SHORT HYDROGEN PLASMA BUNCHES

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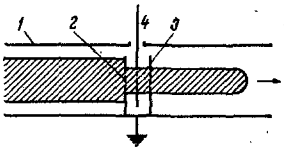

Fig. 1

The following condition [1] must be satisfied for coherent acceleration of a plasma bunch by an electromagnetic wave:

$$a \ll \lambda/2\pi$$

Here a is bunch size and λ is the wavelength. The bunch becomes completely opaque to the wave for a plasma density $n_* \approx 10^{13}/\lambda$ (with λ in cm). This gives interest to experiments with plasma bunches having $n > n_*$ and $n < n_*$. The choice of wavelength thus determines the size and density of the plasma bunch.

Meter waves are undesirable, because the apparatus becomes bulky. Centimeter waves require small dense bunches, which are difficult to produce. Decimeter waves are therefore chosen, which implies bunches 5–15 cm long and of density adjustable within the limits 10^{10} to 5×10^{11} cm^{-3}. The transverse size may be set by a system of stops, and the only difficulties arise over length, density, and purity (it is desirable to have hydrogen bunches).

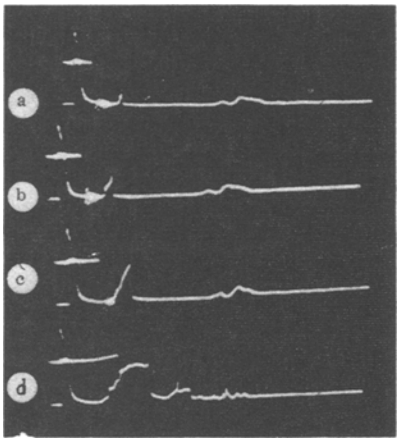

Fig. 2

The hydrogen plasma runs first in the plasma jet produced by any source, so this may be isolated in some way to give a hydrogen bunch of appropriate length, e.g., by the use of an electric field. Figure 1 shows the essentials of a pulse device for the purpose. The plasma jet moves in the tube 1, passing through the grounded grids 2 and 3 enclosing the control grid 4. A voltage pulse is applied to the grid when the bunch is as shown in the figure; the sign of the pulse determines whether ions or electrons are passed. Past the grid system we have a plasma bunch, with particles of only one sign at the rear. Long-term joint motion of particles of one sign is impossible, on account of the Coulomb interaction.

If an adequately dense plasma passes through the grid system, complete separation into the components does not occur. However, the paths are altered for particles passed after application of the pulse, and the plasma may be retained by a stop system.

Pulses were used with a plasma of only 10^{10} cm^{-3}, with gating of a denser plasma (10^{12} cm^{-3}) by dc. In the first case, the plasma was recorded by a screened probe and time-of-flight mass spectrograph, while in the second only the screened probe was used. The distance from the plasma source to the grid system was 110 mm.

A source of Bostik type was used with the low-density plasma, the screened probe being placed a few mm from grid 3 (Fig. 1), where the inlet of the mass spectrograph was also located. This spectrograph had a length of 1.5 m, the ions being recorded by an electron multiplier, whose signal passed to an OK-17M oscilloscope.

If the rear edge of the bunch is recorded at time t, while the pulse is applied at time t_1, the time of flight for the particles at the rear edge is $\tau = t - t_1$. The mass composition may be deduced from τ,

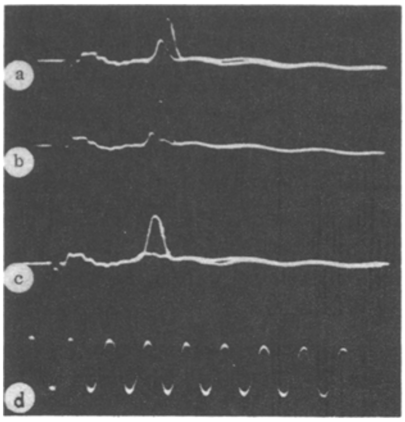

Fig. 3

the distance traveled in the mass spectrograph, and the potential difference traversed at the input. Figure 2 shows four mass spectrograms for grid operation at different times (sweep duration 27 μsec).

The pulse on the extreme left in each case is due to the action of the light pulse from the plasma source on the first dynode of the electron multiplier; the second is due to the arrival of the short hydrogen bunch at the mass-spectrograph input. Then there are several pulses corresponding to other components of the plasma that have passed through the grid system because a fairly short voltage pulse was used. The first pulse has under it a horizontal line, which is the signal from the second oscilloscope beam, with the gating pulse starting at the right edge of this line (leading edge not visible). It is clear that the length of the hydrogen bunch may be adjusted via the time of the gating pulse. The lower oscillogram shows the case where the gating pulse is applied so late that impurities have already passed through the gate. The density at the rear edge of the hydrogen plasma bunch (Fig. 3c) was 10^{10} cm^{-3} at the point of cutoff, the length being 18 cm.

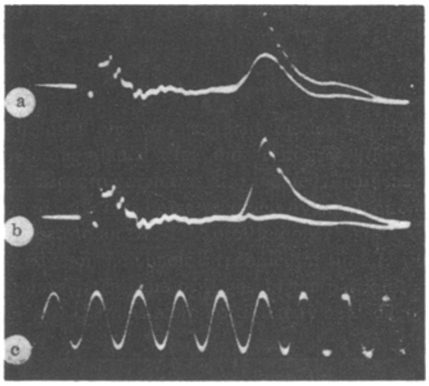

Fig. 4

The depth of penetration of the field into the plasma is important in gating a dense plasma. Screening occurs at the Debye radius for a plasma at rest, while the penetration depth becomes indefinitely great when the ion speed equals the thermal velocity of the electrons. In that case the jet can be cut off completely by the electric field.

Cutoff for a dense plasma jet was tested experimentally with an apparatus similar to that described above, but with a plasma source corresponding more closely to the requirements. The rise time at the leading edge was such that this edge did not need any additional shaping (e.g., by a gate). This source used a discharge between planar electrodes along the surface of lucite from a 0.3 μF capacitor charged to between 0.5 and 8 kV, the total inductance of the discharge system being 40 cm. The source produces a plasma bunch of maximum density 10^{12} cm^{-3}, with a leading edge moving at 10^7 cm/sec.

The gating device consisted of two grids made of molybdenum wire 0.03 mm thick and 0.5 mm apart (grid 2 of Fig. 1 absent).

Figure 3 shows the current at the screened probe with a steady voltage on the gating grid; the curves have been brought together in pairs for convenience. These oscillograms were recorded at 0 and +100 V (Fig. 3a), 0 and +200 V (Fig. 3b), and 0 and +300 V (Fig. 3c), while Fig. 3d shows a calibration curve (frequency 2 MHz). The probe was 45 mm from the gating grid.

Figure 3 shows that the electric field does not penetrate instantly into the plasma. Roughly the same oscillograms are obtained with the gating grid negative, but the effects are not so great. Figure 4 shows the probe current when the probe was 185 mm from the grid, with the voltage pairs 0 and +100 V, 0 and +200 V, the calibration curve (2 MHz) being below.

Comparison of Fig. 3b with Fig. 4b shows that the effect of the field is seen better if the probe is far from the gate (ratio of amplitudes in the first case 3, in the second 20). This shows that cutoff by the gate is accompanied by path alteration in the production of short pulses. These tests gave short bunches of hydrogen plasma of density 10^{10} cm^{-3}. The results for dc gating of a moving plasma of density 10^{12} cm^{-3} indicate that short plasma bunches of this density can be produced.

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REFERENCES

1. V. I. Veksler, "Coherent acceleration of charged particles," Atomnaya energiya, no. 5, 1957.

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