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H^- production in pure hydrogen discharges of surface-plasma sources

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Résumé. — La décharge en hydrogène pur produite dans les sources plasma-surface à configuration semiplanotron des électrodes est décrite. Dans le mode d'impulsions courtes (10^{-3} s) la densité de courant d'ions H^- atteint 1,1 A/cm^2 pour une densité de courant à la cathode de 60 A/cm^2. Les impulsions courtes multi-fente ont permis l'extraction d'un courant d'ions H^- jusqu'à 1 A. Dans le mode d'impulsions longues (0,6 s) le courant d'ions H^- était de 0,15 A pour une densité de courant de décharge de 10 A/cm^2. Les expériences ont montré une forte dépendance du courant d'ions H^- de la forme, de la température et des conditions de la surface cathodique. Les spectres d'énergie des ions H^- extraits contiennent plusieurs groupes, correspondant à l'origine, en surface (anode et cathode) ou en volume, des ions H^-.

Abstract. — The pure-hydrogen discharges in surface-plasma sources with a semiplanotron electrode configuration are described. In short pulse (10^{-3} s) mode the extracted H^- emission density was up to 1.1 A/cm^2 at cathode discharge current density 60 A/cm^2. The multi-slit short pulse extraction delivered the H^- output with current of up to 1 A. In the long pulse (0.6 s) mode the H^- yield was 0.15 A at discharge current density 10 A/cm^2. The experiments have shown strong dependencies of H^- yield on the shape, temperature and conditions of cathode surface. The energy spectra of extracted H^- ions consisted of several groups, corresponding to the surface (anode and cathode) and volume origin of H^- ions.

In the last decade the interest to Pure Hydrogen (PH) gas discharge systems for H^--production has increased in connection with the study of a new intense channel for H^--production *via* vibrationally excited molecules.

This channel enabled one to explain the anomalously high negative ion density in hydrogen plasma [1] and high negative ion output from PH discharges [2]. The discovery of the surface-plasma negative ion production method [3], delivering the multiampere beams of H^- with an emission current density up to 5 A/cm^2 gave a priority to the studies and development of Surface-Plasma Sources (SPS) with high current hydrogen glow discharge and cesiated electrodes. The H^- output from PH discharges of SPS had also relatively high emission density of up to 0.75 A/cm^2 as it has been established [3] in 1972. Results on H^--production in PH multi-aperture SPS with large emission surface are described below.

The experimental device.

The PH discharges in SPS with a semiplanotron electrode configuration were investigated. The high current glow crossed field discharge was sustained in the extended narrow gap between the massive Mo-cathode and the anode cover (Fig. 1). Electron oscillations were maintained in the space between the cathode side projections along the magnetic field lines. One of the cathode ends was made with the increased up to 4 mm cathode side projections for improving electron confinement and accumulation and decreasing the hydrogen density in the glow discharge [4]. The discharge propagated over the

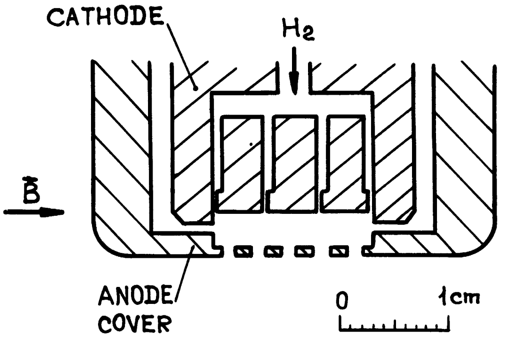

Fig. 1. — Layout of a flat cathode semiplanotron.

extended interelectrode gap due to a crossed field plasma drift from the ignition area.

Flat and honeycomb [5] cathodes were used. The electrode temperature was monitored by thermocouples. A groove was made in the inner part of the anode cover. The anode groove width and profile were varied.

The glow discharge was maintained at an average hydrogen density in the gap of more than 6×10^{15} cm^{-3} and magnetic field of 0.1-0.3 T. The discharge voltage was 500-700 V and decreased down to 300-400 V after conditioning the electrodes. The discharge current was varied within the range 10–750 A. The electrode temperature was varied by changing the discharge repetition rate.

Negative ions (NI) were extracted by a multislit extractor through the system of slits or round holes in the anode cover. In the case of honeycomb cathode the emission holes were situated at the geometric focuses of the cathode spherical depressions (I in Fig. 2) or far from the points of geometric focusing (II in Fig. 2). The extraction voltage up to 25 kV was supplied to the source body, the extractor electrode was grounded. H^--production was investigated in a short (0.6-3.0 ms) and long (up to 0.6 s) pulse modes. In the long pulse mode NI were extracted by a set of rectangular high-voltage pulses of 0.5-1.0 ms duration and repetition rate up to 100 Hz.

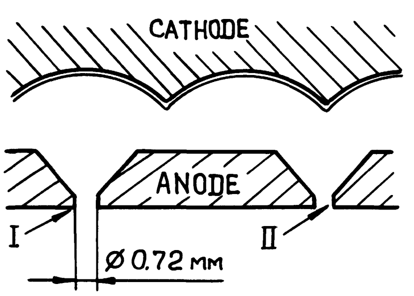

Fig. 2. — Layout of a concave cathode semiplanotron : I-emission hole at the geometric focus ; II-emission hole far from the geometric focus.

An external magnetic field separated H^- beam from heavy impurity ions. Accompanying electrons were dumped on molybdenum shields of magnetic poles. The total beam current, its composition and density distribution were measured with Faraday cup collectors located at a distance of 20 cm from the extraction region.

The multi-slit extraction.

The highest H^- output was obtained in high current pulse discharge mode and extraction through the 5 narrow emission slits of 0.8×52 mm^2 each during the operation with flat molybdenum cathode. The dependence of H^- output as a function of PH discharge current is shown in figure 3. The H^- yield increased linearly with discharge current I_d in the 50-200 A range. Inspite of a lower H^- increase rate with I_d observed at high I_d, the saturation of H^- yield was not detected up to the discharge current 600 A. An H^--beam of current more than 1 A and average emission current density in emission slits up to 0.5 A/cm^2 was achieved (Fig. 3), the corresponding average discharge current density on the cathode was 60 A/cm^2. The total extracted NI current was up to 1.2 A, but ~ 17 % of the beam were heavy impurity ions. The heavy negative ion current decreased at the pulse end. The « decrement » time was of 0.5-1.0 ms and increased with discharge current.

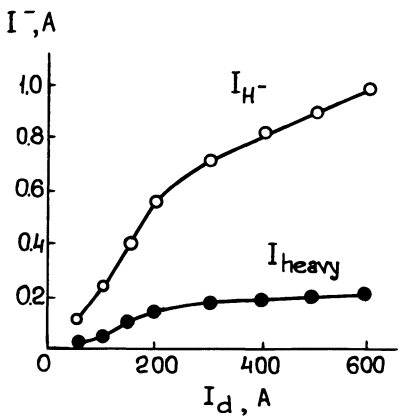

Fig. 3. — NI-yield *versus* discharge current.

H^- yield had its maximum value at the minimum hydrogen density of 6×10^{15} cm^{-3}. This density was substantially lower, that the optimum hydrogen density of PH planotron [3] or reflex-discharge source [2]. This fact is an evidence in favour of existence in PH SPS of a more effective H^- generation channel *via* molecules, so that the addition of gas to a discharge suppressed this production channel (or enhanced H^- destruction).

Some non-typical for « volume » sources features were observed. For example, the H^- yield depended on electrode temperature and reached its maximal value at the average cathode temperature of 750 K (Fig. 4). The anode temperature at optimum was 600 K.

Round emission holes.

A detailed study of a semiplanotron emission capability was carried out for short and long pulse (up to 0.6 s) modes with NI extraction through the round emission holes of a different profile. The H^- beam of 28 mA was obtained with the flat cathode and

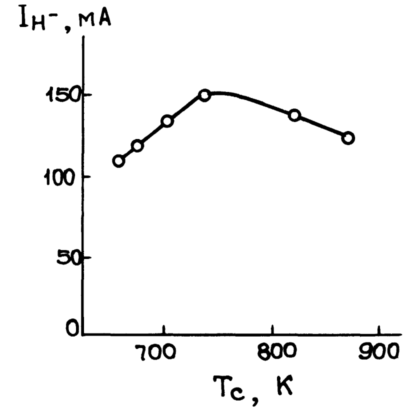

Fig. 4. — Dependence of H^- yield *versus* average cathode temperature.

extraction through 5 holes of ϕ 0.72 mm drilled in the central part of the anode cover. The H^- yield and emission current density increased with the discharge current growth (III in Fig. 5). The H^- emission current density achieved a value as high as 1.1 A/cm^2 at a discharge current of 600 A.

The H^- yield was strongly affected by the cathode shape. In the case of emission holes, situated at Geometrical Focuses (GF) of cathode depressions (I in Fig. 2) the total NI output was two times larger compared to the case of the flat cathode, mainly due to heavy NI. The dependence of H^- emission current density in the case *I versus* discharge current is given in figure 5. At low discharge current ($\leq$ 100 A) the H^- output was a little higher for the extraction through the points of GF, than for the flat cathode. At high discharge current (600-700 A) the H^- yield with GF was saturated.

In the case of emission holes, drilled far from the points of GF (II in Fig. 2) the H^- output and H^- emission current density were 5-6 times less, than in the case of GF or flat cathode (curve II in

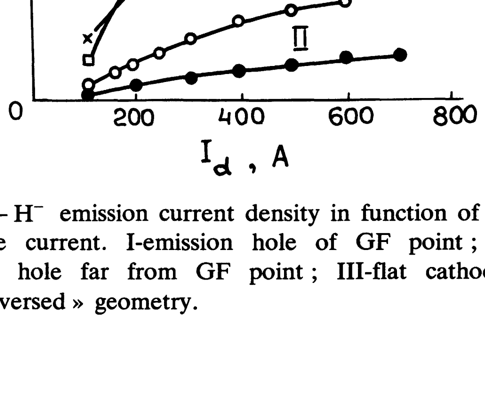

Fig. 5. — H^- emission current density in function of the discharge current. I-emission hole of GF point ; II-emission hole far from GF point ; III-flat cathode ; II_{RG}-« reversed » geometry.

Fig. 5). Extraction of NI through the intermediate hole, shifted from GF point by 0.7 mm only resulted in a decrease in the output down to 60 % of GF output.

The discharge with « Reversed » Geometry (RG) was maintained under similar hydrogen density, but « reversed » polarity of voltage and magnetic field. The external electrode served as a cathode in this RG. The extraction of H^- from the same emission holes in RG showed, that H^- emission current density had rather high value of up to 0.4 A/cm^2 (II_{RG} in Fig. 5). The heavy NI output was 20 % of a total beam, close to the case of semiplanotron flat cathode.

The analysis of the positive ion beam, extracted through a hole in the RG cathode showed, that the total positive ion flux to the cathode was proportional to discharge current and decreased with increasing hydrogen supply. At a discharge current of 180 A the ratio of ion species $I_{H^+} : I_{H_2^+} : I_{H_3^+} : I_{heavy}$ in the flux to RG cathode was 0.5 : 3 : 2 : 1.

There were several groups of NI observed in the energy spectra of extracted H^- current. The main groups have energies of 0.15-0.25 eU_d, 0.5-0.9 eU_d and 1.3-1.8 eU_d, where U_d is the discharge voltage and the relative height of the groups was 1 : 2 : 1 correspondingly.

The long-pulse mode.

The long-pulse tests of the PH semiplanotron showed that the uniform high current glow discharge had similar characteristics and H^- emission capability up to pulse duration of 0.6 s and discharge current of 90 A. Further tests were limited by the characteristics of the discharge power supply system. Because of the limited pumping (2×10^4 l/s), the beam extraction was carried out through the 90 emission holes each 0.72 mm in diameter, arranged on the anode cover in the orthogonal matrix with a 3 mm shift. The extracted H^- current increased with the discharge current growth. At the discharge current of 90 A the H^- yield was 0.15 A at the beginning of the pulse and decreased down to 0.1 A at the end of the 0.6 s pulse due to the heating of non-cooled electrodes.

H^- production mechanism.

The experiments showed strong dependencies of H^- yield on the shape, temperature and conditions of the cathode surface. The mechanism of this influence can differ from the well studied surface-plasma H^- production in Cs-H discharge [4].

In pure hydrogen conditions the positive ion direct conversion into H^- ions on the molybdenum surface may have a value $I^-/I^+ \sim 1$ % at molecular ion energies of 300-400 eV[6] and can contribute with

~ 25 % of the total H^- output from PH modes of SPS. The main part of incident ion flux to PH cathode is reflected as fast neutrals, which can be converted to H^- on the walls of emission slits or holes and gives the « medium » group in the energy spectra of NI. The group of H^- with lower energy may be produced by volume processes in the near-anode plasma, enriched by low energy electrons and vibrationally-excited molecules.

The electrode surfaces of SPS can be an intense source of vibrationally-excited molecules due to the high level of the molecular ion flux to hydrogen saturated electrodes. Collision of fast atoms with molecules in the plasma can be another source of vibrationally-excited molecules :

$$H + H_2 \rightarrow H + H_2(\nu'') .$$

Conclusion.

The investigation of SPS PH discharges showed that the H^- current emission density was proportional to the discharge current and had values up to 1.1 A/cm^2 at the average discharge current density to the cathode of 60 A/cm^2. The H^- beams with an intensity of above 1 A was obtained in the short pulse mode. The H^- beam was 0.15 A at the 90 A discharge current in quasi-steady-state mode. The high H^- production rate in the PH mode is caused by the conversion of fast gas discharge particles into NI on the cathode and anode surfaces, and by the intense generation of vibrationally-excited molecules on the electrode surface and in the plasma sheath.

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