Title

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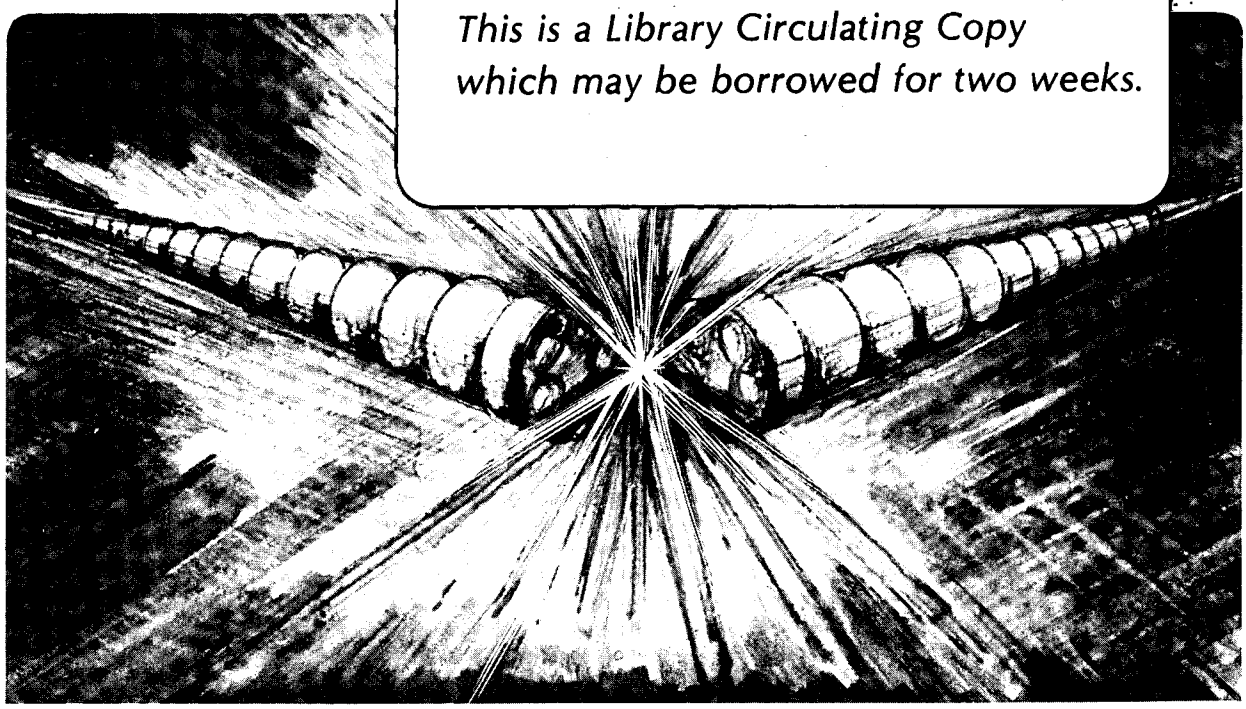

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Atomic Hydrogen Density Measurements in an Ion Source Plasma Using a Vacuum Ultraviolet Absorption Spectrometer

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Abstract

A system to determine the density and temperature of ground state hydrogen atoms in a plasma by vacuum ultraviolet laser absorption spectroscopy is described. The continuous tunability of the spectrometer allows for analysis at any of the Lyman transitions. The narrow bandwidth of the laser system allows for the accurate determination of the absorption lineshape and hence the translational temperature. The utility of the system is exemplified by data obtained on an ion-source plasma. The measurements demonstrate the quality of the data as well as illustrating the behavior of this ion source under varying discharge conditions.

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I. Introduction

Efficient sources of H^- and D^- are of great interest to the fusion and accelerator community. In particular, high current, long pulse sources of H^- are required for driving or heating fusion devices.[1] A candidate for these sources is the magnetic multilinecusp ion source being developed at LBL and elsewhere.[2] In spite of its importance, however, the precise mechanisms involved in producing the negative ions in this source are not well understood.

Previous studies on similar sources[3] have focussed attention on the H^- concentration, H_2 vibrational distribution, and the electronically excited atomic hydrogen. However, no direct measurements of the ground state atomic hydrogen density and temperature in these ion sources have been performed. To measure this important species we have developed a vacuum ultraviolet laser absorption spectrometer.

The vacuum ultraviolet laser spectrometer produces continuously tunable light throughout the spectral region (90-122 nm) of the Lyman atomic hydrogen transitions. The high photon flux and narrow bandwidth of the VUV allows the absorption measurement to be made on optically bright plasmas with high accuracy. Values for the density and temperature are directly obtained from the absorption measurement. The system is quite flexible and can be used on a variety of plasma sources within a wide range of hydrogen-atom densities. In this paper we briefly describe the spectrometer system and illustrate its use with data obtained on a multicusp ion source.

II. Experimental

The vacuum ultraviolet laser spectrometer system, which has been previously described in detail,[4] is shown schematically in Fig. 1. The vacuum ultraviolet light is produced using the nonlinear-optical four-wave sum mixing (FWSM) technique.[5] In this process, three photons of energy ϵ_1, ϵ_2, and ϵ_3 are combined in a nonlinear medium to produce a single photon whose energy ϵ_4 is equal to the sum of the input photons. To enhance the efficiency of the mixing

process, the sum $\epsilon_1 + \epsilon_2$ is chosen to be equal to a real energy level in the mixing medium. FWSM has been demonstrated using a variety of media; for the wavelength region around 100 nm, mercury vapor has been shown to be have high efficiency across a broad output frequency range.[6]

The high intensity input photons needed for FWSM are generated by excimer laser-pumped pulsed dye lasers. In our scheme, $\epsilon_1 = \epsilon_2$, so that only two frequencies of light are needed. The ϵ_1 needed is in the ultraviolet, which is created by frequency doubling one of the dye laser outputs in a second harmonic generation crystal. These light beams are focussed into the mercury vapor cell, where the VUV is generated. Approximately 10^{10} photons of VUV are produced in 20 nsec pulses, with a bandwidth of 0.3 cm^{-1}. After emerging from the mercury oven, the VUV is separated and focussed using a VUV grating and directed towards the plasma region. In addition, by monitoring the VUV's second-order diffracted beam from the grating, we can normalize the absorption signal for intensity variations in the VUV.

After attenuation by the plasma, the VUV continues into a vacuum monochromater. Detection, both in the grating chamber and at the monochromater output, is accomplished using microchannel plates. The resulting signals are amplified, integrated, and sent to a computer system which computes the ratio of the attenuated signal to the normalization signal on a shot-by-shot basis. Typically 200 shots are averaged for each wavelength. By taking the natural log of the ratio of the attenuated beam with and without plasma, Eq. 1, the absorbance is determined.

$$\text{Absorbance} = -\ln\left[\left(\frac{I_{attn}}{I_{norm}}\right)_{\text{plasma on}} \Big/ \left(\frac{I_{attn}}{I_{norm}}\right)_{\text{plasma off}}\right] \qquad (1)$$

The VUV wavelength is then reset by shifting the frequency of the ϵ_3 dye laser, with the acquisition process then being repeated.

By stepping the wavelength through the transition to be measured, the absorbance profile can be determined. The area under the

absorbance curve is directly proportional to the concentration of absorbers along the VUV beampath, and since the transition strength is known, the line density ($\int_{path} n_H dl$) can be determined. In addition, the translational temperature of the H-atoms can be determined by fitting the observed absorbance profile to a Gaussian, with the width of the line yielding the temperature.

The plasma source used to illustrate the VUV absorption technique is a multicusp hydrogen discharge source.[2] The chamber is stainless steel with copper end plates, and is 30 cm long by 25 cm diameter. The cathode is a coaxial LaB_6 element.[7] Discharge currents range from 5 A to 30 A with voltages from 100 V and H_2 pressures of 0.5 mTorr to 8 mTorr. Plasma densities on the order of 10^{12} cm^{-3} and electron temperatures of 2-3 eV are obtained.

III. Results and Discussion

Figure 2 displays a typical absorbance profile obtained with the spectrometer system. For these data, we used the Lyman-γ transition at 97.25 nm. From this spectrum, one derives a line density of 2.9×10^{14} cm^2. The uncertainty of the measurement is estimated to be less than 7%. Changing the spectrometer wavelength to other Lyman-transitions increases the range of measurable line densities, as each transition has a different absorption strength. Table I shows the line densities which can be measured for the various Lyman transitions assuming a 0.5 eV H-atom temperature and a peak absorption of between 10% and 98%. The lower limit on absorption is derived from signal-to-noise ratio considerations, while the upper limit is chosen to minimize the effect of stray.

The atom density as a function of H_2 pressure, as shown in Fig. 3, shows linear growth. For the discharge powers used, the fraction of H/H_2 is 10%. In contrast, Fig. 4 displays a non-linear growth in H density as a function of arc current. In this case, a limit on the H-atom line density of about 1×10^{14} atoms cm^{-2} is approached at high current. The leveling off may represent a saturation of the dissociation processes at the relatively low (3.3×10^{13} molecules cm^{-3}) H_2 density used to obtain Fig. 4. A line density of 10^{14} atoms cm^{-2} would represent an H/H_2 fraction of 10%,

the same as obtained in the pressure dependence experiment, which indicates that those measurements were obtained on "saturated" plasmas. Also interesting is the data shown in Fig. 5, where the H-atom density is observed to decrease with increasing arc voltage. Since, at a constant arc current, the discharge power scales linearly with arc voltage, Fig. 5 shows a 30% decrease in atomic hydrogen with a four fold increase in arc power.

The temperature measurement also yields interesting results. For the discharge measured in Fig. 2, we obtain a temperature of 0.1 eV. This can be contrasted to a temperature of 0.3 to 0.6 eV in a similar but much higher discharge-power ion source[8]. However, our absorbance lineshape is not well characterized by a single Doppler profile, as the wings of the experimental data are much larger than the calculated fit. This implies a non-thermal translational energy distribution. Such distributions have been observed in similar discharges using emission spectroscopy.[9] A better fit to our data is obtained using a sum of two Gaussians with a common center frequency but independent amplitudes and widths. A preliminary analysis indicates that although a majority of the atoms can be assigned a temperature of 0.06 eV, a substantial group of hydrogen atoms can be characterized with a temperature in excess of 0.8 eV. These results reflect the complex chemistry occurring in these sources and show the need for more measurements before an understanding of the processes occurring in the ion source will be attained.

Other plasma devices could also be measured with our spectrometer system. The available space for the plasma to be measured, which is the region between the grating chamber and the spectrometer, is determined by the focal length of the VUV generating optics. By increasing this focal length, a larger plasma source could be accommodated. This would also allow the VUV source and the detectors to be moved from the vicinity of plasma, as in cases where access is limited or hazardous.

IV. Conclusions

We have demonstrated the application of a vacuum ultraviolet laser-absorption spectrometer system to the direct measurement of ground-state atomic hydrogen density and temperature in a plasma. Studies performed on a multicusp ion source illustrate the method and show the need for a better understanding of the chemistry occurring in these sources. Experiments are now underway to correlate the atomic density to electron density and temperature, H- density, and state-specific molecular hydrogen populations.

V. ACKNOWLEDGEMENT

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REFERENCES

1. W.S. Cooper, O.A. Anderson, C.F. Chan, L.T. Jackson, W.B. Kunkel, J.W.Kwan, K.N. Leung, A.F. Lietzke, P. Purgalis, L. Soroka, R.P. Wells, R.S. Devoto, and J.S. Fink, *Proceedings of the 12th Symposium on Fusion Engineering, Monterey, CA,* October 12-16, 1987, (IEEE, New York, 1987) p. 294.

2. K.N. Leung, K.W. Ehlers, and R.V. Pyle, Rev. Sci. Instrum. 56 364 (1985).

3. M. Pealot, J-P. E. Taran, M. Bacal, and F. Hillion J. Chem. Phys. 82 4943 (1985) and references cited therein.

4. G.C. Stutzin, A.T. Young, A.S. Schlachter, J.W. Stearns, K.N. Leung,
   W.B. Kunkel, G.T. Worth, R.R. Stevens, Rev. Sci. Instrum (accepted).

5. C.R. Vidal, in Topics in Applied Physics, Vol. 59: Tunable Lasers edited. by L.F. Mallenauner and J.C. White (Springer-Verlag, Berlin, 1987),p. 57.

6. P.R. Herman and B.P. Stoicheff, Opt. Lett. 10 502 (1985).

7. K.N. Leung, D. Moussa, and S.B. Wilde Rev. Sci. Instrum., 1274 (1986).

8. C.F. Chan, C.F. Burrell, and W.S. Cooper, J. Appl. Phys. 54 6119 (1983).

9. D.H. McNeill and J. Kim, Phys. Rev. A, 25, 2152 (1982).

Figure Captions

Figure 1 Schematic diagram of the vacuum ultraviolet laser absorption spectrometer. Wavelengths shown are for Lyman-β generation.

Figure 2 VUV absorption profile of plasma generated hydrogen atoms, using Lyman-γ radiation H_2 pressure was 7 mT, with a discharge current of 25 A at a voltage of 150 V. The measured hydrogen line density is 2.9 x 10^{14} atoms-cm^{-2}. See text for a discussion of the temperature.

Figure 3 Hydrogen atom line density as a function of H_2 pressure, measured using Lyman-ß radiation. Discharge parameters were 25 A and 130 V.

Figure 4 Hydrogen atom line density versus discharge current, measured using Lyman-ß radiation. Discharge voltage was 100V, H_2 pressure was 1.0 mTorr.

Figure 5 Hydrogen atom line density versus discharge voltage, measured using Lyman-ß radiation. Discharge current was 8 A and H_2 pressure was 1.0 mTorr.

TABLE I. Peak cross sections and useful line density ranges for some Lyman absorption lines. Cross sections are based on an atom temperature of 0.5 eV, and the ranges calculated using peak absorptions of 10% to 98%.

Lyman Line	$\sigma (cm^2)$	Useful Line Density (cm^{-2})
Alpha	7.8 E-14	2E12 - 5 E13
Beta	1.2 E-14	8 E12 - 3 E14
Gamma	4.3 E-15	2 E13 - 9 E14
Delta	2.1 E-15	5 E13 - 2 E 15
Epsilon	1.1 E-15	9 E13 - 4 E15

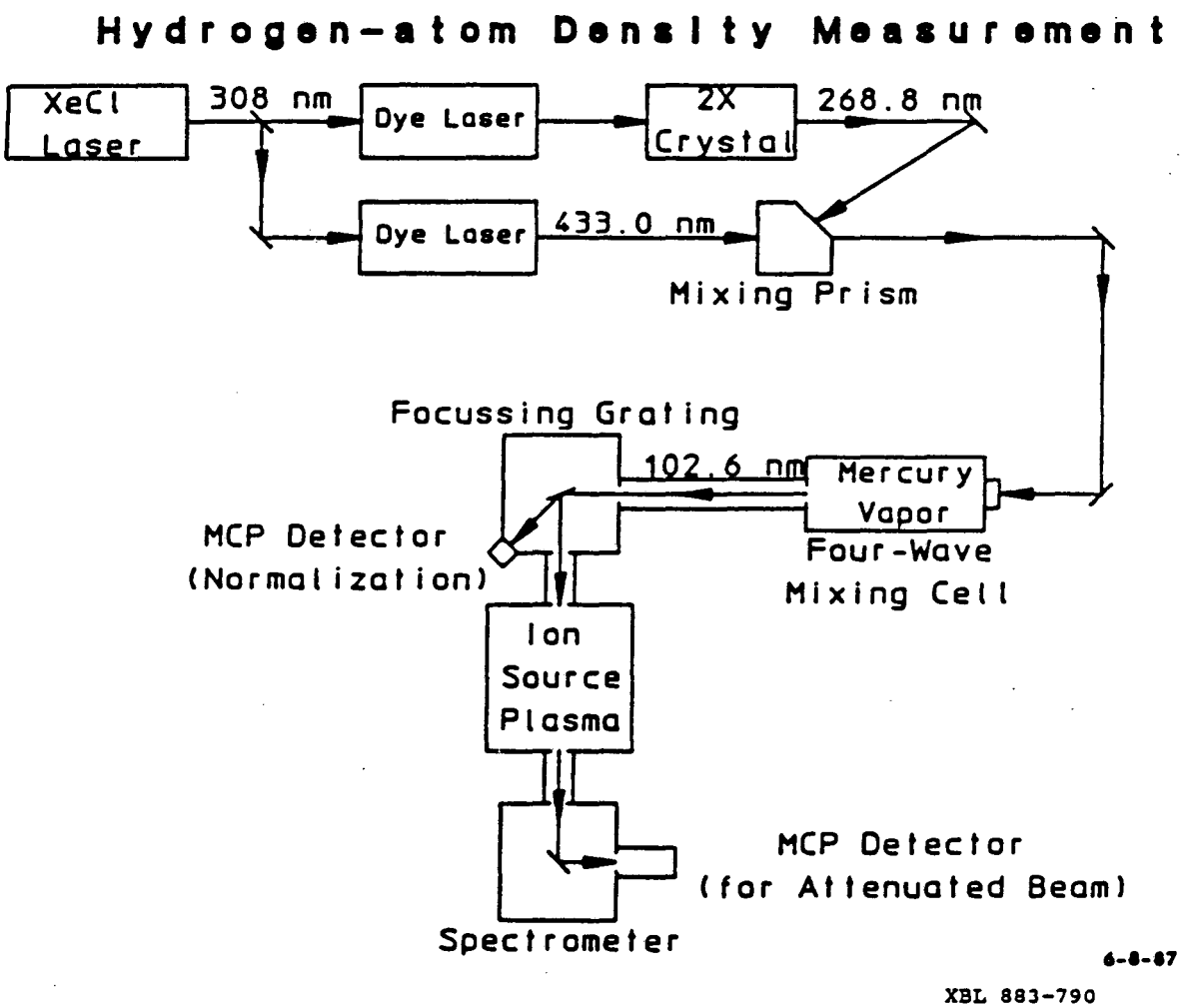

Hydrogen-atom Density Measurement
XeCl Laser
308 nm
Dye Laser
2X Crystal
268.8 nm
Dye Laser
433.0 nm
Mixing Prism
Focussing Grating
102.6 nm
Mercury Vapor
Four-Wave Mixing Cell
MCP Detector (Normalization)
Ion Source Plasma
MCP Detector (for Attenuated Beam)
Spectrometer
6-8-87
XBL 883-790

Figure 1

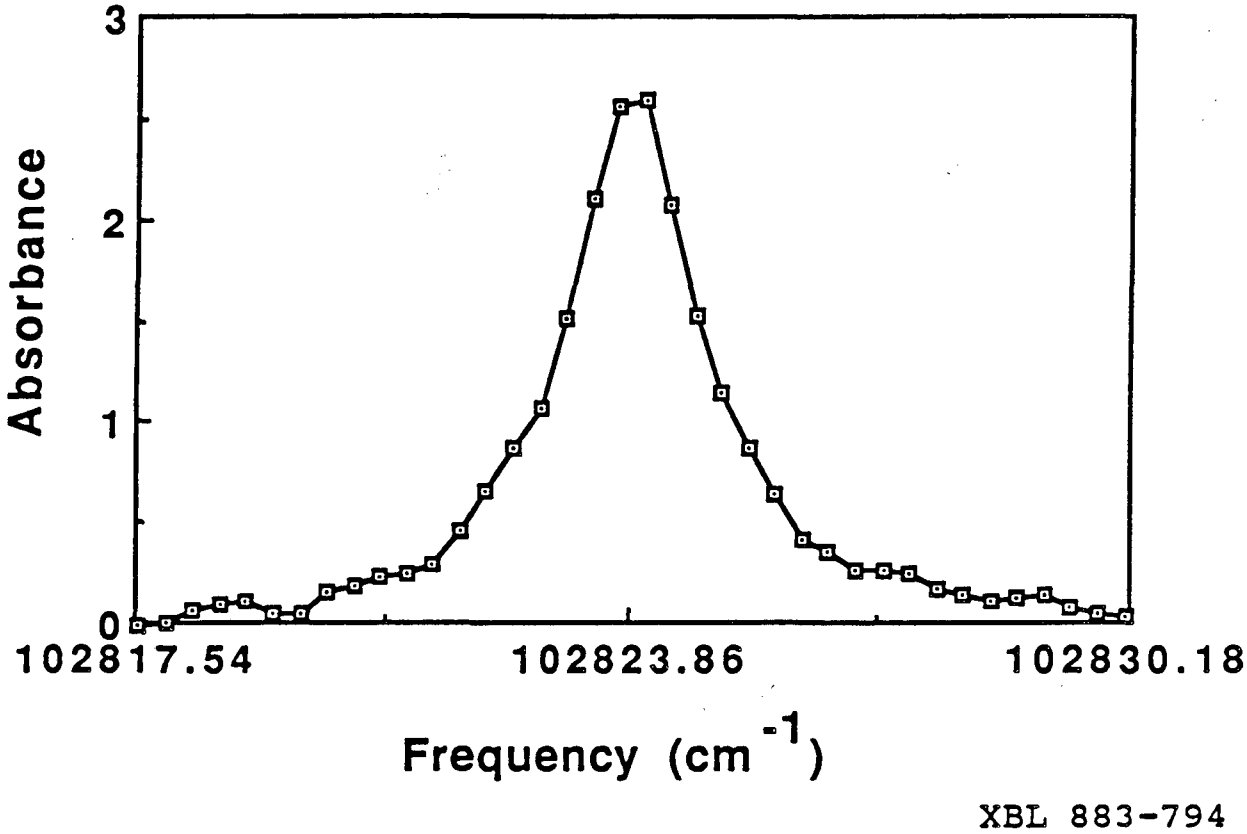

3
2
1
0
Absorbance
102817.54
102823.86
102830.18
Frequency (cm -1)
XBL 883-794

Figure 2

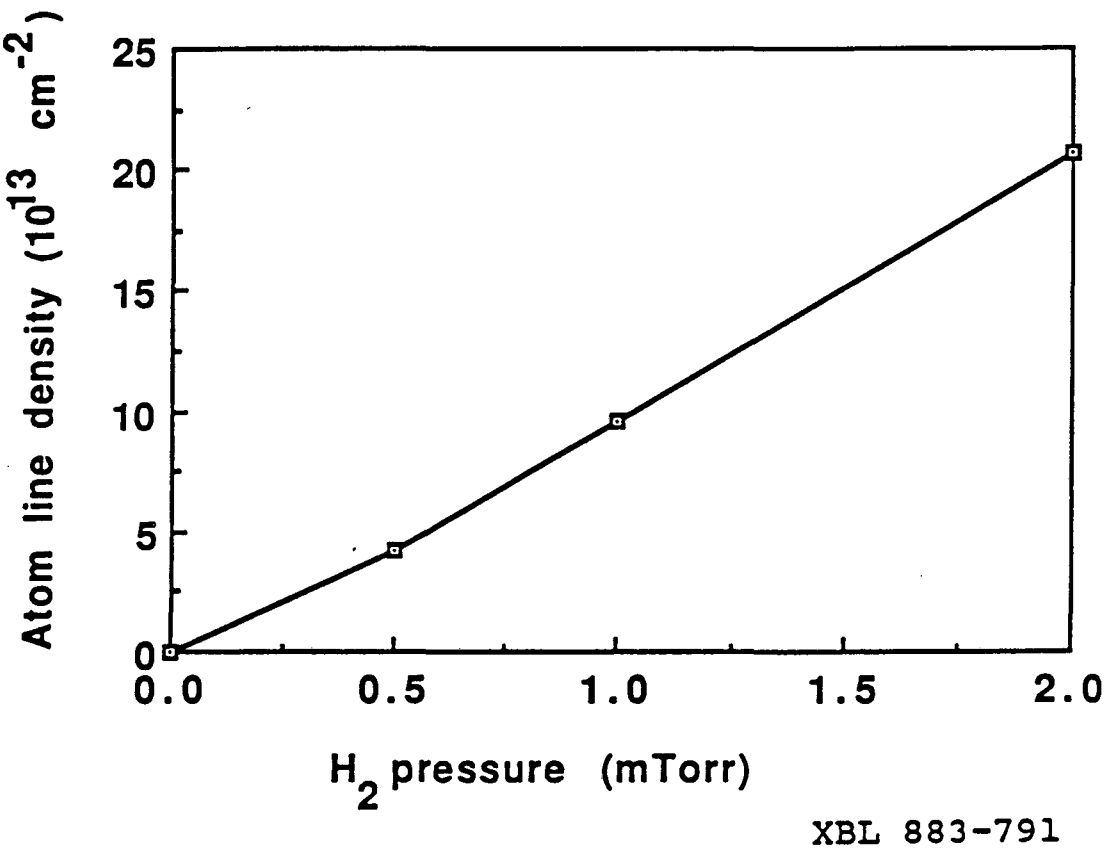
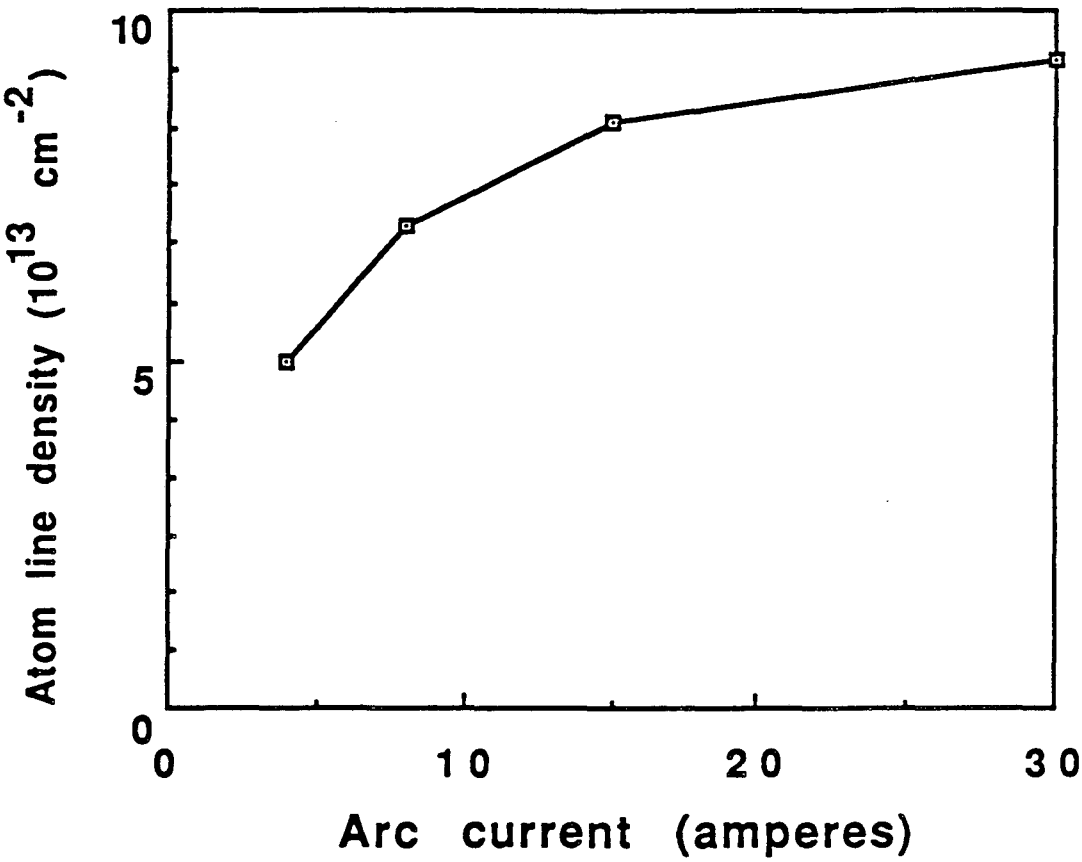
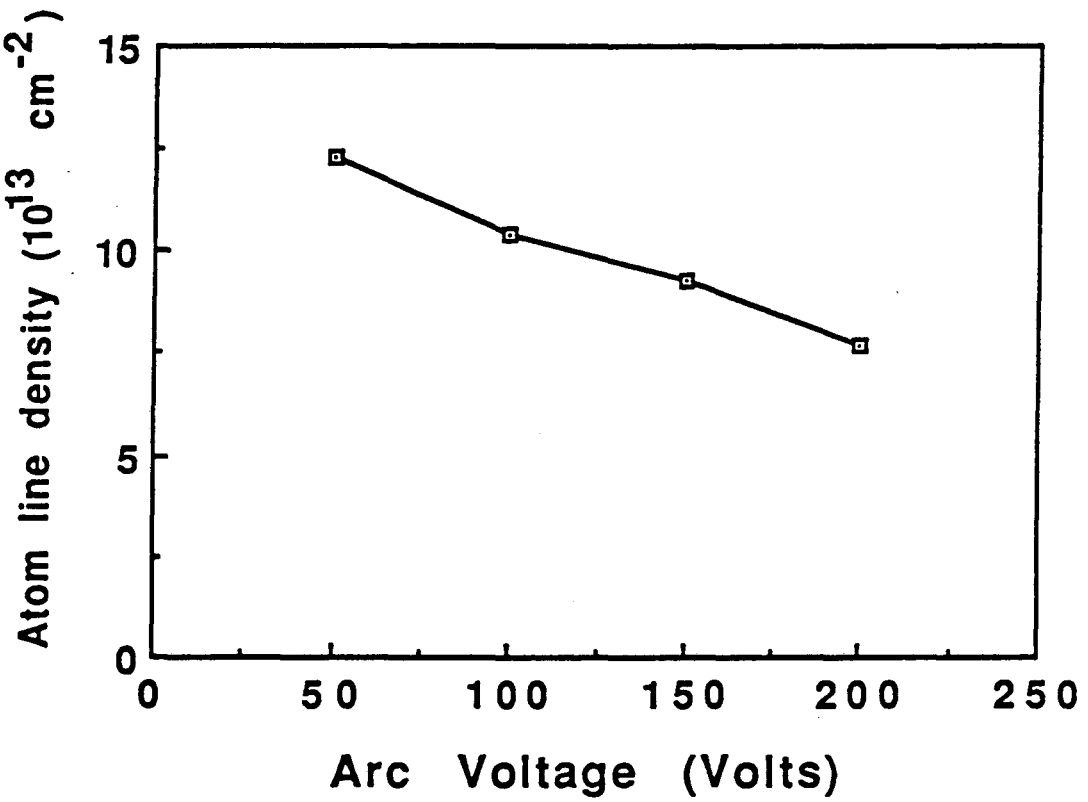

Atom line density (10^{13} cm^{-2})
25
20
15
10
5
0
0.0
0.5
1.0
1.5
2.0
H_2 pressure (mTorr)
XBL 883-791

Figure 3



XBL 883-793

Figure 4



XBL 883-792

Figure 5

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