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MEASUREMENT OF H^- DENSITY IN A PLASMA BY PHOTODETACHMENT

M. Bacal, G.W. Hamilton*, A.M. Bruneteau, H.J. Doucet and J. Taillet+.

*Laboratoire de Physique des Milieux Ionisés**, Ecole Polytechnique, 91128 Palaiseau Cedex, France.
+Office National d'Etudes et Recherches Aérospatiales, 92320 Chatillon, France.

Improved techniques for measuring the density of H^- or D^- in a plasma are required because of certain limitations of the techniques of Langmuir probes and mass analysis[1]. Interpretation of probe data requires an assumption of the mass of positive ions and are restricted in usefulness by the Debye distance. Mass spectra measured by ion mass analyzers tend to be useful only for relative measurements unless calibration techniques are included to determine absolute ion densities. The requirement for reliable measurements of H^- and D^- is based upon the need for development of D^- ion sources suitable for neutral injection into controlled fusion devices.

Photodetachement has previously been used to measure negative ion densities in oxygen plasmas[2]. Photodetachement consists of the detachment of the extra electron of a negative ion by a photon (H^- + photon $\longrightarrow$ H + e). Therefore photodetachement in a plasma produces an increase in electron density, which can be measured by probes or microwaves depending upon the geomerey. The photon energy should be selected such that it is lower than the threshold energy of other photon interactions such as photoionization, photoexcitation, photoemission or photodetachment of other species. The light from a ruby laser (1.8 eV photon energy) is suitable for this purpose. The photodetachment cross-section for H^- (4×10^{-17} cm^2) is near its maximum at this photon energy[3]. We used a ruby laser capable of a 1 J pulse in a time about 30 ns.

To assure that the photodetachement signal is proportional to the density of H^- and not of other negative ions such as OH^-, O^-, or O_2^- (for which the cross-sections are one or two orders of magnitude lower) we have magnetically analyzed the negative ions extracted from the plasma and also have verified (Figure 1) that our measurements agree with the theoretical photodetachement fraction computed from the cross section for the photodetachment of H^-, but not with that for other ions :

$$\text{photodetachment fraction} = \Delta n_-/n_- = 1 - \exp\left(-\text{laser pulse energy/area} \times \sigma/h\nu\right) \quad (1)$$

The test of Figure 1 should be repeated whenever the experimental conditions change to authenticate the measurements.

Figure 1 shows that the photodetachment fraction $\Delta n_-/n_-$ is essentially 100 % if the laser pulse energy is more than 0.1 J. Under this condition we can determine the relative density of H^- from the change in the probe electron current density :

$$n_-/n_e = \Delta n_e/n_e = \Delta j_{probe}/j_{probe\ dc} \quad (2)$$

We found some large noise signals when the laser energy is higher than 0.2 J ; we observed an increase of these noise signals when the laser light hits a surface situated close to the probe (e.g. the stainless steel wall of a multipole). The noise signals at high laser power density (2 to 10 MW/cm^2) may be due to the interaction of laser light with solid surfaces or to the onset of multiphoton effects or free-free electron interactions. This problem can be avoided by monitoring the laser pulse energy and using the data only for pulses within the range from 0.1 to 0.2 J.

We explored the photodetachment signal spatially by moving the probe in two dimensions. We found no measurable signal when the probe was completely out of the laser beam. The signal was approximately constant when the probe was moved along the

beam. Therefore when we compute the ratio of probe current densities in Eq. (2) we consider that only the section of the probe immersed in the laser beam is effective for photodetachment.

Figure 2 shows the experimental apparatus schematically. The plasma was produced in a hydrogen atmosphere of 10^{-2} Torr by thermionic electrons emitted by a cathode at a negative potential of 60 to 120 V. Densities of plasma and of gas were controlled by adjustment of the thermionic emission and of the gas feed. Light pulses from a ruby laser were injected via a reflecting prism and a 2 cm diameter glass window, and were monitored by a photomultiplier through a partially reflecting mirror. The light monitor was calibrated versus injected laser energy using a calorimeter within the vacuum chamber.

Two types of cylindrical tungsten probes were used to measure the densities of electron and ions. For absolute measurements of n_e and of n_+ it is necessary to measure the complete probe characteristic and to analyze it either by the Langmuir theory (if the probe radius is less than 3 Debye distances) or by a theory for larger probes. On the other hand, for measurements of changes in n_e and n_+ it is sufficient to use large-area probes of which the radius may be more than the Debye distance, so the probe would be self-supporting and so the pulsed probe currents would be easier to measure. The self supporting probe did not require the exposure of a supporting insulator to laser light. The best probe geometry is such that the probe axis is parallel to the laser beam, and the probe area within the laser beam is larger than the probe area outside the laser beam.

The measurements by the technique described were reproducible and independent of the probe diameter, showing n_- increasing in proportion to n_e^3 in the range of n_e between 10^9 and 2×10^{10} cm^{-3}.

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* Permanent address : Lawrence Livermore Laboratory, Livermore, California, U.S.A.

** Groupe de Recherche N° 29 du Centre National de la Recherche Scientifique.

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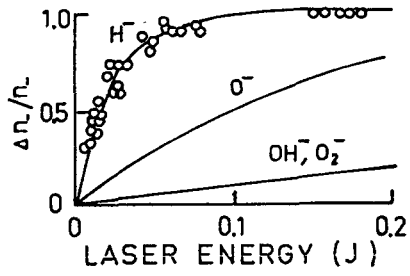

Figure 1 : Photodetachment of several negative ion species by ruby laser light as a function of laser pulse energy, according to theory of equation (1). Experimental data points are superimposed upon the theory of equation (1) for H^-, where $\sigma/h\nu \simeq 139$ cm^2/J and the area of the laser beam is 3 cm^2.

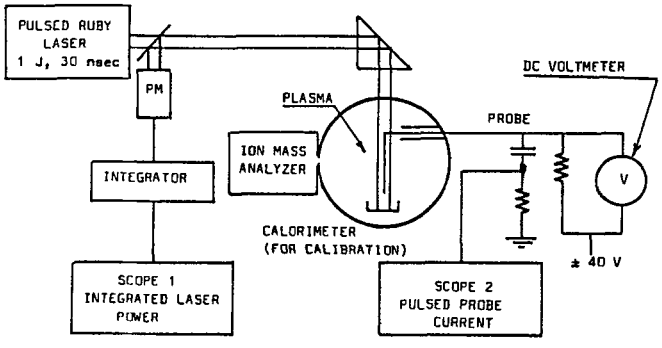

Figure 2 : Equipment diagram