VIII-4. APPLICATION OF A MICROWAVE TECHNIQUE TO THE MEASUREMENT OF ELECTRON DENSITY AND RELAXATION TIME

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The measurement of ionization rate and electron densities in thermally ionized gases attracted the attention of many scientists and engineers working in the aerospace field. Determination of these parameters is of importance not only in the field of communication with reentering bodies, but is also of vital importance in understanding combustion and other rapid chemical reactions. Initial ionization is usually attributed to collisions between molecules, but as the electron density increases, collisions between electrons and neutral particles may also become important or even dominant in the ionization process. Depending on the efficiency of molecular collision processes, on the physical and chemical properties of the gas and its purity, a time lag or relaxation time will result between the heating of the neutral gas and the attainment of equilibrium electron density. Since in a shock tube, samples of gas can rapidly be heated to temperatures in excess of 10^4 °K without introducing an excess of impurities, this kind of device is ideally suited for the above-mentioned studies.

Several methods have been used to measure this delay time and the equilibrium electron density. In this investigation an attempt has been made to apply a microwave resonant cavity technique to measure the relaxation time and electron density behind a reflected shock in a shock tube. A particular cavity arrangement well-suited for this measurement is an "end wall" cavity operated in the TE_{011} mode. Fig. 1 shows the schematic of this type of a resonant cavity. Fig. 2 shows a schematic representation of the experimental apparatus including the cavity and the basic external circuity. As shown in Fig. 1, the dielectric window of the cavity forms the end of the shock tube. When the incident shock is reflected from the dielectric window, the ionized gas behind the reflected shock forms a conducting wall which completes the cylindrical cavity. The depth of penetration of the cavity field into the plasma depends on the electron density at the wall. Neglecting collisions and assuming no d.c. magnetic field, it is given by [1,2]

$$z = \frac{c}{\omega_p}\left[1-(\omega/\omega_p)^2\right]^{-\frac{1}{2}}$$

where c is the velocity of light, ω is the frequency of the applied electromagnetic field and ω_p is the plasma frequency given by $\omega_p = (ne^2/m\epsilon_0)^{\frac{1}{2}}$.

† This research has been conducted in part under Contract Nonr 839(38) for PROJECT DEFENDER, and was made possible by the support of the Advanced Research Projects Agency under Order No. 529 through the Office of Naval Research.

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Since the resonant frequency of the cavity depends on its axial dimension and therefore on the penetration depth, the measurement of the resonant frequency may be used to determine the electron density.

Calibration of the cavity is done by sliding a metallic piston in the shock tube and measuring the resonant frequency of the cavity as a function of penetration depth (i.e., distance between the metallic piston and the dielectric window: penetration depth into metallic piston is neglected). Using this with Eq. 1, a calibration curve is obtained, as shown in Fig. 3. There $\Delta f = f_0 - f_r$ where f_0 is the resonant frequency with the metallic plug at $z = 0$ and f_r is the resonant frequency with the plasma. At high electron densities the change in resonant frequency as a function of electron density is given by [3]

$$\frac{\Delta \omega}{\omega_0} = -K \frac{\omega_0}{\omega_p} \left[1 - \frac{i\nu}{\omega_0}\right]^{\frac{1}{2}} \qquad (2)$$

where ν is the electron collision frequency, and K is a configuration constant easily obtainable through calibration.

To perform a measurement, two or more microwave signals are applied simultaneously to the cavity. When two signals are applied simultaneously, they are displaced below the resonant frequency f_0 and from each other by Δf_1 and Δf_2 of the order of about 10-20 mc/s. The frequency displacements Δf_1 and Δf_2 thus represent very small fractions of the operating frequency f_0 of about 9 kmc/s in this case. The cavity will thus resonate for each signal when the corresponding electron density forms in front of the dielectric window. By repeating a number of closely controlled tests, and shifting the frequency applied to the cavity, it is possible to obtain an electron density profile behind the reflected shock as a function of time.

Typical results obtained by this method with shocks in air and argon are given in Figs. 4, 5. They have been found to be in good qualitative agreement with results reported by other investigators [4,5,6]. Some of the problems with these measurements were:

1) Theoretical time resolution of the cavity is ~0.3 μ sec, making measurements in air difficult.

2) Plasma formation time (time for the reflected shock to travel the penetration depth) is of the order of 1 μ sec, or approximately the measured ionization times in air. This means that the measured ionization times in air are only upper limits.

3) Effects of the dielectric wall in cooling and contaminating the test gas are unknown. This was investigated, however, using different dielectric materials with small changes noticed.

4) Impurity gases, especially in tests involving argon, may change the ionization processes and are very difficult to eliminate.

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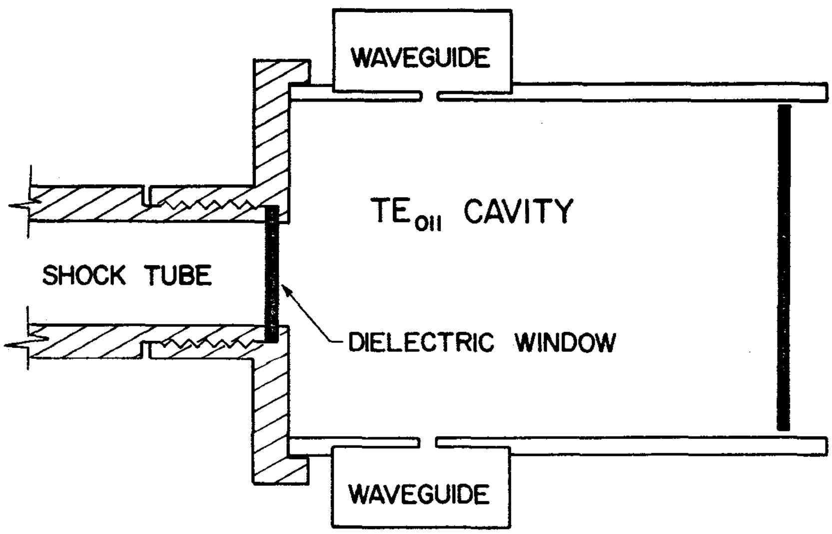

Figure 1. End Wall Cavity

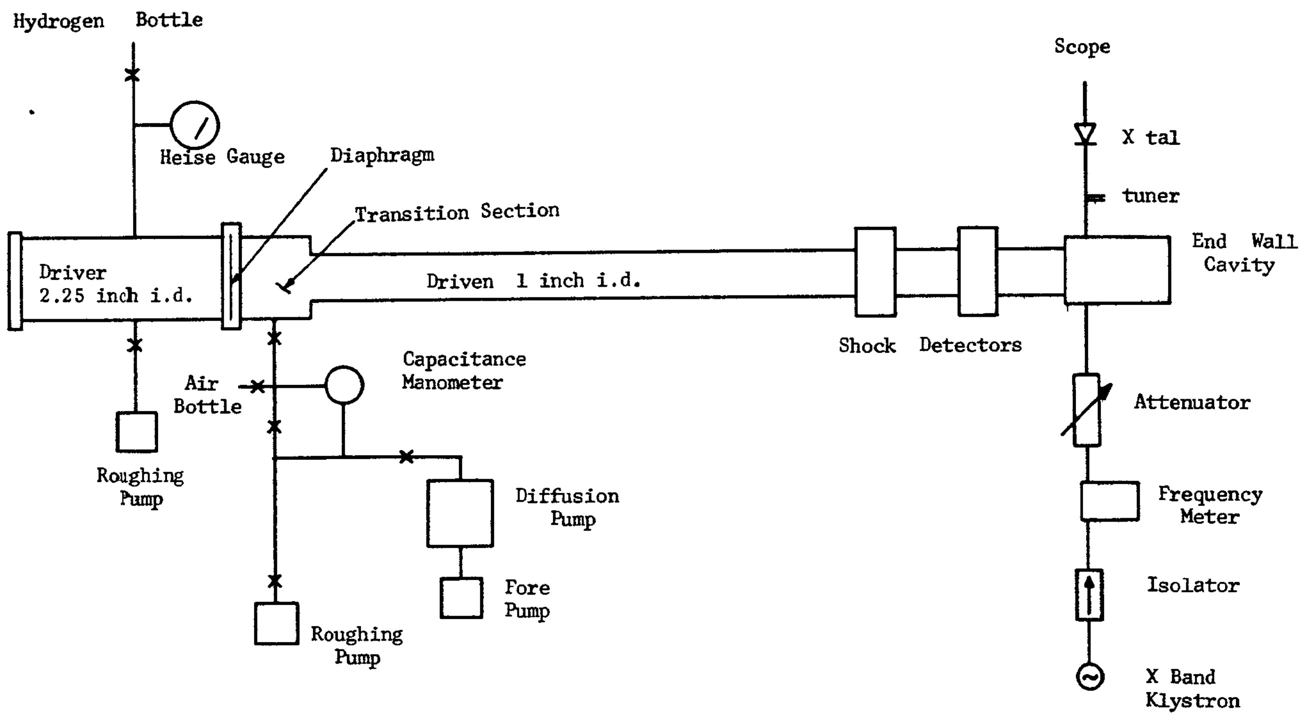

FIG. 2. SCHEMATIC REPRESENTATION OF THE EXPERIMENTAL APPARATUS

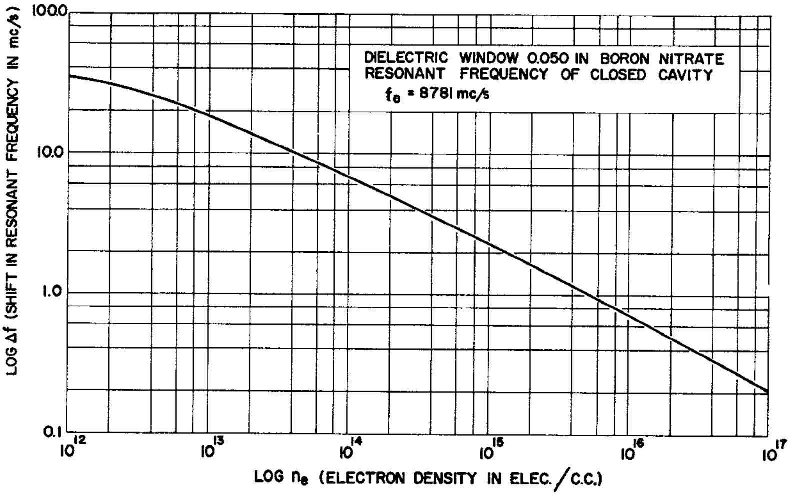

FIGURE 3 CALIBRATION OF END WALL CAVITY

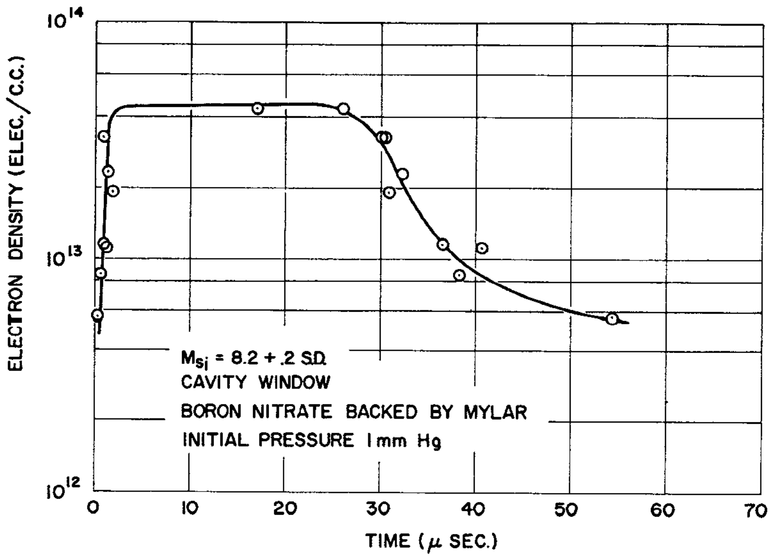

FIGURE 4 ELECTRON DENSITY PROFILE BEHIND A REFLECTED SHOCK IN AIR, P_1 = 1.0mm Hg , M_{s_i} = 8.2 + .2 S.D.

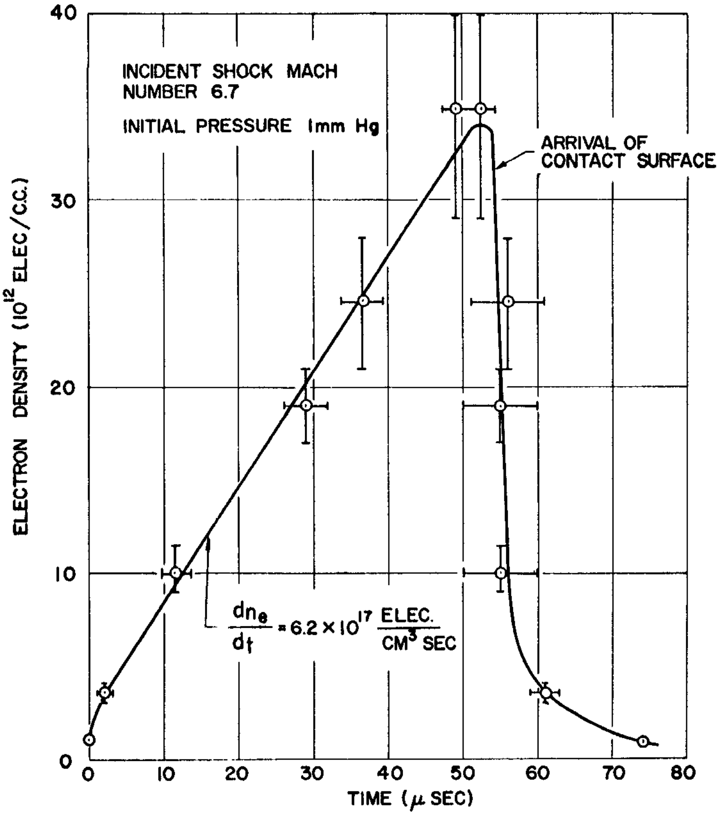

FIGURE 5 IONIZATION PROFILE BEHIND A REFLECTED SHOCK IN ARGON.