MECHANISMS OF ELECTRON DISAPPEARANCE IN A DECAYING PLASMA ARC
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It is generally accepted that during argon plasma decay at atmospheric pressure, the disappearance of charged particles is brought about by electron-ion recombination. For a temperature of about 1 eV, recombination is partially counterbalanced by ionization. When the plasma is confined the electron losses through ambipolar diffusion are not negligible. The aim of this communication is to show the relative influence of the various processes by comparing the experimental results with theoretical estimations.

EXPERIMENTAL RESULTS. The experimental set-up is described in reference/1/. The arc is a wall stabilized one and the decay is governed by a fast thyristor.

In steady state conditions the electron number density, $n_e$, was determined with respect to the radius, by measuring the absolute intensity of the continuum radiation at 423 nm. The electron temperature, $T_e$, was deduced from relative intensity measurements of the lines.

In the extinction phase, the electron number density and the variation of the atom density $n_a$ were measured by laser interferometry, at two wavelengths, along the axis of the discharge. Also $n_e(r,t)$ was determined by measuring the continuum radiation (fig. 1). The values at $r=0$ are in good agreement with the results deduced from interferometry. Finally, the variations of light intensity of some Ar I lines were measured along the axis of the discharge ($r=0$). Certain results are given in another communication/2/ presented at this ICPIG: for current intensities less than 25 A, the intensity of these lines rose sharply after cutting off the current (time of increase $\sim 5$ $\mu$s) then fell to zero after 250 to 300 $\mu$s. It is shown/2/ that this phenomenon is due to the rapid relaxation of the electron temperature to the gas temperature.

THEORETICAL ANALYSIS. In a decaying argon plasma, with cylindrical symmetry and no axial gradients, the variation of $n_e$ is described by:

$$\frac{\partial n_e}{\partial t} + \frac{1}{r} \frac{\partial}{\partial r}(rn_e v_e) = - \alpha n_e^2 + \frac{1}{2} \frac{\partial}{\partial r}(rn_e v_e)$$

where $v_e$ is the average velocity of the electrons, $\alpha$ the recombination coefficient, $S$ the ionization coefficient and $n_a$ the density of atoms in the ground state.

The most rigorous calculation of $\alpha$ and $S$ was made using a collisional radiative model/3/. For argon the deepest study was made by Katsonis/4/. In order to apply his results to equation (1), $n_e$, $T_e$, $T_h$ and the diffusion flux must be locally known. For high values of $n_e (n_e > 10^{16}$ cm$^{-3}$) the plasma approaches LTE and the values of the different parameters must be known with great accuracy: for $T_e$ and $n_a$, the experimental results are not accurate enough. For this reason we developed a model which allowed us to calculate $T_e$, $T_h$ and the atom densities from experimental values of $n_e(r)$ and the axial electric field $E$. This model is based...
on the resolution of a coupled system of balance equations for the population of each real energy level of Ar I and the electron energy balance, in the steady state plasma. For level $j$:

$$\dot{\nu}_j(n_j) = \sum_{i=1}^{j-1} n_i \epsilon_i C_{ij} - n_j \epsilon_j \sum_{i=1}^{j-1} n_i n_{ij} S_{ij} + \sum_{k=j+1}^{N} n_k \epsilon_k K_{kj} + n_j \epsilon_j C_{jk} + n_j^2 \epsilon_j R_j$$

Equation 2

$$\sigma \frac{\dot{e}}{e} = \dot{\nu}_{\text{re}} + \nu_{\text{inel}} + k \sum \nu_{\text{eh}} (T_e - T_h) n_e$$

Equation 3

where $C_{ij}$ and $F_{ij}$ are rate coefficients for collisional excitation and de-excitation; $S_j$ the collisional ionization rate coefficient; $R_j$, $Q_j$ rate coefficients for radiative and collisional recombinations; $\Lambda_j$, $A_{ij}$, $\Lambda_{ij}$, escape factors of radiation. The electron energy balance (equation 3) is described in detail in/2/.

For the excited levels, diffusion is negligible and we can write:

$$\frac{1}{r} \frac{\partial}{\partial r} (r n_e \nu_e) = - \frac{1}{r} \frac{\partial}{\partial r} (r n_e \nu_e)$$

Equation 4

A model with such a make-up allows the calculation of $T_e$, $T_h$, $n_1$, $n_2$, ... and the deduction of the ionization and recombination coefficients. The rates of these reactions are the population and depopulation rates of the ground state by collision and radiation.

As already stated, when $E = 0$, the electron temperature drops to $T_h$ before $n_e$ and $n_a$ have had the time to change. The coefficients $\alpha$ and $S$ therefore must be calculated for an electron temperature equal to $T_h$.

COMPARISON OF THE RESULTS. The following table gives values of $\alpha$ and $S$ with respect to some of the values of the $(n_e, T)$ couple corresponding to real cases.

<table>
<thead>
<tr>
<th>$n_e$ (cm$^{-3}$)</th>
<th>$T_e$ (K)</th>
<th>$\alpha$</th>
<th>$S$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$8.8 \times 10^{16}$</td>
<td>12 500</td>
<td>1.5 $10^{-29}$</td>
<td>2.7 $10^{-13}$</td>
</tr>
<tr>
<td>$4.0 \times 10^{16}$</td>
<td>11 000</td>
<td>2.5 $10^{-29}$</td>
<td>5.9 $10^{-14}$</td>
</tr>
<tr>
<td>$1.5 \times 10^{16}$</td>
<td>9 500</td>
<td>5.6 $10^{-29}$</td>
<td>5.7 $10^{-15}$</td>
</tr>
<tr>
<td>$8.0 \times 10^{15}$</td>
<td>8 400</td>
<td>1.2 $10^{-28}$</td>
<td>8.4 $10^{-16}$</td>
</tr>
</tbody>
</table>

(1) our values, (2) Katsonis /4/

The values of Katsonis, under the conditions of reabsorption found in the arc, are lower than ours; this is due to the choice of the excitation cross section of the first levels of Ar I.

In fig. 2 all the experimental and calculated results are presented. The 3 curves of the calculated results correspond to 3 different parameters: $\alpha$ is the recombination coefficient; $\gamma = \alpha - \frac{S_n}{n_e^2}$ the apparent recombination coefficient and $\frac{(\partial n_e/\partial t)/n_e^3}{n_e^3}$ the electron disappearance coefficient. A good agreement is seen between the calculated and measured values of $(\partial n_e/\partial t)/n_e^3$ which would seem to justify our calculation of $\alpha$ and $S$ (Katsonis' values are not in such good agreement). As the electron density increases, so do the ionization phenomena; this can be seen by comparing $\alpha$ and $\gamma$. Finally, the comparison between $\gamma$ and $\frac{(\partial n_e/\partial t)/n_e^3}{n_e^3}$ shows the influence of diffusion which may represent 30% of the electron disappearance mechanisms.

Fig. 2. Experimental and calculated values of recombination and disappearance coefficients of the electrons.

/1/ H. Kafrouni and allii, to be published in JQSRT (1979).