

Recirculation and arc effects in argon-hydrogen expanding cascaded arc plasmas

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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-H₂ 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).

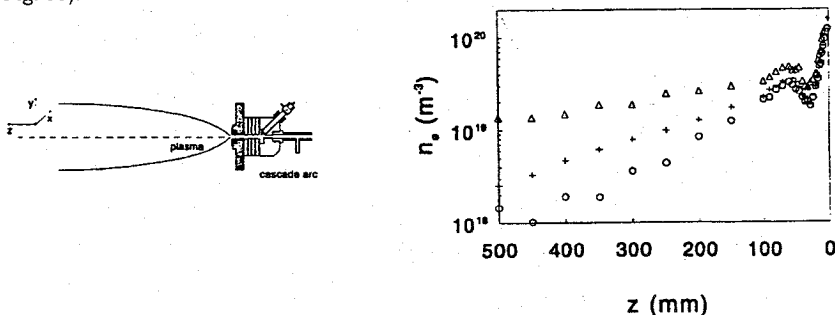


Figure 1. (a) (left): the expanding cascaded arc plasma; (b) (right): Thomson scattering measurements [4,5] (n_e vs. z , the axial position): Δ : pure argon, +: 0.7 vol.% H₂, \circ : 1.4 vol.% H₂.

This anomalous decrease in ionization cannot be attributed to atomic processes [2,3], but associative charge exchange between H₂ 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 H₂ seed fractions). Therefore wall-associated molecules are thought to participate in these fast recombination processes: H₂ 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 H₂ seed fractions (Fig. 2a). For H₂ 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.% H₂ and D₂ 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 H₂ and D₂ 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 H₂ and D₂ 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 H₂ will penetrate the arc channel further by a factor of $\sqrt{2}$ (compared to D₂) 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 H₂ or D₂ 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.

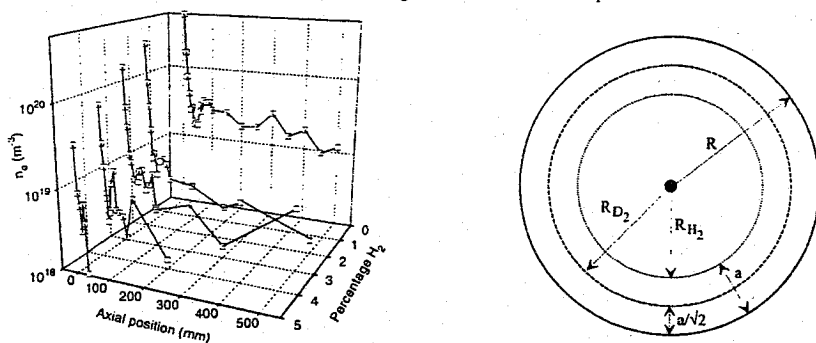


Figure 2. (a) (left) Thomson scattering measurements for higher H₂ seed fractions; (b) (right) a cross-section of the arc channel as envisaged in the simple model. A wall-associated H₂ molecule penetrates over a distance a , whereas D₂ only gets as far as $a/\sqrt{2}$ due to its larger mass.

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