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NOISE GENERATED IN MERCURY VAPOR DISCHARGES

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Abstract: Observations of low and high frequency noise generated in a DC low pressure arc in mercury vapor are reported. High frequency noise, monitored at 160 ± 2.5 MHz, occurs at the transition between space charge limited and temperature limited cathode operation and propagates in the form of surface waves. Low frequency noise spectra are recorded in both cathode regimes, and deviations from simple ion sound generation established.

1. Introduction

Discharge tubes commonly used for plasma physics experiments are strong sources of noise. This paper deals with observations of such noise in two frequency domains on a sealed-off diode with mercury vapor run in d. c. regime. Details of the cathode region are shown in Fig. 1. The cathode was a tungsten wire, heated by an a. c. power supply. The constriction marking the transition between the cathode region and the long tube where the positive column was formed (not shown here) was found to act as a powerful source of noise.

Numerous observations of noise on similar systems are reported[1], but all the mechanisms of noise generation are still not entirely clear.

This paper deals with experimental data regarding noise at a very low frequency of the order of 100 kHz, and noise within the high frequency band

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of (160 ± 2.5) MHz. These two regions were dictated by the usable ranges of the available spectrum analysers.

2. *Low-frequency fluctuations*

Preliminary observations of low-frequency density fluctuations detected by an oscilloscope have already been reported by one of the authors[2]. Those measurements, using a dipole coupler similar to the one used by Crawford *et al.*[3], indicated that the density of the positive column was modulated at 30 or 80 MHz, depending on the value of discharge current. We also found that these amplitude density fluctuations were in phase along the whole tube, indicating a high phase velocity of the disturbance (small value of propagation constant). Similar results were obtained by other authors[3, 4] and the undesirable features of such a density modulation for propagating microwave signals through plasma were discussed by Kino *et al.*[5] In our case, attempts made to gain additional information about these fluctuations by calculating the correlation function of the oscilloscope traces of these density fluctuations at various places along the tube, remained without success, probably due to the very high phase velocity of these disturbances (estimated at more than 10^9 cm/s by other authors[6]).

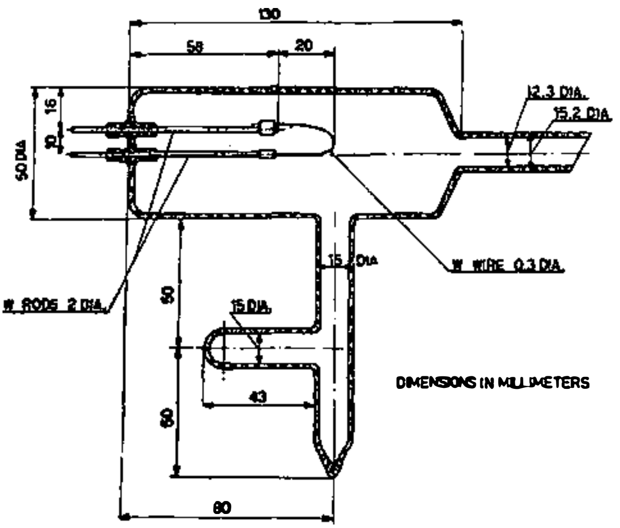

Fig. 1. Details of cathode region.

As density fluctuations were found to be closely related to potential fluctuations[3], the potential from a Langmuir probe immersed well within the positive column region of the discharge tube was studied with a low frequency analyser. In addition to a fairly broad spectrum of noise in the range of hundreds of kiloherz, there was a pronounced peak at about 80 kHz. The exact value of the frequency depends on various tube parameters (Fig. 2). When the tube was run at a constant discharge current (100 mA) and the cathode mode of operation was gradually changed from space charge limited to temperature limited (by lowering the cathode heating power), the frequency of the peak increased from around 90 to about 130 kHz (Fig. 3), while the amplitude decreased until it could not be distinguished from incoherent noise. Furthermore, this coherent low-frequency noise component could be virtually eliminated by introducing local magnetic field (few tens of gauss) near the tube constriction (Fig. 4). Finally, this peak was not prominent at low values of discharge curent, but began to appear at around 75 mA showing a slight increase in frequency (from 78 to 87 kHz) with increasing discharge current from 75 to 125 mA (see Fig. 2).

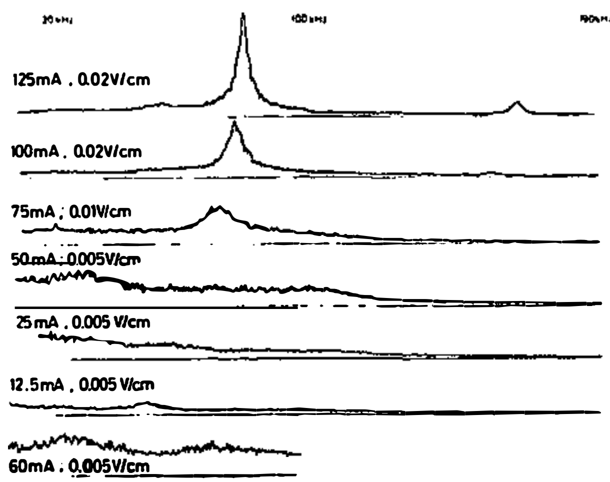

Fig. 2. Spectra of tube noise at various discharge currents, measured with a cylindrical probe in ion saturation.

A possible explanation of the mechanism of generation of the prominent component of these low frequency density and potential fluctuations is that it represents a radial mode of ion acoustic waves at cutoff[7]. In this case the frequency of the peak should increase with the electron temperature ($f \sim T^{1/2}$). In regard to our observations, the increase in frequency when passing into temperature limited regime may be explained by a rise in average electron temperature due to the rise of cathode voltage drop. Furthermore, the dependence of frequency of the peak on the discharge current would imply that electron temperature increases when the discharge current rises, which agrees with some published results[1, 8], but not with our results of Langmuir probe measurements[9]. Thus, there is doubt as to whether ion acoustic waves are solely responsible for low frequency fluctuations, especially since there

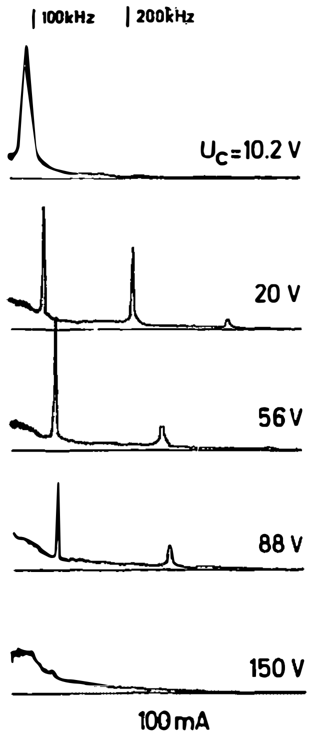

Fig. 3. Spectra obtained at 100 mA discharge current. The parameter is the cathode voltage drop.

is incoherent noise present as well, which indicates the existence of additional noise generation mechanisms in this frequency band.

3. *High-frequency fluctuations*

Observations of high frequency fluctuations in the band of (160 ± 2.5) MHz were reported earlier[10] and will be summarized for the sake of completeness. As was the case with LF fluctuations, this narrow band of HF noise is generated in the cathode region and/or at the tube constriction, and only within a certain interval of the *V-I* plot, as shown in Fig. 5. This was the transition between the space charge limited and temperature limited cathode operation, and there was a faint blue light present in the cathode region from one point within this interval (indicating the presence of high-energy electrons[11]). The existence of this noise was further limited by temperature (i. e., Hg vapor pressure) and was observed at temperatures from 24 to 28 °C. As shown on Fig. 6, the noise appeared intermittently, only near the zeroes of the cathode heating current and was not detected with d. c. heating. The above features of HF noise do not seem to have been reported in literature.

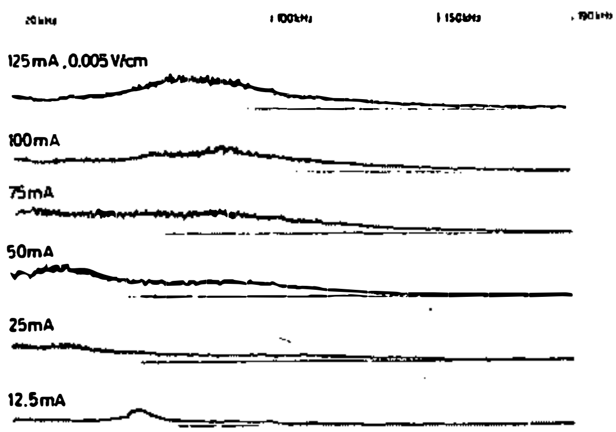

Fig. 4. Spectra of tube noise with a magnetic field near the cathode and constriction, adjusted to eliminate the prominent noise component when the tube current is 125 mA.

There were also certain features common to observations of other authors. The presence and amplitude of noise were highly dependent on application of magnetic field (by merely placing a small permanent magnet) to the cathode region or the tube constriction. With small values of the field (a few gauss), the HF fluctuations were completely suppressed, while with field values of a few hundred gauss, the signal level rose by 30 dB and was no longer intermittent with respect to heating current. This profound effect of magnetic field on the level of noise has been reported by many authors[1, 4]. The fact that the intermittent character of noise generation depends on external magnetic field seems to point out that the noise generation depends on the periodic variation of the electric and magnetic field of the cathode filament.

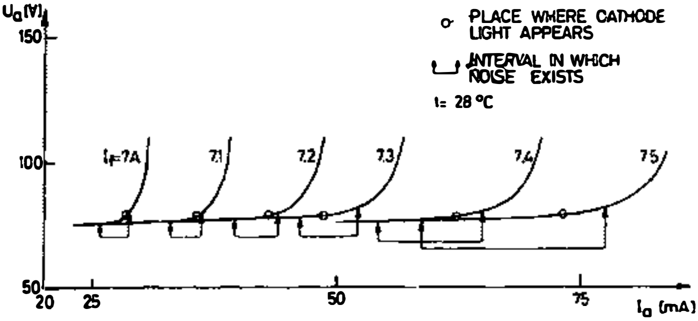

Fig. 5. Appearance of cathode light and high-frequency noise before saturation is reached.

Finally, this band of HF noise was noted to propagate down the plasma column as surface waves. Fig. 7 shows the dispersion of surface waves propagating as noise, besides the externally stimulated waves and the theoretical plot of the axially symmetric mode[12, 13] for comparison. Similar results were reported by other authors[14, 15], who were also able to detect the dipolar surface mode.

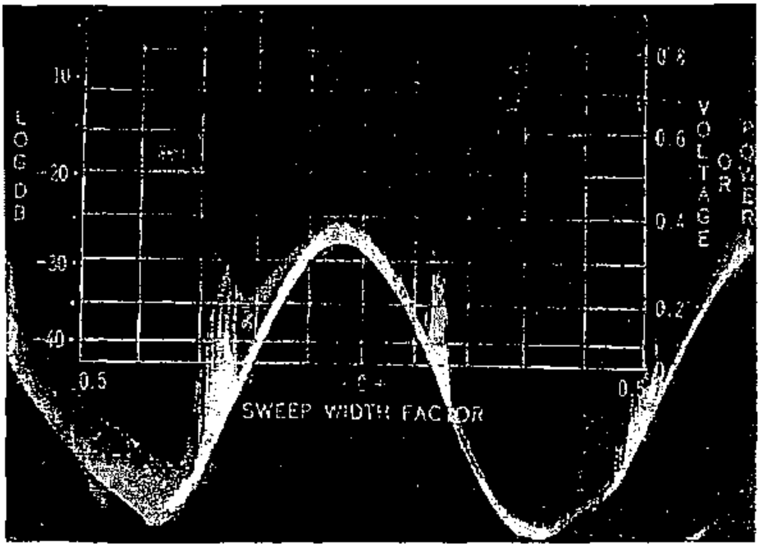

Fig. 6. High-frequency spectrum at (160 ± 2.5) MHz, with mains sine wave superimposed. The spectrum analyzer sweep is at the mains frequency. Noise appears only around the zeroes of the heater curent waveform, although in fact all frequencies in the 5 MHz band are generated.

It should be emphasized that the characteristics of both the low and high frequency fluctuations were sensitive only on conditions in the vicinity of the cathode or tube constriction and could not be significantly altered by changing conditions near the anode or probes.

4. *Discussion*

The observed fluctuations might be generated as the result of the break-up of the electron beam which is emitted from the cathode and is scattered to form plasma. Due to our geometry (Fig. 1) no well-defined meniscus[8] could be formed, but there is a geometrically ill-defined region where the shot noise from cathode has reached such magnitude as to break up the beam and form plasma. This region, together with the meniscus, acts as a strong noise generator of HF fluctuations, while its spatial position oscillates with a frequency of the order of the LF fluctuations described above. Thus, the interaction of the electron beam from cathode with the plasma which it forms may be responsible for generating both LF and HF fluctuations[16].

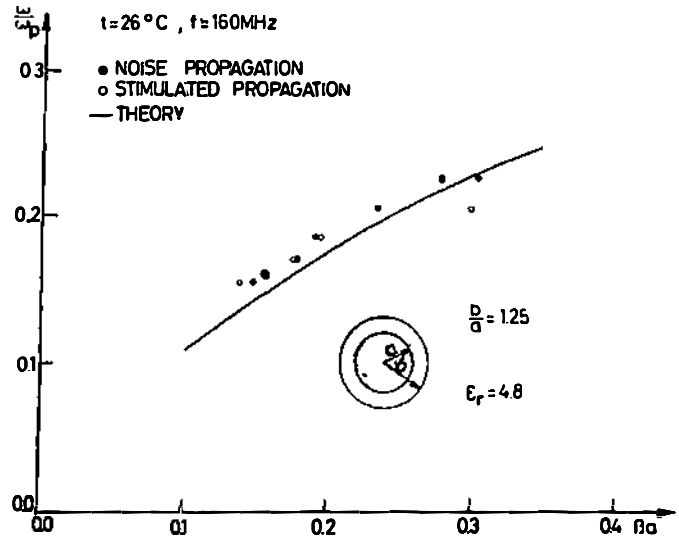

Fig. 7. Dispersion relation of a narrow band of the noise propagating in the form of surface waves, compared with stimulated propagation and theory.

Furthermore, shot noise amplified by the electron beam could be an additional source of the observed 160 MHz fluctuations, since in our experimental conditions a convective instability[17] is present (frequency of the observed signal is lower than the plasma frequency), so that low noise level at the cathode can be substantially amplified by the time the beam reaches its break-up region.

It was not possible to carry out a complete comparison of experiment and theory. Only very recently ionization waves have been included in the theory of low-frequency fluctuations in low-pressure arcs, and their coupling with ionacoustic waves shown to modify dispersion relations[18]. One can hope that comparison of theory and experiment will be possible after the completion of the finite plasma version of this concept.

In conclusions, it may be stated that discharges of the type described in this paper represent strong noise sources. Beam-plasma interaction is probably of great importance for generating noise. The level of noise may be altered by varying the conditions near the cathode and the constriction.

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O NASTAJANJU ŠUMA KOD PRAŽNJENJA U ŽIVINOJ PARI

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Sadržaj

Saopštavaju se posmatranja visokofrekventnog i niskofrekventnog šuma koji nastaje u jednosmernom luku na niskom pritisku u živinoj pari. Visokofrekventni šum je posmatran spektralnim analizatorom na $(160 \pm 2{,}5)$ MHz i nađeno je da se prostire u obliku površinskih talasa. Ovaj šum se javlja na kolenu jednosmerne karakteristike luka tj. na prelazu između režima prostornog naelektrisanja i zasićenja katode. Niskofrekventni šum je spektralno analiziran u oba režima katode; osobine šuma odstupaju od predviđanja elementarne teorije jonskog zvuka u pozitivnom stubu. Vrši se poređenje sa radom drugih autora; diskutuju se mogući mehanizmi generacije šuma.