Supersonic expansion of a cascaded arc plasma : a new neutralizer for negative ions?

Supersonic expansion of a cascaded arc plasma: a new neutralizer for negative ions?

G.M.W. Kroesen and D.C. Schram

Eindhoven University of Technology, Department of Physics, P.O. Box 513, 5600 MB Eindhoven, The Netherlands

It has been calculated[1)] that neutralization of intense negative ion beams can be performed more effectively by using plasma targets in stead of gas targets. Provided that some demands are met the neutralization efficiency can thus be enhanced from 55% to over 80%. This will cut down appreciably on the power loss and thus enhance the efficiency with which neutral beams can be produced. The actual attainable neutralization efficiency depends on the target thickness $\overline{n_e \ell}$ defined as the electron density integrated over the line of sight along the negative ion beam and the ionization degree. In Ref. 1 it has been shown that for effective neutralization the following two requirements have to be met:

1. Target thickness $\overline{n_e \ell} \sim 10^{19}/m^2$.
2. Ionization degree $n_e/n_a > .2$.

Other requirements to be met are:

3. Sufficiently low values for d.c. and fluctuating E and B fields, in order to minimize sizeable deflection of the incoming beam and increase of the divergence.
4. Long life-time of the components
5. Power consumption substantially lower than the power gained by enhancing the efficiency.

In this paper we will discuss the possible potential of an expanding plasma developed for plasma deposition for the use as plasma neutralizer.

In principle two ways can be followed. The first one would be to employ in situ plasma production. In view of demand 3, this has to be achieved in low E and B fields, whereas still a high density is required. In Ref. 2 a possible way is discussed: the combination of RF and multipole fields. It still looks to be a hard task to achieve the required high densities at low fields. The alternate route would be to use an expanding plasma. In this way the E and B fields are confined to the plasma production section, whereas the recombining expanding plasma will have negligibly small residual c.s. fields. Also these passive plasmas are expected to be much more quiescent than active plasmas in which power is fed to the plasma in the neutralizer itself. Also in this concept the plasma production can be optimized with regard to power efficiency and gas efficiency. The other side, however, is that expanding plasmas will exhibit drift velocities which may be in the order of 10^3 m/s.

In order to elucidate the reasoning, imagine a plasma target as sketched in Fig. 1. The ion fluence emanating from the source is equal to

$$\dot{N}_i^+ = n_i\, w_i\, \ell\, b = n_i\, \ell\, w_i\, b\ .$$

As the product $n_i\, \ell$ must be equal to the required target thickness $10^{19}/m^2$ we find:

$$\dot{N}_i = 10^{19}\, b\, w_i\ .$$

The dimension b is dictated by the incoming H^- beam and is here supposed to be in the order of 10^{-1} m. With the estimated value for $w_i \sim 10^3$ m/s a rather high fluence of $10^{21}/s = \dot{N}_i$ is required. We may note at this point that the present arrangement is designed for deposition, in which application a large plasma velocity is even desired to obtain large fluxes. In the application of neutralizer a two sided injection (see Fig. 2) from two plasma sources and sidewards pumping is most probably a better arrangement in which a higher density can be reached with substantial smaller fluences. Nevertheless, in this paper we will show that even in the one sided high flux deposition arrangement already large values of target thickness can be obtained.

Further the power requirement should be discussed. In the plasma beam the transported energy is equal to

$$\epsilon_i = n_i\, w_i\, \ell\, b\, \epsilon^{ion} = \dot{N}\, \epsilon^{ion}\ ,$$

in which ϵ^{ion} is the ionization energy. In this estimate the thermal energy is ignored, as this is small compared to the ionization energy. This energy flow has been provided from the arc with overall efficiency, η^{ϵ}; so $\epsilon_i = \eta^{\epsilon} P$. Typical efficiencies in the ascaded arc sources are around 10%. These high efficiencies are needed to keep the consumed power appreciably smaller than the saved power in the beam because of better efficiency (see demand 5).

Finally, a few words should be said about the requirements 3 and 4. First, electric and magnetic fields are very small and quiescent operation is expected as we deal with recombining plasmas with high densities and low temperatures. Also operation life-time is good for the present equipment as the same is needed for deposition purposes. At present only the cathodes need replacement typically after 100-1000 hours of operation. All the other parts are practically service-free.

So it appears that the expanding plasmas are very promising for the application as plasma neutralizer. Two sided injection should be evaluated, as it is expected to boast considerably the already promising features.

Experimental and modelling results of the present arrangement

In Fig. 3 the deposition reactor is shown, including in an insert an enlargement of the cascaded arc plasma source. Both in the source section and in the expansion chamber measurements have been made. The electron density is measured by Stark broadening of H_β-line emission. The electron temperature is obtained from an ArII line to continuum ratio. The plasma velocity and gas temperature are determined by Doppler shift and Doppler broadening of suitable lines of the analyzed species. The model is based essentially on the mass, momentum and energy conservation laws.

Details about measurement techniques and models can be found in Ref. 3. In Fig. 4a,b,c results on n_e, T and p are given for the source section. We observe satisfactory agreement with the model. This shows that the source can be optimized by changing parameters in the model. In Fig. 5a,b,c a three dimensional plot is given for the plasma velocity and lateral and axial profiles for the electron density are presented. It is shown that required target thickness is already approached with only 10 kW of consumed power.

As conclusion the potential of the use of expansion plasmas from cascaded arc plasma sources has been demonstrated. Further investigations are planned to evaluate possible future use as plasma neutralizer for NET-negative ion beams.

References

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2) K.G. Moses and J.R. Trow, Plasma neutralizers for high energy neutral beam injectors. 3rd European Workshop on the Production and Application of Light Negative Ions, Amersfoort, The Netherlands (1988).

3) G.M.W. Kroesen, Plasma deposition: investigations on a new approach. Thesis, Eindhoven University of Technology (1988).

Figure captions

Fig. 1 *Schematic arrangements of the neutralizers.*

Fig. 2 *Two sided injection.*

Fig. 3 *Sketch of the present arrangement used for deposition.*

Fig. 4a,b,c *Electron density, temperature and pressure in the source section as as function of the axial position in the plasma source.*

Fig. 5a,b,c *The plasma velocity (a) and the plasma density as a function of lateral and axial dimensions (b,c) in the expanding chambre.*

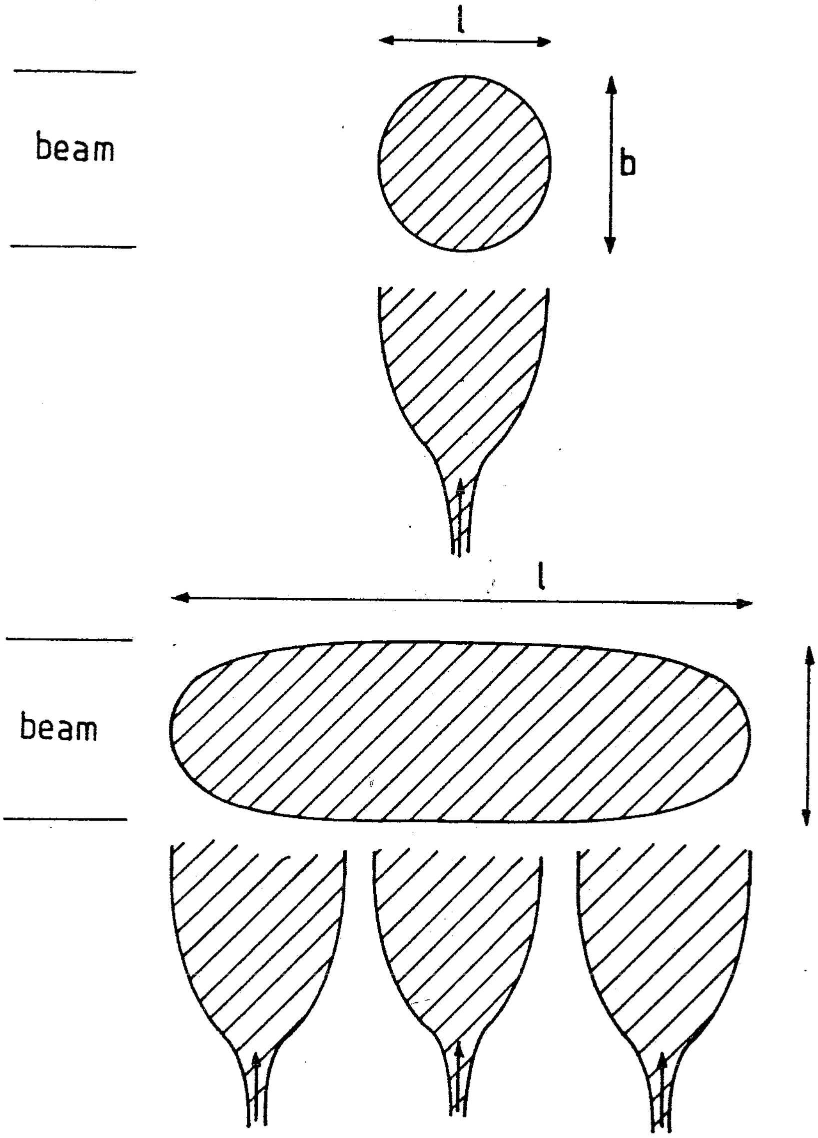


fig.1

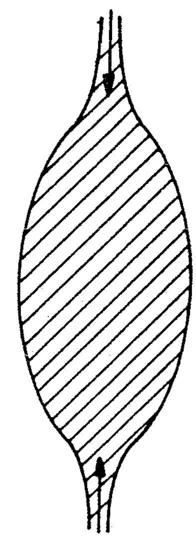
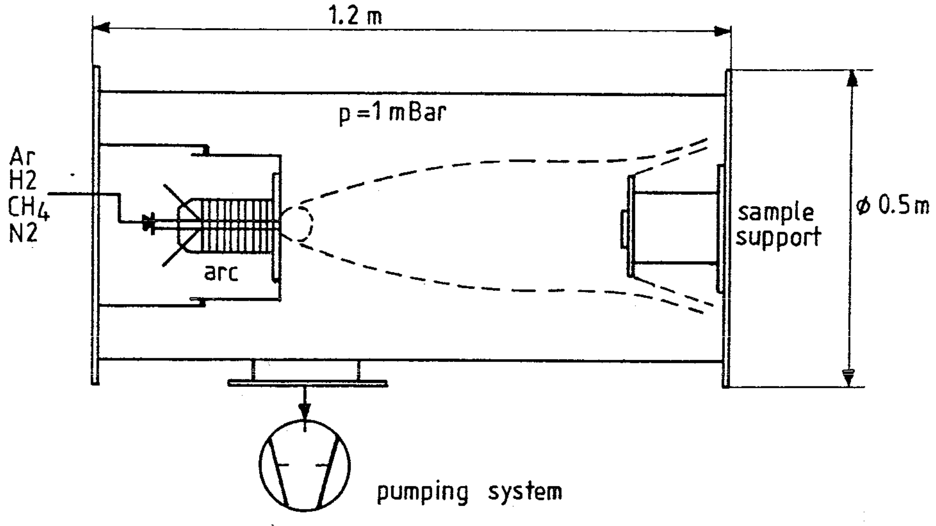


fig. 2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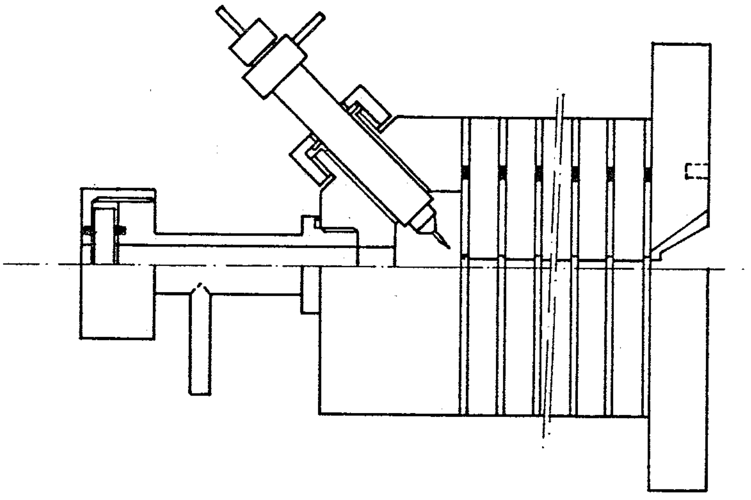

fig 3

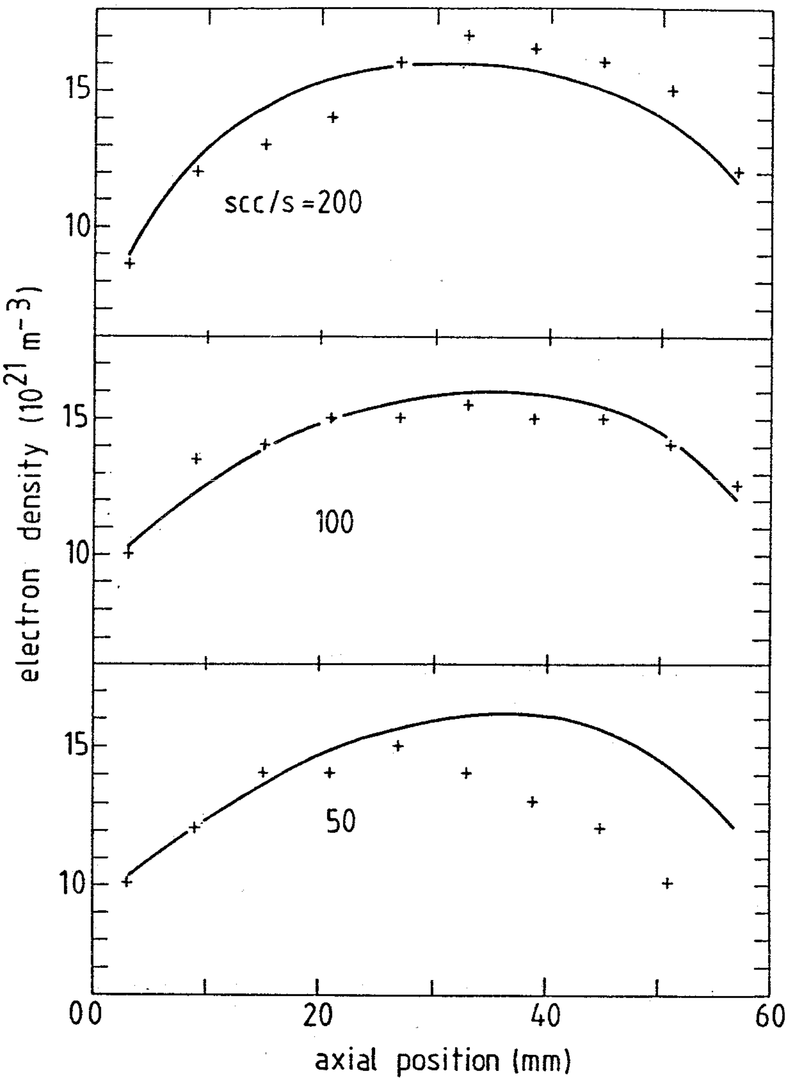

fig 4a

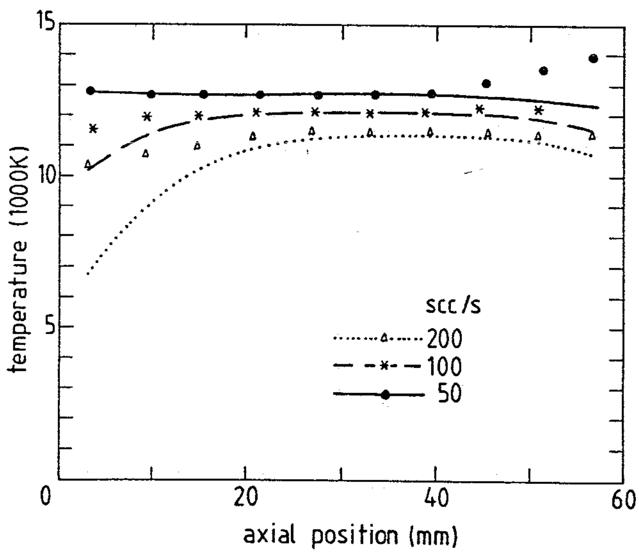

fig. 4b

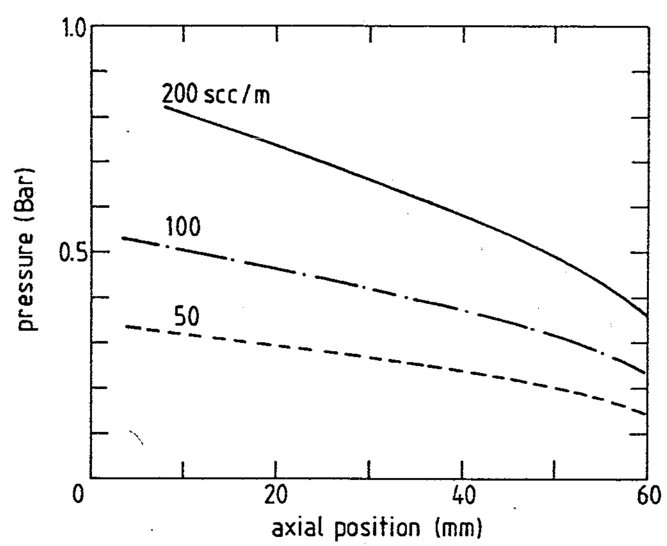

fig. 4c

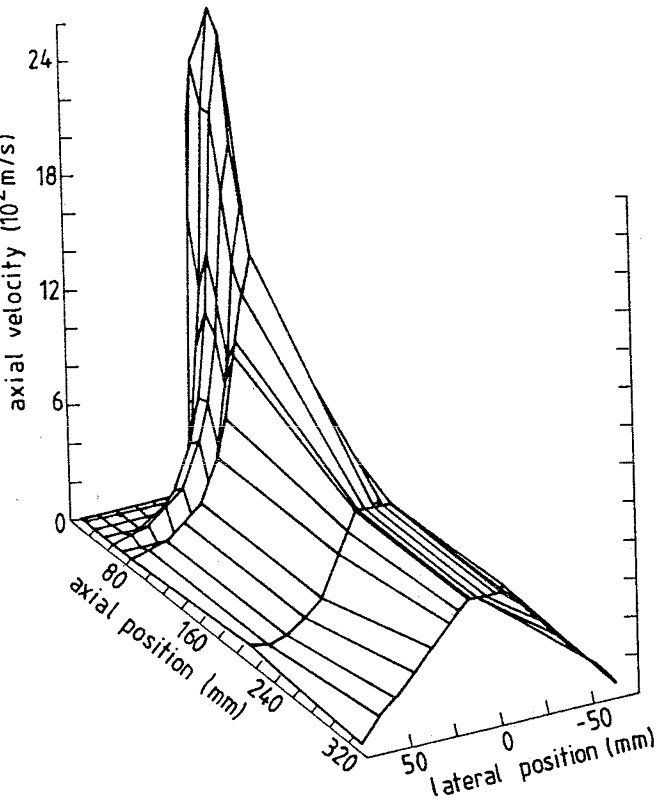

fig 5a

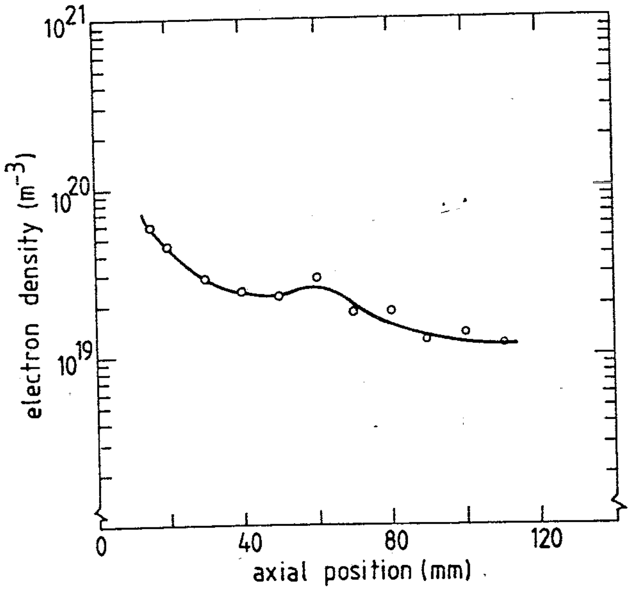

fig 5c

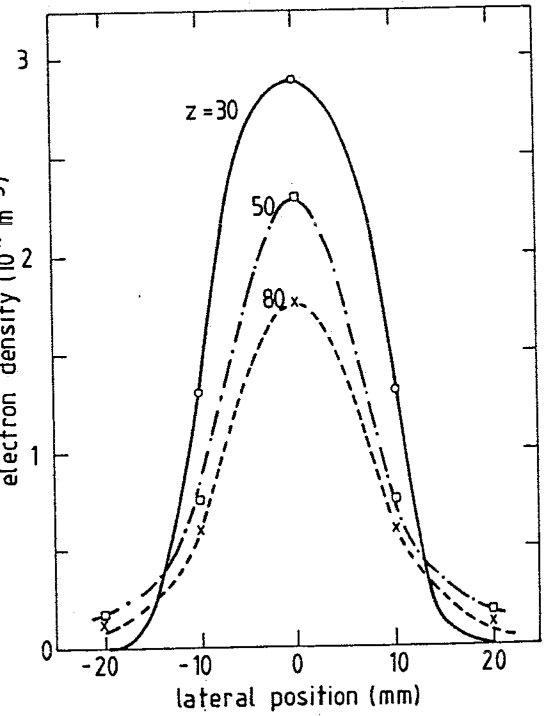

fig. 5b