EFFECTS OF RESIDUAL GASES IN THE ELECTRON TEMPERATURE AND DENSITY IN A VACUUM ARC PLASMA CENTRIFUGE

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Abstract

Measurements of electron temperature and plasma density were carried out in a vacuum arc plasma centrifuge to investigate the influence of residual gases in these parameters. The measurements were performed in a magnesium plasma utilizing a cylindrical Langmuir probe. Hidrogen, helium and argon were used as residual gases with pressure varying in the range of 1×10^{-4} to 1×10^{-1} Pa. With no gas (1×10^{-4} Pa) the electron temperature and plasma density are pratically constant over the entire plasma current pulse. The introduction of a gas changes this picture appreciably. For the range of $10^{-2} - 10^{-1}$ Pa the electron temperature decreases about 50% while the plasma density increases by the same factor with regard to the vacuum value, in the initial stage of the discharge, but approaches to the vacuum value at the end of the discharge.

1 Introduction

One of the most important parameters in the study of isotope enrichment is the separation factor which quantify the ability of a process to separate two isotopes (or elements). For a mechanical or plasma centrifuge this parameter is given by the expression [1,2]

$$\alpha(r) = exp\left[\frac{\Delta m \omega^2 r^2}{2K_B T_i}\right]$$

where Δm is the mass diference of the isotopes (or elements), ω is the angular velocity of the plasma column, r is the radial position, K_B is the Boltzmann's constant and T_i is the ion temperature ($T_i \cong T_e$ in vacuum arc plasma centrifuge).

In vacuum arc plasma centrifuge [3,4] it has been obtained high separation factor probably due to the high angular velocity achieved in these experiments [5]. On the other hand the temperature is high and depends on the cathode material with values in the range $0.6 - 6\,\mathrm{eV}$

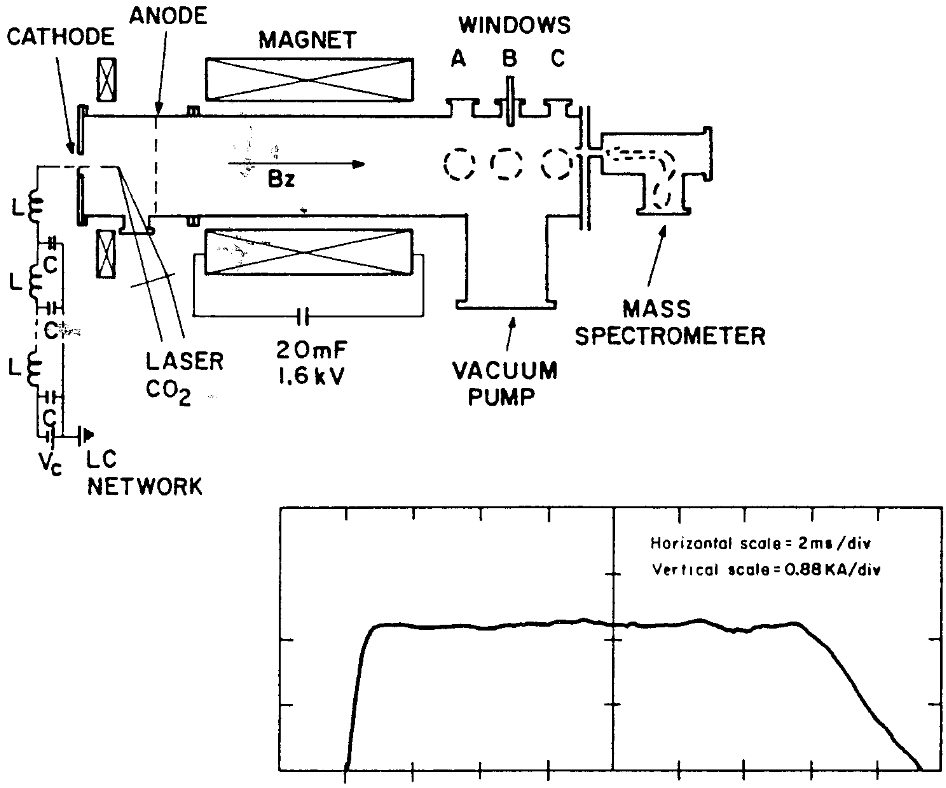

Figure 1. Schematic diagram of the vacuum arc plasma centrifuge of LAP/INPE and a typical plasma current pulse

[6]. For comparison, in mechanical centrifuges $T \sim 0.03\,\text{eV}$ and in partially ionized plasma centrifuges $T \sim 0.3 - 0.5\,\text{eV}$. From the expression of the separation factor it can be observed that the temperature is one of the parameters that can be controlled in order to increase even more the separation factor of the vacuum arc centrifuge. This work presents the results concerning the investigation of the effect of residual gas in a vacuum arc plasma centrifuge as an attempt to decrease its temperature.

2 Experimental Arrangement

Figure 1 shows the schematic diagram of the vacuum arc plasma centrifuge at LAP/INPE. A CO_2 laser initiates the discharge of the main capacitor bank connected between the cathode and the anode, producing a plasma column from the cathode material that expandes through the anode mesh. The interaction of the plasma current, produced by the discharge, with the axial magnetic field puts the plasma column in rotation by the $\vec{J} \times \vec{B}$ force. The base pressure is about 1×10^{-4} Pa and the LC network produces a flat top plasma current pulse of $\sim$ 14 ms, as shown in Figure 1. The electron temperature and plasma density measurements were taken carried out using a cylindrical Langmuir probe biased by a triangular sweep generator [7]. Figure 2 shows the schematic diagram of the diagnostic apparatus used for acquisition and analysis of the probe signals.

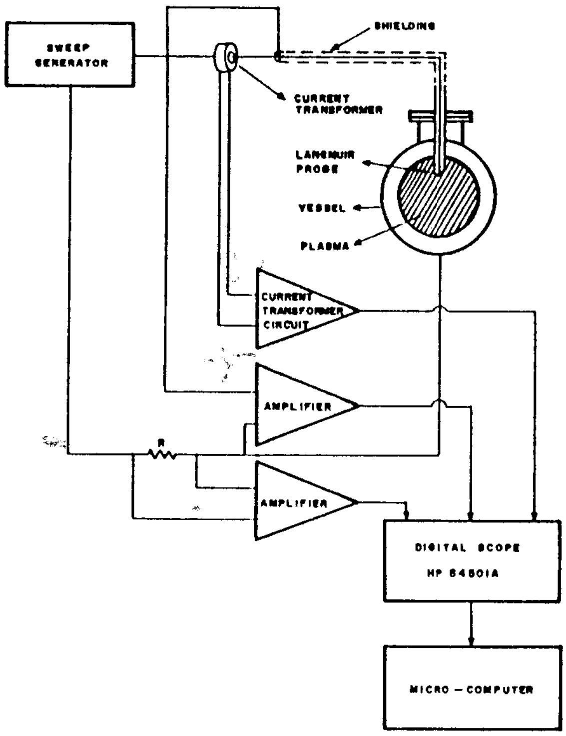

Figure 2. Schematic diagram for acquisition and analysis of the probe signal

3 Results and Discussion

It was used a magnesium cathode to produce the plasma. The plasma current and the axial magnetic field were kept fixed at 1 kA and 0.1 T, respectively. The gases (H_2, He, Ar) were introduced up to the maximum pressure supported by the diffusion pump ($\sim 1 \times 10^{-1}$ Pa). Each experimental point presented in this work is the average of at least five shots.

Figure 3 shows the temporal dependence of electron temperature for Ar as residual gas. With no gas the electron temperature is pratically constant during the pulse ($T \sim 5.5$ eV, dashed line), but with the introduction of Ar, Te is lower (~ 3 eV) at the beginning, increasing during the discharge and coming close to the vacuum value at the end of the pulse. Similar results were obtained when H_2 and He were used. The temperature as a function of the hidrogen gas pressure, for three different instants of the discharge is shown in Figure 4. As can be seen, the influence is high (low temperature compared with the vacuum) only in the range of $10^{-2} - 10^{-1}$ Pa and at the beginning of the discharge. Similar results were obtained when He and Ar were used as residual gas.

The plasma density is proportional to the ion saturation current of the Langmuir characteristic curve. The temporal profile of the ion saturation current is shown in Figure 5, for H_2 as residual gas. It can be observed that the density has a maximum at $t \sim 5$ ms and decreases to the vacuum value (dashed line) at the end of the pulse. Increasing the residual gas pressure increases the collision frequency between the gas molecules and the magnesium ions and probably occurs a strong ionization of the residual gas in the beginning of the pulse increasing the ion density. The decrease of the plasma density during the pulse occurs probably due to the recombination process and diffusion across the axial magnetic field lines. At the same time energy is transferred from the magnesium plasma to the residual gas decreas-

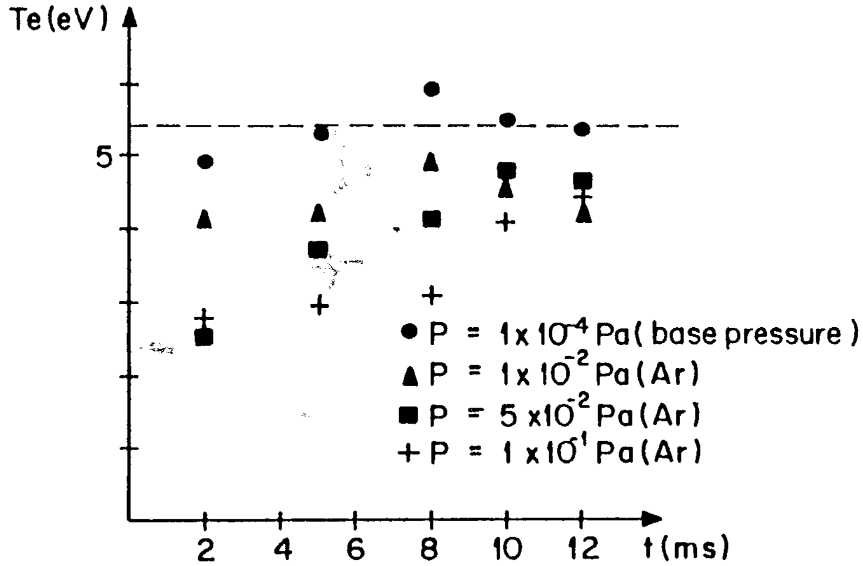

Figure 3. Temporal profile of the electron temperature for Ar as residual gas

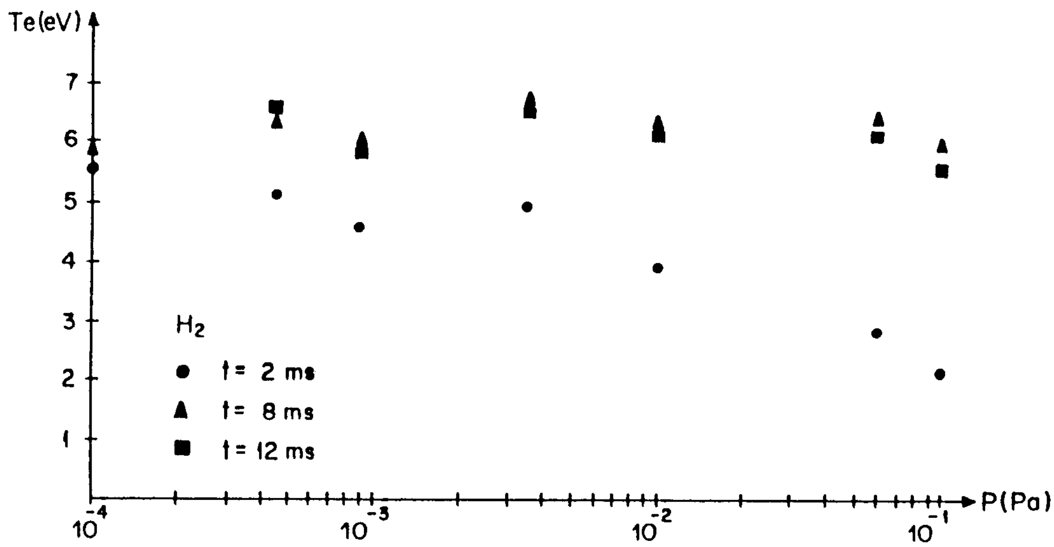

Figure 4. Electron temperature as a function of the pressure for H_2 at three different instants of the pulse

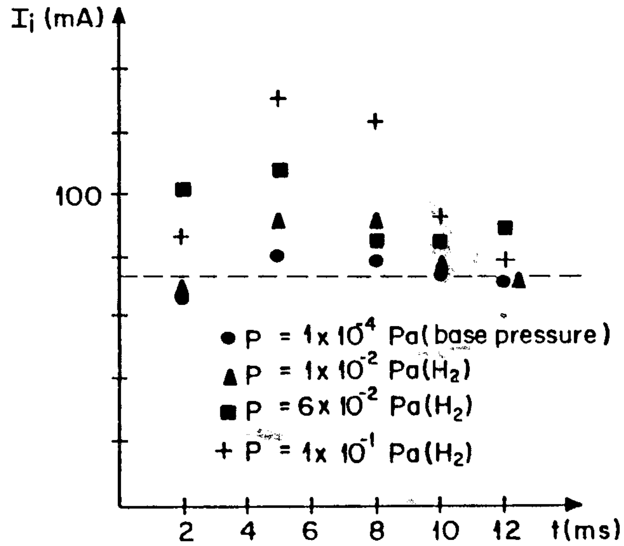

Figure 5. Temporal profile of ion saturation current for H_2 as residual gas

ing the plasma temperature. The temporal evolution of the electron temperature and density shows a minor influence of residual gas at the end of the plasma pulse.

4 Conclusion

The decrease of the temperature obtained with the introduction of a residual gas can contribute to obtain higher separation factor. On the other hand it was been observed that the residual gas decreases the angular velocity in about 20% and reduces appreciably the flutuactions observed in the floating potential signal of the probe showing a stabilization effect. The measurements of net result of these effects on the separation factor are in progress.

5 References

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