_e(x)$ for Ar agree with ones obtained by probe measurements [2] and with the results of [7], in which a microwave resonance method was used. The condition $\nu_e^2 \ll \omega^2$ is not obligatory for He, since ν_e is independent of U_e for $U_e > 3$-4 eV [8].

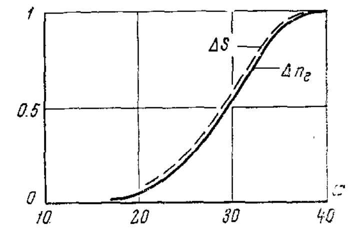

Fig. 3

Figure 3 shows the scale Δn_e of the variation in n_e and also the scale ΔS of the emission variation along the axis (distance x, cm, from the cathode) of the column for He at i = 500 mA, with Δn_e and ΔS given relative to the values for maximum sharpness. The two curves are virtually identical. This is important, since previous measurements [6,9] have been based on the emission intensity.

The UHF results (from K) for the length l and frequency f of the striations agree precisely with those from measurement of S. A double-beam oscilloscope was used to determine the phase shift between K and S. A maximum in S(x) always coincided with a maximum in the derivative $n_e'(x)$. The U_e and S curves should not differ substantially in position [10], so this shift may be considered as a shift between n_e and U_e, which was first detected by probe measurements [2].

The microwave method appears to be very useful. The calibration curve can be applied to other inhomogeneous columns, e.g., separation in a discharge in a mixture of gases.

The waveguide method differs favorably from the cavity method in that the limit to measurement of n_e is set not by the critical value $n_* = m\omega^2/4\pi e^2$ (e and m are the charge and mass of an electron), but by the ratio of the thickness of the skin layer to the radius of the tube, and this limit exceeds n_* by about two orders of magnitude. This method gives about the same absolute accuracy for n_e in a stratified positive column as does the probe method for a homogeneous column, while relative changes can be measured much more accurately.

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