

STATIONARY BEAM-PLASMA DISCHARGE IN CROSSED
ELECTRIC AND MAGNETIC FIELDS AS THE DEVICE FOR
SEPARATION OF PLASMA CHEMISTRY REACTION PRODUCTS.

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ABSTRACT

Quenching is known to be one of the difficult problems in plasma chemistry. Plasma rotating in crossed electric and magnetic fields represents great interest for a space separation of plasma chemistry reaction products. Beam-plasma discharge in crossed electric and magnetic fields gives a possibility of obtaining a high degree ionisation plasma in which an effective separation of elements, differing by masses was received. In this work we present the experimental results on the investigation of the space distribution of the separating component density, and the density and the space potential of plasma; the electron temperature in different regimes of electron beam plasma discharge in crossed electric and magnetic fields under stationary flow of binary mixture of noble gases through the reaction chamber.

1. INTRODUCTION

Preliminary study of beam driven discharge plasma centrifuge shows, that realization of very efficient separation for binary mixtures is possible (1). The case of collisionless plasma centrifuge appears to be most interesting, separation being due to ion polarization drift across magnetic field (3). Detailed mechanism of separation is as follows: ions are neutralized on the end surface insulators, then neutrals come back to plasma volume and ionization occurs. This processes determine polarization current, i.e. displacement of ions as a whole across magnetic field. As usually, formula for polarization drift velocity is

$$v_r = cE(H\omega_{ki}\tau)^{-1}$$

where E-radial electric field, H-magnetic field, ω_{ki} -Larmor ion frequency, τ -time, determined by ionization processes.

In our case τ is the sum of two terms: the first one is ionization time $\tau_{ion} = \frac{L}{v_{ion}}$, and the second one is the transient time, equal to L/c_s , where L the length of the system, c_s being the ion sound velocity. So the formula for radial current has the next form

$$I_2 = 2\pi R l_{ion} n_e \cdot v_2 = 2\pi R n_e \frac{CE}{H} \frac{l_{ion}}{\omega_{Hi}} \left[\frac{1}{\frac{v_{ion}}{c_s} + \frac{L}{c_s}} \right] \quad (2)$$

It follows from formula (2), that two limiting cases are of interest. If plasma density is high enough, i.e. $\frac{v_{ion}}{c_s} > \frac{L}{c_s}$, radial current will be independent on plasma density, otherwise $I_2 \propto n_e$. It should be born in mind that radial current is the main characteristic of efficiency of the system: the more radial current, the higher separation. However, as it was above mentioned, there is a saturation current for given system parameters, even if plasma density is very high. So the surface mechanism of separation can not be improved by increasing of plasma density. Another way is to transform the surface mechanism of separation into volume one. It can be done principally if some background gas with high ionization potential is added to the gas under study, e.g. one can add to argon having 15 volts ionization potential some helium with 24 volts potential. If background gas density is high enough, one can see the increasing of radial current due to collisions of ions under study with background gas atoms. The formula for the velocity of ions across magnetic field has the well known form:

$$v_2^0 = \frac{CE}{H} \frac{v_{in}}{\omega_{Hi}} \alpha(M_i; M_o) \quad (3)$$

Here v_{in} - frequency of ion neutral collisions, and $\alpha(M_i; M_o)$ - coefficient depending on ion-neutral mass ratio. For example for the case when $v_{in} \gg v_o$, $\alpha = \frac{M_o}{M_o + M_i}$, $v_{in} = n_n v_o \cdot \lambda >$, n_n being neutral density. Detailed calculations were made for comparison of surface and volume mechanisms.

II. EXPERIMENTAL

Experimental device consists of cylindrical metallic chamber 4 with endplates insulators 3. This work chamber is placed in axial magnetic field which is produced by magnetic coils 5. The electron beam gun 1 and the collector of electron beam 7 are situated on the diametrically opposite insulator plates of the work chamber. Since the anode of electron beam gun is isolated, and plasma along the chamber axis is in direct contact with the anode and acquires its potential, a possibility appears to generate a radial electric field in the plasma by applying the potential difference between the gun anode and chamber walls. In diagnostic volume Langmuir probe 6 and quartz valve 8 which is connected with mass-spectrometer are situated. Experiments were carried out at the next typical regims: the pressure of the work gas mixture

$P=10^{-4} \cdot 10^{-3}$ tor, electron beam current $I_e \approx 10$, the energy of electrons is of about $3 \cdot 10$ keV, the maximal value of magnetic field H 5kH, the diameter of electron beam $d=1$ cm. Figures 2a and 2b show the radial distribution of plasma and total gas and plasma density for two cases. The first one gives the densities distribution without radial electric field, the second one, when 100v radial potential is applied. Plasma density was measured by Langmuir probe. Total gas and plasma density was measured by mass-spectrometer. Figure 3 shows the floating potential distribution in plasma for both cases. It is seen, that plasma density rapidly decreases in the electron beam region, even when radial potential is not applied. It should be pointed out, that correlation between plasma density and total density takes place, so we are dealing with fully ionized plasma. Near the electron beam region the positive floating potential appears. (See fig. 3 $\phi=0$, solid curve). High degree of ionization and volume discharge do occur when electron beam power exceeds a threshold. If the power is lower, plasma will exist only in the beam region independently whether radial potential is applied or not. (See fig. 4). Fig. 3 shows the applied radial potential distribution for this case. There is a critical radial voltage for volume discharge as well. This critical voltage depends on the beam power, gas density and other characteristics of the system. If applied voltage is greater than critical, disruption of volume discharge will occur and calorimetric measurements showing that electron beam power does not transfer to plasma. So, radial electric field can stabilize the plasma beam instability. Calorimetric measurements permit to find the fraction of electron beam power which comes to the plasma. For the residual pressure of order of 10^{-6} tor and beam power 1,5 kW ($U_1=3$ keV, $I_1=0,5$ A), 1,4 kW transferred to calorimeter, so only 100 W are in plasma. For gas pressure $3 \cdot 10^{-4}$ tor, $U_2=0$, there is no volume discharge, for the same beam power, 400 W dissipate in plasma. When radial voltage $U_2=100$ v is applied and volume discharge occurs, 1,1 kW dissipate in plasma.

Experiments with the mixture He and Kr show, that no helium ions are present at all. Radial current for the beam power 6kW, krypton density $n_{Kr} = 10^{13} \text{ cm}^{-3}$ and $U_2 = 130$ v without helium is equal 1,5 A. Adding of background helium with density $n_{He} = 8 \cdot 10^{14} \text{ cm}^{-3}$ permits to increase radial current up to 4,5 A. Calculating the increase of radial current by the formulas (2) and (3) one gets a good agreement. It's of interest, that beam power is almost the same for the Krypton and mixture both. Nevertheless very essential increase of radial current occurred. So, adding of background gas can essentially improve the characteristics of plasma centrifuge.

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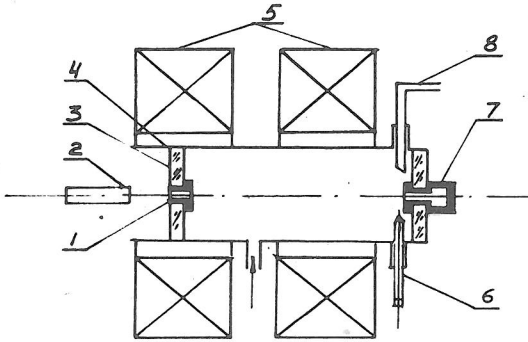


Fig. 1

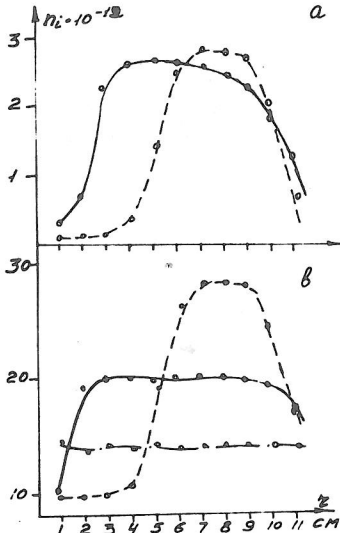


Fig. 2

Fig. 1. Block diagram of the device with a discharge in crossed fields.
 1-anode, of electron beam gun,
 2. electron beam gun,
 3. endplate insulator,
 4. cylindrical conducting chamber,
 5. magnetic field coil,
 6. Langmuir probe,
 7. electron beam collector,
 8. quartz valve

Fig. 2 a) radial distribution of plasma density, measured by Langmuir probe
 b) radial distribution of summary density of plasma and neutral component.

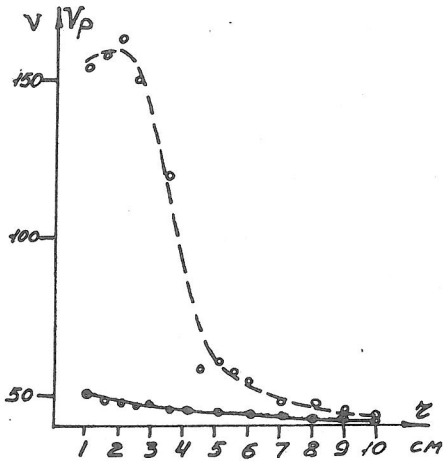


Fig. 3-radial distribution of plasma potential

Fig. 3

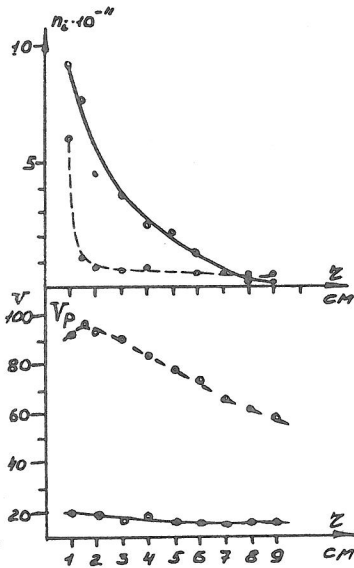


Fig. 4 a,b-radial distribution of plasma density and plasma potential, when discharge is in the electron beam zone.

Fig. 4