J. Indian Inst. Sci. 63 (B), Feb. 1981, Pp. 1-5

Short Communication

Stationary plasma double layers sustained by differential vacuum pumping

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Received on October 10, 1980.

Abstract

The differential vacuum pumping of a plasma column introduces a strong axial dependence into the electron-gas ionization rate leading to axially varying plasma density and potential. Such a configuration may be useful as a gridless ion extraction system, a unidirectional ion source discharge, or to enhance the gas efficiency of an ion source.

Key words : Ion sources, plasma double layers.

In the present paper a new type of ion source extraction system is proposed in which the acceleration potential is provided not by grids but rather by a stationary self-consistent plasma double layer.

Our method for maintaining a (stable) stationary potential double layer depend critically upon the recent experimental demonstration of plasma-gas ionization augmented differential vacuum pumping[1]. Plasma augmentation has been investigated in the differential pumping geometry shown in Fig. 1. The source plasma chamber (to the left in Fig. 1 and similar in design to that described previously in refs. 2-5) and the plasma dump (to the right in Fig. 1) are at either end of a cylindrical magnetized plasma column and operate at ~ 2 orders of magnitude higher neutral pressure than does the central experimental region. The conductance of the apertures leading from one chamber to another is reduced considerably ("augmented") by the presence of dense plasma flowing along the magnetic field from the source chamber and into the plasma dump region. The axial dimensions of the (tubular) pumping apertures are

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sufficient such that free streaming neutrals have a very small chance of passing from the high pressure chambers into the low pressure experimental region.

We assume that the source plasma is quiescent, ions are created with the energy distribution of the neutral gas molecules and then free-fall along the axial magnetic field lines under the influence of the self-consistent plasma and sheath potential gradients[6]. The plasma potential V_p is everywhere positive with respect to the end electrodes in order to maintain equilibrium in the ion and electron loss rates. Under these conditions electron flow will maintain an axially uniform electron temperature T_e and the Boltzmann equation will apply

$$n_e(z) = n_{e0} \exp\left[\frac{-e V_p z}{T_e}\right] \tag{1}$$

where e is the electronic charge and n_{e0} is the peak electron density which occurs at the point where V_p is maximal.

Ionization is due to electron-neutral collisions and ions are created throughout the source volume at a rate given by

$$n_e(z)\, n_n(z)\, \langle \sigma\, v_e \rangle_{T_e} + n_p(z)\, n_n(z)\, \sigma\, v_p(z) \tag{2}$$

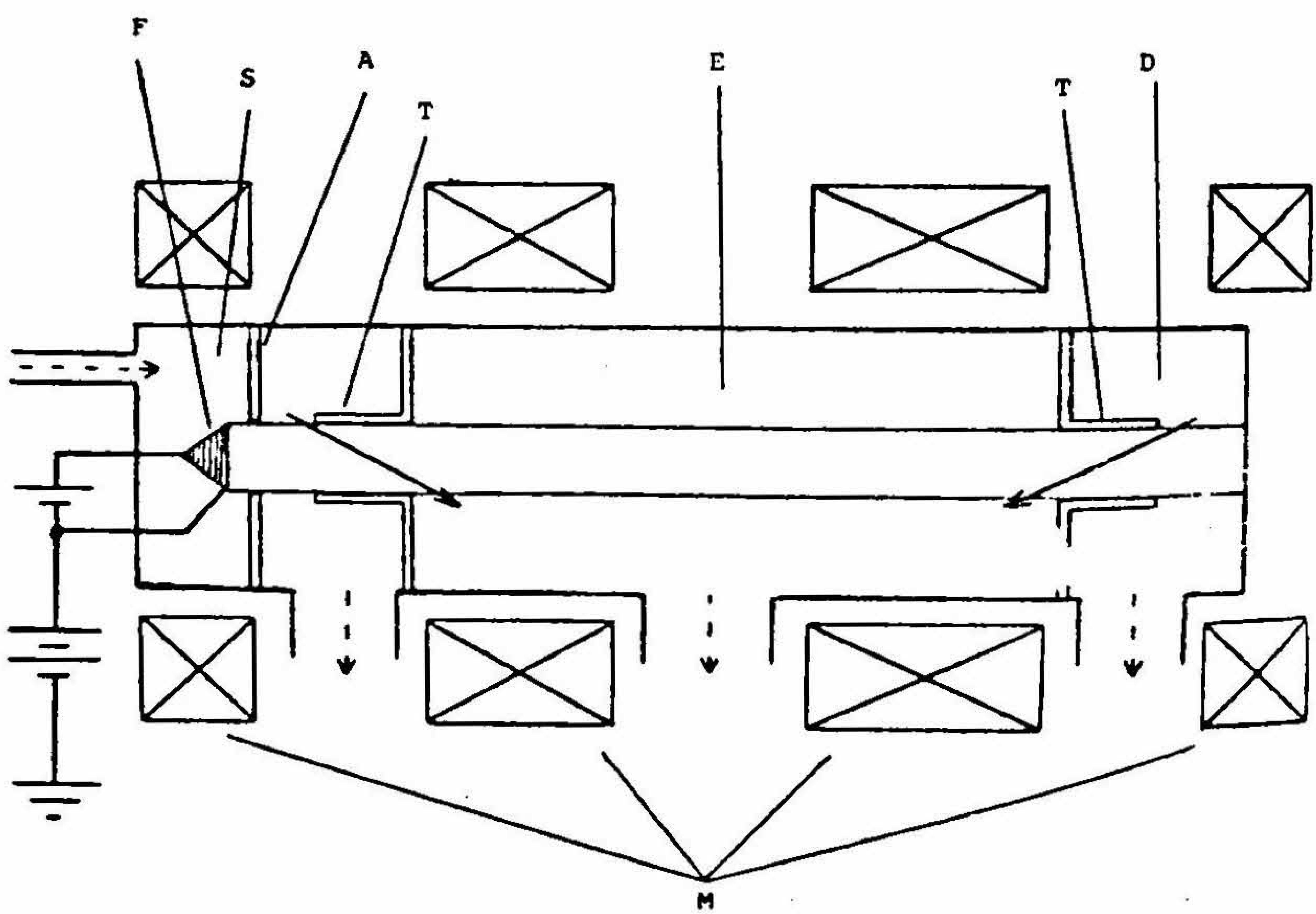

FIG. 1. Differentially vacuum pumped plasma experiment having : hot conical tantalum filament, F ; anode, A ; source chamber, S ; experimental chamber, E ; plasma dump chamber, D ; solenoid magnets, M ; and aperture tubes, T.

where $n_n(z)$ is the axially variable neutral gas density, $\langle \sigma v_e \rangle_{T_e}$ is the electron-gas ionization rate coefficient averaged over a Maxwellian distribution of plasma electrons of density $n_e(z)$ and $n_p(z)$ and $v_p(z)$ are the primary electron density and velocity.

The ions generated at $z_e \leqslant z' \leqslant z$ free-fall down the monotonically decreasing plasma potential, acquiring a velocity v_i such that the ion density at z is:

$$n_i(z) = \int_{z_e}^{z} \frac{n_n(z')}{v_i^{\,\prime}} \; [n_e(z') \langle \sigma v_e \rangle + n_p(z') \sigma v_p(z')] \;\; dz'. \tag{3}$$

The plasma potential must satisfy the Poisson equation

$$\frac{d^2 V_p(z)}{dz^2} = -4\pi e \, [n_i(z) - n_e(z) - n_p(z)]. \tag{4}$$

For a specified function $n_n = n_n(z)$, eqns. (3) and (4) can be solved numerically[6], along with the Boltzmann equation (1), for boundary conditions such as

$$V_p = 0, \quad dV_p/dz = 0 \text{ for } z = z_e \tag{5}$$

in order to obtain $n_e = n_e(z)$ and $V_p = V_p(z)$.

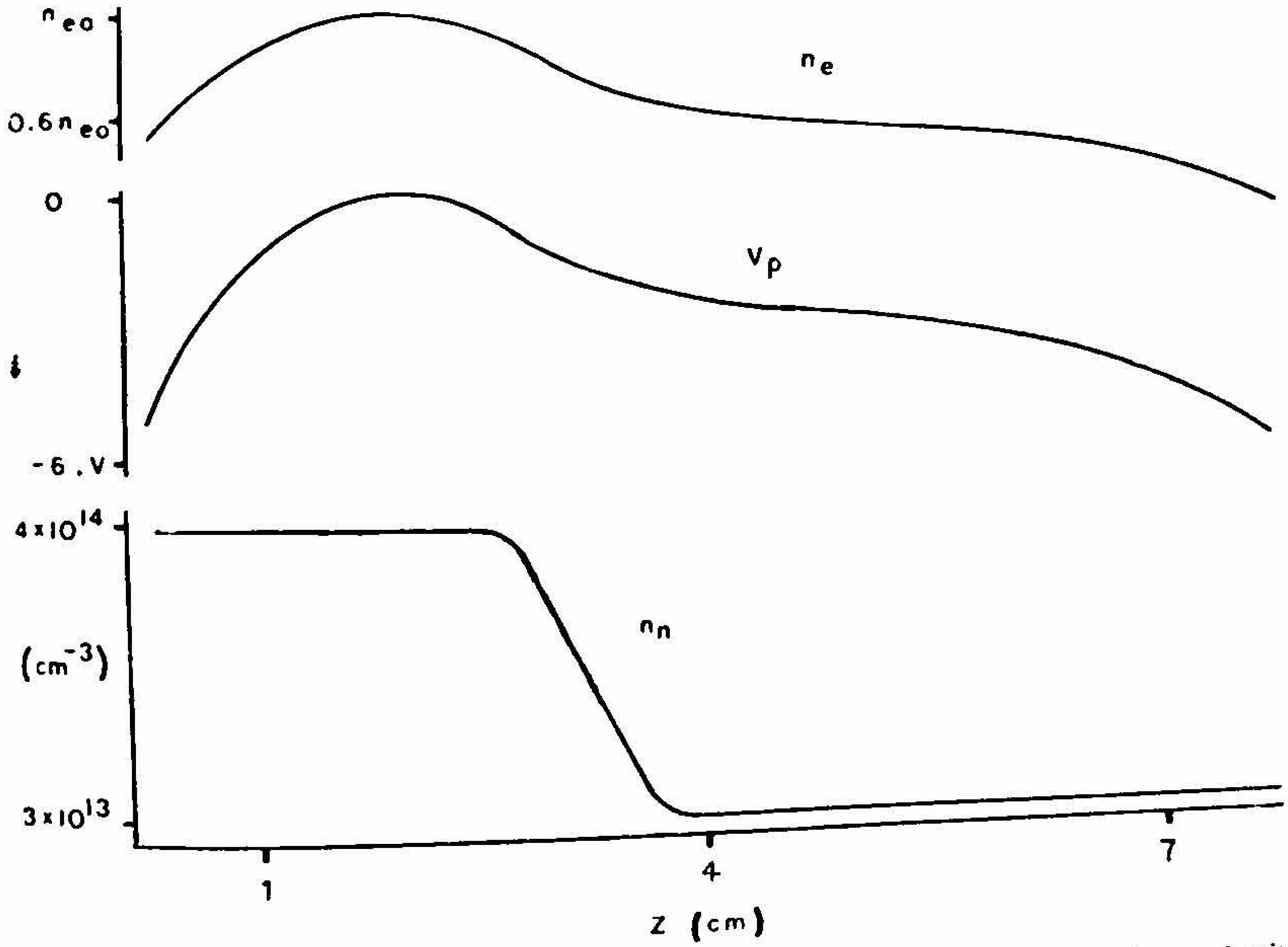

FIG. 2. Neutral gas density profile, n_n, calculated plasma potential profile, V_p, and plasma density profile, n_e.

The functional form of $n_n(z)$ can then be iterated in order to obtain some desired potential distribution $V_p(z)$. In actual fact, we must try to restrict our attention to neutral density profiles that are likely to be realizable in practice as these are responsible for the potential double layer. The ion current drawn through this double layer is neutralized and can exceed the Child-Langmuir limit to which most other ion sources are subject[7].

At the present time no detailed axial measurements have been made but it is known that the gas density does jump by as much as two orders of magnitude over an aperture tube length of 6 cm for a 1–2 cm diameter experimental plasma. (The use of plasma augmented differential pumping will also reduce residual gas release from the dense ion source plasma region and improve gas efficiency.)

For an electron temperature of 5 eV and given gas density profile we have computed the corresponding (typical) potential and density profiles (Fig. 2). In Fig. 3 second pumping aperture has been added to allow the creation of an ambipolar end plug making the ion source unidirectional[8].

Hollow cathode discharges should produce effects similar to these but are limited to very small diameters It would also be possible to create transient double layers using gas puffs, aerosols, or ablating solids.

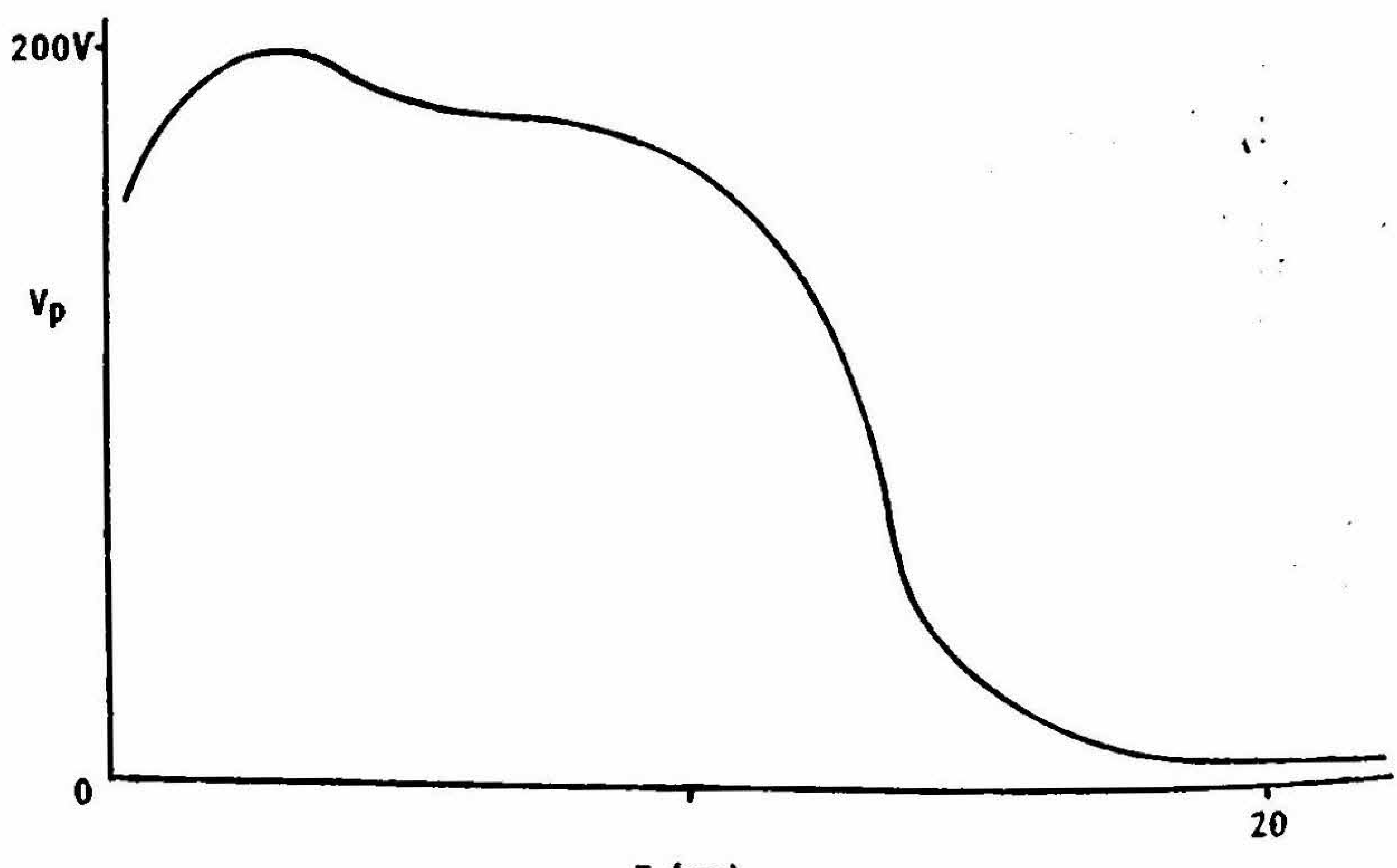

FIG. 3. A typical calculated axial plasma potential profile, V_p, for an intense unidirection ion source having two pumping apertures; at 5 and 10 cm, respectively.

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Note added in proof

Ion trapping can occur on the low potential side of the double layer. By means of numerical modelling, Belova *et al** have recently shown that double layers with $e\Delta V_p/T_e$ of at least 270 can be produced in a current carrying plasma.

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