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RECIRCULATION AND ARC EFFECTS IN ARGON-HYDROGEN EXPANDING CASCADED ARC PLASMAS

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Expanding cascaded arc plasmas are used in a number of applications, including the fast deposition of carbon- and silicon-containing thin films (e.g., [1]) and the realization of particle sources [2,3]. Fundamental study of this type of plasma has focused on Ar and Ar-H_2 expanding plasmas [4,5]. The experiment is sketched in Fig 1a.

A sub atmospheric thermal plasma ($T_e \approx T_h \approx 1$ eV) is created in the arc channel (diameter 4 mm). The plasma is allowed to expand into a low pressure background (40 Pa) through a conically shaped nozzle, creating a supersonic expansion. After a stationary shock front at about 50 mm, the plasma expands subsonically with a speed of about 600 m/s.

When a small amount of hydrogen is added to the incoming gas flow, the behaviour of the plasma jet changes drastically: a very strong decrease in the electron density n_e is observed (Fig. 1b).

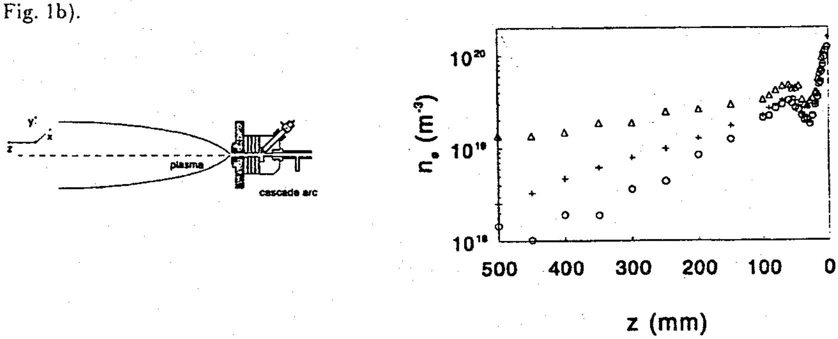

Figure 1. (a) (left): the expanding cascaded arc plasma; (b) (right): Thomson scattering measurements [4,5] (n_e vs. z, the axial position): △: pure argon, +: 0.7 vol.% H_2 , ○: 1.4 vol.% H_2 .

This anomalous decrease in ionization cannot be attributed to atomic processes [2,3], but associative charge exchange between H_2 and Ar^+ and subsequent dissociative recombination of the formed molecular ion ArH^+ constitutes a much faster recombination channel [5]. However, the fast decrease in n_e after the shock front can not be explained by these reactions if only the hydrogen molecules that survive the arc are considered (especially at these low H_2 seed fractions). Therefore wall-associated molecules are thought to participate in these fast recombination processes: H_2 formed at the stainless steel vacuum vessel walls can be transported to the plasma by a recirculation flow, thus explaining the observed n_e decrease.

Further measurements, however, have shown that the arc itself changes its behaviour drastically at higher H_2 seed fractions (Fig. 2a). For H_2 seed fractions exceeding 2 vol.%, n_e is already lower in the very first part of the expansion.

To investigate this phenomenon, a set of carefully calibrated Thomson scattering measurements is performed for pure argon, and for 2 vol.% H_2 and D_2 seed fractions, at z=15 mm. The idea is to make observable eventual differences in arc behaviour resulting from the fact, that the masses of H_2 and D_2 differ by a factor of 2 (resulting in diffusion times and thermal speeds differing by a factor of $\sqrt{2}$). The results are: $n_{e,Ar}$: $5.66 \cdot 10^{19}$, $n_{e,Ar+H_2}$: $3.60 \cdot 10^{19}$, $n_{e,Ar+D_2}$: $4.30 \cdot 10^{19}$ (all in m^{-3}, $\pm$ 5%) The difference between H_2 and D_2 admixture (factor 1.19 $\pm$ 10%) can be explained using the simple model of Fig. 2b. We assume that also *in the arc*, wall association of H (D) atoms (or ions) to molecules takes place, and that formed H_2 will penetrate the arc channel further by a factor of $\sqrt{2}$ (compared to D_2) due to its smaller mass. If we now assume this to result in a narrowing of the arc channel (due to fast molecular recombination if H_2 or D_2 is present) we can calculate the difference in n_e outside the arc, if the electron density in the arc channel remains the same. For the ratio $n_{e,Ar+D_2}/n_{e,Ar+H_2}$ we find 1.15, in agreement with the experimental data.

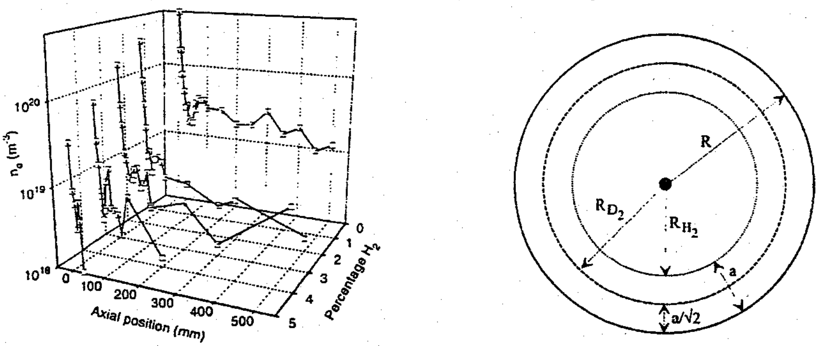

Figure 2. (a) (left) Thomson scattering measurements for higher H_2 seed fractions: (b) (right) a cross-section of the arc channel as envisaged in the simple model. A wall-associated H_2 molecule penetrates over a distance a, whereas D_2 only gets as far as $a/\sqrt{2}$ due to its larger mass.

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