[7] G. M. Zverev, T. N. Mikhailova, et al., ZhETF Pis. Red. 5, 391 (1967) [JETP Lett. 5, 319 (1967)].
[8] I. L. Fabelinskii, Molekulyarnoe rasseyanie sveta (Molecular Scattering of Light), Nauka, 1965 [transl. in preparation, Plenum].

* Such an appreciable backward-scattering power was observed earlier only for carbon disulfide [1,3,4].

PLASMA CONTAINMENT IN A THREE-DIMENSIONAL TRAP FORMED BY A MICROWAVE QUASIPOTENTIAL

G. S. Luk'yanchikov
P. N. Lebedev Physics Institute, USSR Academy of Sciences
Submitted 14 September 1967
ZhETF Pis'ma 6, No. 11, 934-938 (1 December 1967)

The existence of an averaged quasipotential $\varphi = e^2E^2/4m\omega^2$, produced by an electromagnetic field of amplitude E and frequency ω [1], makes possible three-dimensional containment of a rarefied plasma ($\omega_L < \omega$) without the use of a constant magnetic field. We have attempted in the present investigation to contain a plasmoid by means of the forces of an averaged microwave potential. The experimental setup was as follows (see Fig. 1): a three-dimensional quasipotential trap was produced in a cylindrical resonator of 9 cm diameter and 12 cm length by exciting, with the aid of a decimeter-band microwave generator, an E_{011} mode in which the electric field is zero at the center. The plasma source was a spark gun 2, the plasma jet from which could pass through the center of the resonator. The plasma was generated by the gun in a time 0.2 - 0.5 μsec. In the experiment, the minimum height of the barrier trap was 700 eV, the resonator Q was 750, the microwave pulse duration was 7 - 9 μsec, the vacuum was 3×10^{-7} Torr, and the plasma-jet density at the center of the resonator was 5×10^9 particles/cm^3.

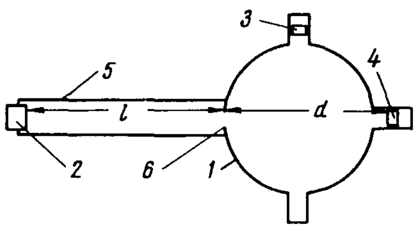

Fig. 1. Arrangement of spark chamber and probes: 1 - resonator; 2 - spark gun, 3,4 - plasma probes; 5 - transit tube; 6 - diaphragm of 0.6 cm diameter.

By delaying the switching of the microwave generator relative to the instant of gun operation, it is possible to investigate two possible modes. In the first, the plasma jet encounters in its path to the resonator an already-produced microwave barrier, T < 11 μsec (T - time between the instant of gun operation and the end of the microwave pulse). In the second, the microwave generator is turned on after the plasma has already entered the resonator, T > 11 μsec.

The oscillogram of probe 4 (Fig. 2d) shows that the plasma does not reach the probe during the time of the focusing microwave power pulse (Fig. 2e), but reaches the probe at a time t following the end of the microwave pulse. Theoretically, the plasma reaching the diaphragm 6 during the time of the microwave pulse cannot penetrate into the resonator, and should be specularly reflected into the transit tube. The probe should be reached only by the plasma that arrives at the diaphragm later than the termination of the microwave pulse. This plasma has a velocity lower than l/T and reaches the probe 4 at a time t longer than $(d/l)T$. If $t < (d/l)T$, then it can be assumed that the registered plasma is one captured at the center of the resonator. Figure 3 shows the experimental points and the line $t = (d/l)T$. We see that in the first mode, $T < 11$ μsec, there is no plasma capture, and the formula $t = (d/l)T$ agrees well with experiment.

In the second mode, with $T > 11$ μsec, the plasma reaches the probe 4 earlier than expected from the formula $t = (d/l)T$. This phenomenon could be attributed to the appearance of a sufficiently rapid plasma component at the instant when the microwave power is turned on, but the experimental results obtained in the first mode show that there is no plasma acceleration at the instant of termination of the microwave pulse. The fact that the plasma reaches the probe 4 before it can appear from the diaphragm indicates that its source is located closer, and at the same time there is no signal at probe 3, thus eliminating breakdown in the residual gas as a cause of the early arrival of the plasma at probe 4. Breakdown would produce the same picture at both probes. The result offers evidence that the plasma is captured by the microwave configuration. The absence of a signal at probe 3 can be due to the fact that the captured plasma jet did not have time to become randomized in all directions.

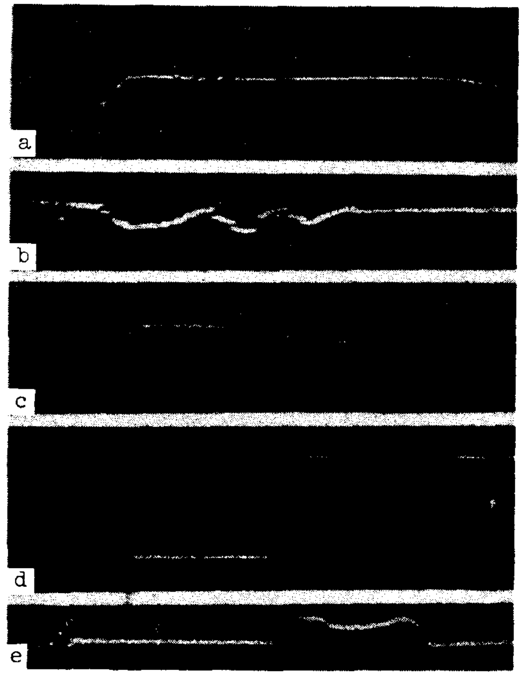

Fig. 2. Oscillograms of power level of H_{111} mode and of probe signals

We used microwave diagnostics in addition to probe measurements. Conditions were created making it possibe to excite in the resonator one more mode, H_{111}, at a low power level, and to observe its level. Since the H_{111} mode is excited at a longer wavelength and the distribution of the electric field in this mode has a maximum at the center of the resonator, the resonator conditions are disturbed by a plasmoid at the

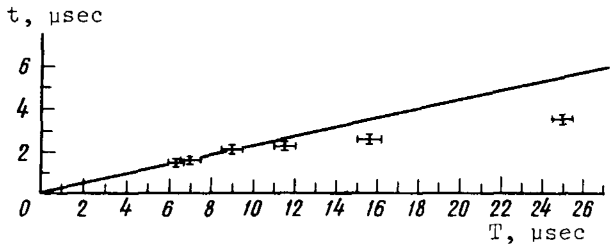

Fig. 3. Delay in arrival of plasma at probe vs. time between instant of gun operation and termination of microwave pulse.

center of the resonator more readily in this diagnostic mode than the resonance condition for the E_{011} focusing mode. Figures 2 (a and c) show oscillograms of the power level of the H_{111} mode. The appearance of the signal is connected with the complete detuning of the resonator at this point by the plasma in the resonator. It has been found theoretically and experimentally that in order to obtain a resonance detuning at the H_{111} mode, similar to that observed (Fig. 2c), it is necessary that no less than 10^9 particles be located in the center of the resonator. At the instant when the microwave pulse was turned on, there were $(5 - 1) \times 10^{10}$ particles in the focusing region. These facts agree with the theoretical notions concerning the possibility of three-dimensional containment of plasma by a microwave quasipotential.

Figure 2 shows the experimentally obtained probe-signal oscillograms and the oscillograms of the H_{011}-mode power levels. Figure 2a shows the resonance detuning in the H_{111} mode. The null line is seen on the left. The upward beam deflection indicates that the power level of the H_{111} mode is decreased as a result of the detuning of the resonator by the plasma coming from the diaphragm 6 (zero microwave focusing power). Figure 2b shows the signal of probe 4, due to the plasma jet from the diaphragm (zero microwave focusing power). The downward deflection of the beam corresponds to arrival of the plasma at the probe. On the left is shown the induced signal produced at the instant of gun operation. Figure 2c shows the resonance detuning in the H_{111} mode (microwave focusing power turned on after the plasma enters the resonator). The fact that oscillogram c practically coincides with oscillogram a indicates that the plasma continues to stay in the resonator after the microwave power is turned on. If the microwave pulse is turned on before the plasma enters the resonator (first mode), no detuning of the H_{111} mode is observed. Figure 2d shows the signal of probe 4 (containment mode) with a focusing microwave pulse duration 8.5 μsec. This oscillogram was obtained with a gain 20 times larger than that used for oscillogram b. The downward deflection of the beam corresponds to arrival of the plasma at the probe. The level line of the plasma signal is due to the fact that the oscilloscope amplifier operated in the saturation mode. After the microwave focusing power is turned on (oscillogram e), the probe signal vanishes and reappears at a time t after the termination of the microwave pulse in the form of a small jagged spike (marked by an arrow). The decrease of this signal is due to the strong defocusing of the plasma jet as a result of multiple reflection from the "walls" of the quasipotential trap. Figure 4e shows the power level of the E_{011} mode.

[1] M. A. Miller, Zh. Eksp. Teor. Fiz. 36, 1909 (1959) [Sov. Phys.-JETP 9, 1358 (1959).