IP3I-60: Do Ions Heat up in the Presheath, in the Direction Perpendicular to the Flow? Results for a Weakly Collisional Argon Plasma.

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ABSTRACT

Laser-induced fluorescence (LIF) measurements made with a diode laser have measured the transverse metastable ion velocity distribution function profile near a negatively biased plate in a low temperature ($T_e < 1eV$), low pressure ($p_0 < 1mTorr$) dc multidipole argon discharge plasma. Results indicate that the transverse temperature doubles as the ions transit the presheath. The metastable argon ions in the $3s^2 3p^4(3P)3d\ ^4F_{7/2}$ state are found to be characterized by a Maxwellian temperature transverse to the direction normal to the plate. For a neutral pressure of 0.3mTorr, **the transverse temperature increases along the presheath from 0.026 eV in the bulk plasma to 0.058 eV at the presheath sheath boundary.** This result is compared with the PIC code simulation results of Meige[1] et al., and the experimental LIF results of the Clare[2] et al.

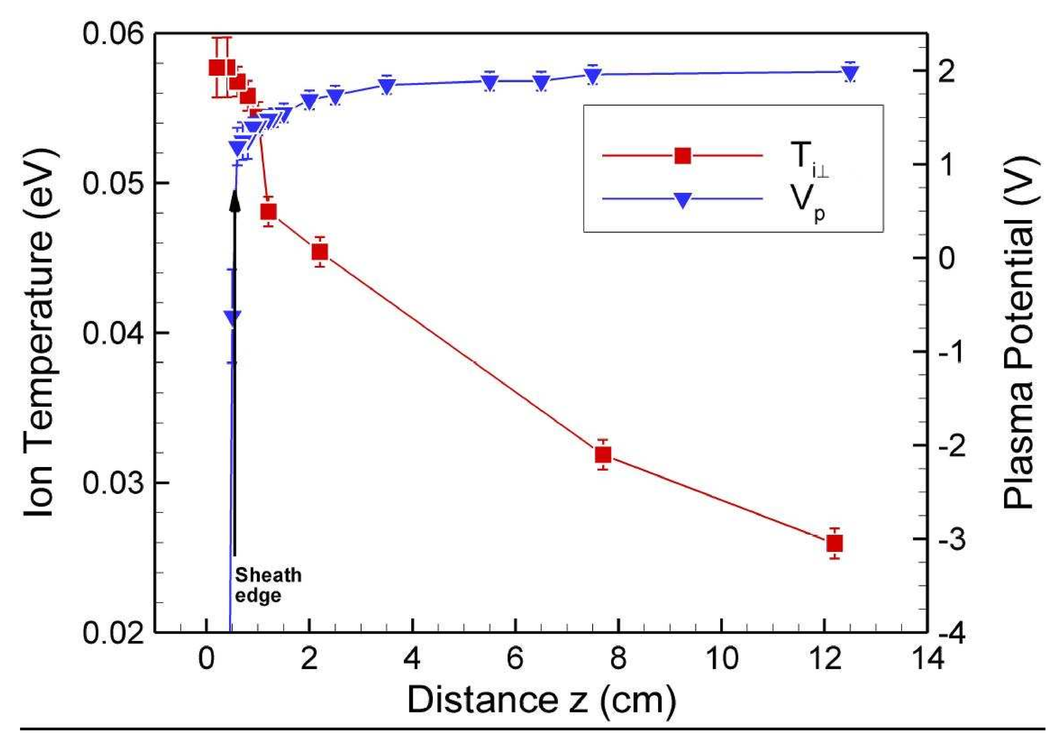


FIGURE 1: LIF measurements of the perpendicular ion temperature demonstrates that $T_{i\perp}$ doubles through the presheath, a bigger change than what was previously thought was the case for weakly collisional, low temperature plasmas.

What is the basic plasma physics problem here, and why do we care about it?

The basic question is this: **how is ion anisotropy ($T_{i\perp} \ll T_{i\|}$) affected as ions transit the presheath?** In some experiments, $T_{i\perp}$ is significantly affected, in others, not at all. How can we understand sets the fundamental, irreducible limit to the anisotropy of the ion velocity distribution function at the sheath edge? The question is important because a critical requirement of plasma etching employed in semiconductor processing is that it is highly anisotropic in order to achieve the high aspect ratio submicron features characteristic of ultralarge scale integration (ULSI). And high etching anisotropy implies $T_{i\perp} \ll T_{i\|}$.

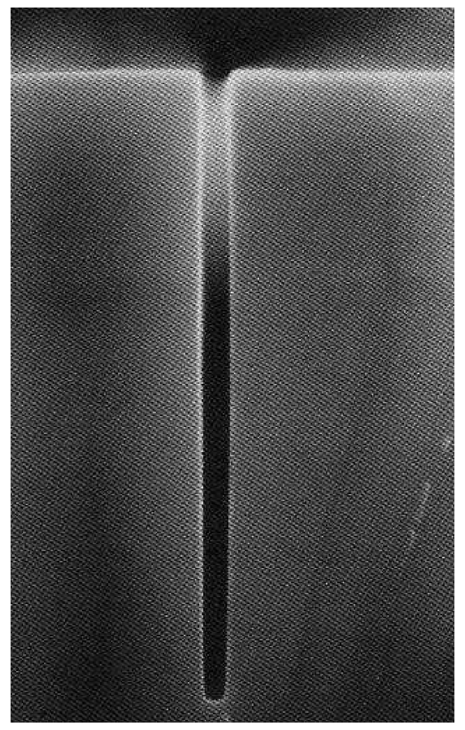


FIGURE 2: This is the first figure in Lieberman's[3], 2nd ed., showing a $.2\mu m$ by 4 μm trench etched in single-crystal Si.

In what follows we describe Laser-induced fluorescence (LIF) measurements of the perpendicular ion velocity distribution functions (ivdfs), and compare our results to simulations and other experiments

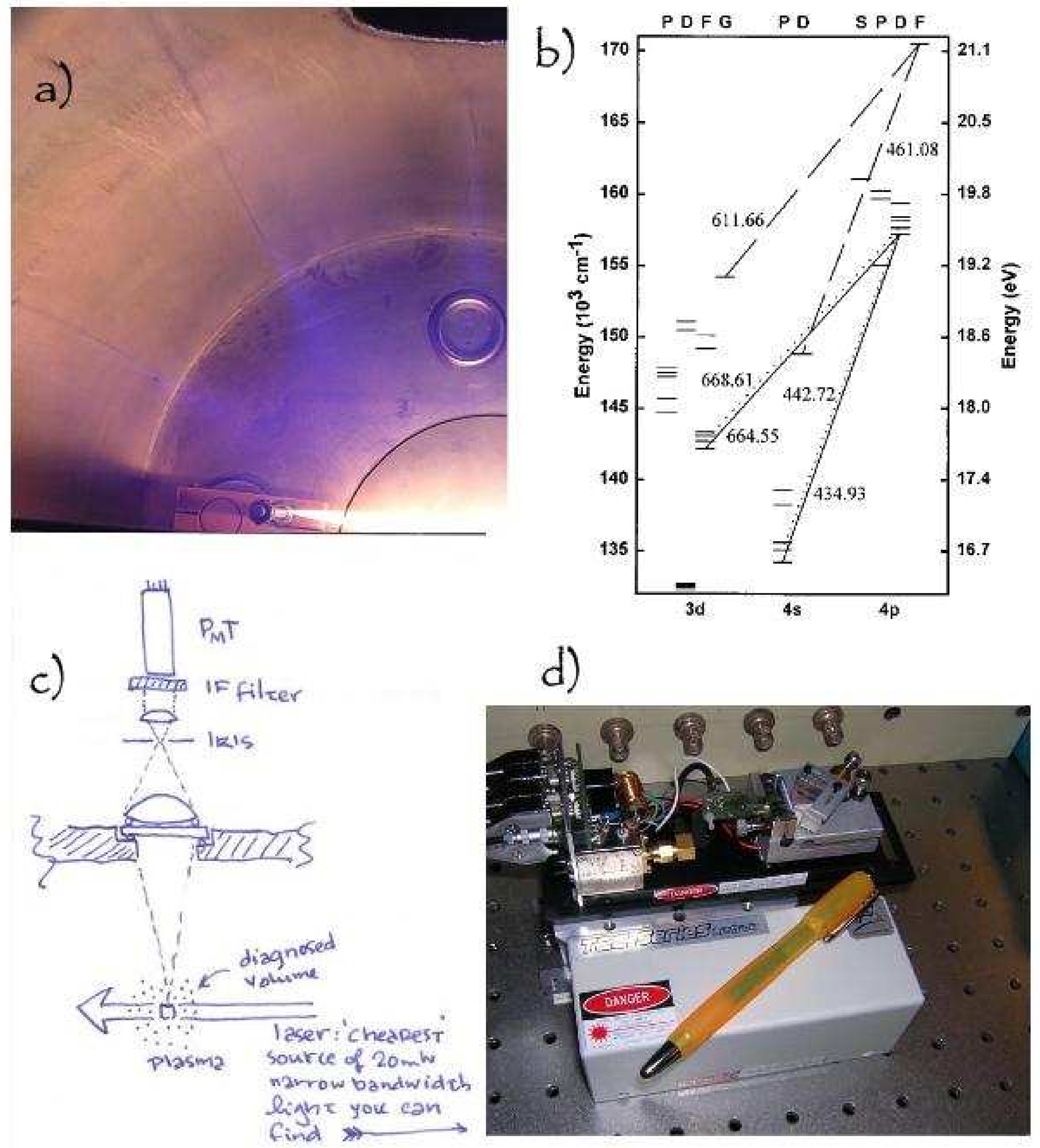
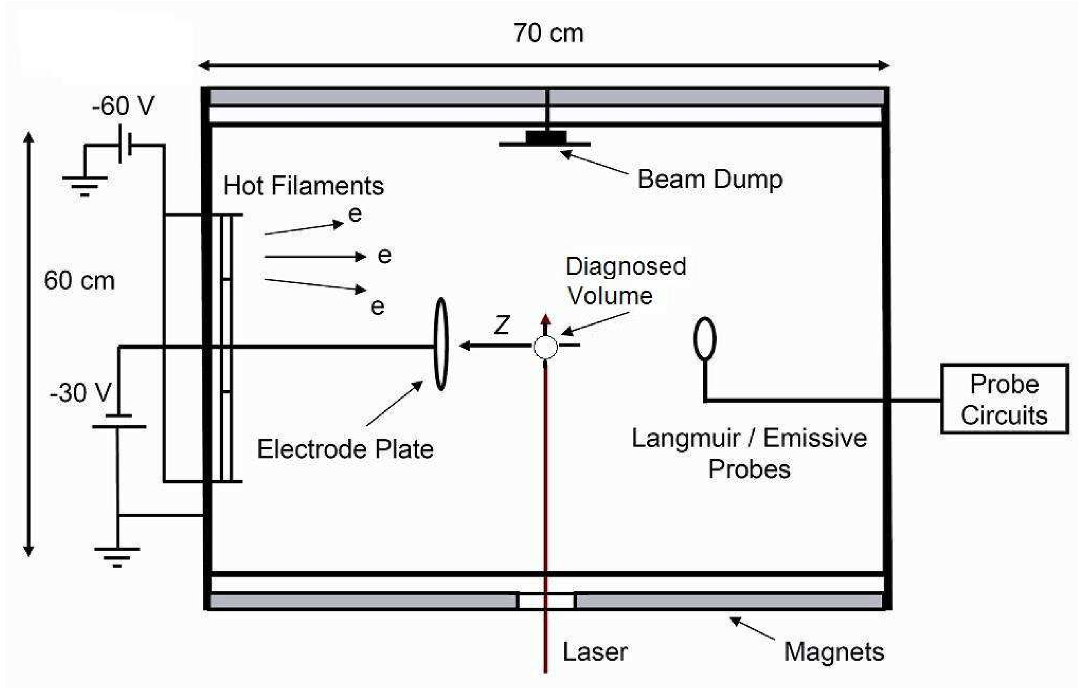


FIGURE 3: These experiments were done in Wisconsin and at USD. One needs a (a) low temperature ($T_e < 1eV$), low pressure ($p_0 < 1mTorr$) DC multi-dipole argon discharge plasma (b) a set of atomic energy levels sufficiently 'populated' to provide an LIF signal, (c) collection optics, and (d) a narrow bandwidth tunable laser with enough power (P¿15mW).

Measurement of the perpendicular ivdfs reveal significant broadening and reduced signal amplitude...



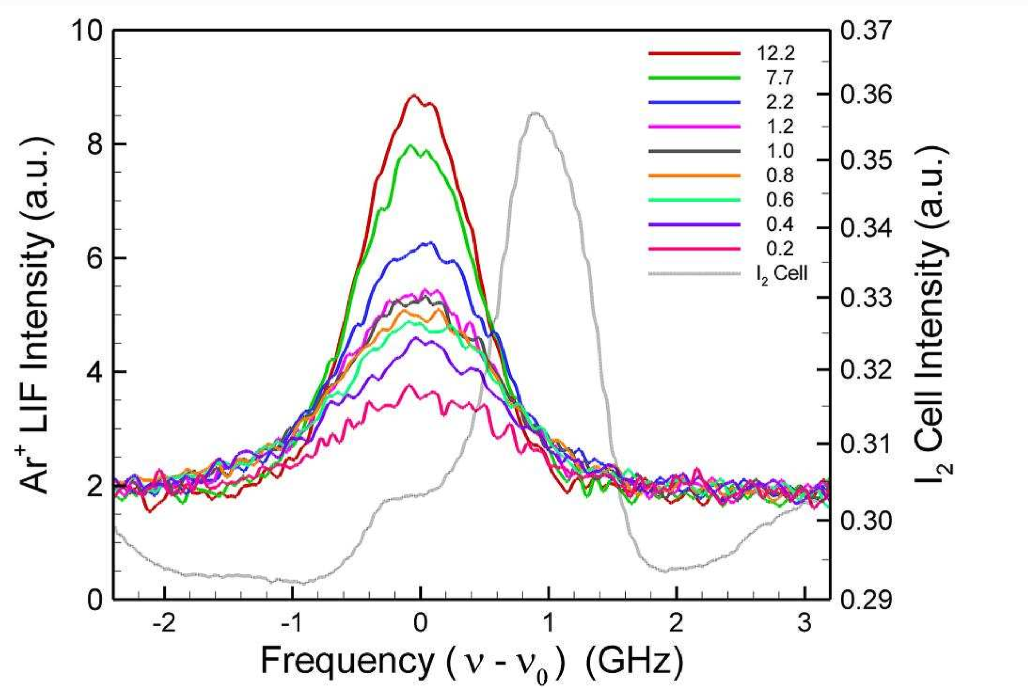


FIGURE 4: Transverse ion velocity distribution functions (tIVDFs)measured at different z positions. The detuning frequency, $\Delta\nu = \nu - \nu_0$, is directly proportional to the transverse ion velocity; $v_t = \lambda_0 \Delta\nu$. The numbers in the legend are in units of centimeters. The fluorescence spectrum from the iodine cell is used for wavelength calibration.

Perpendicular ion temperature (calculated from FWHM) increases significantly as the ions transit the presheath, growing by a factor of 2. This is the principal result of this work.

We take

$$T_{i\perp} = \frac{m_i c^2}{8 \ln 2}\left(\frac{\Delta\nu 1/2}{\nu_0}\right),$$

and observed that as the parallel ion flow speed to the sheath edge increases, the ions spend less time in the diagnosed volume[4], accounting for the reduced signal,

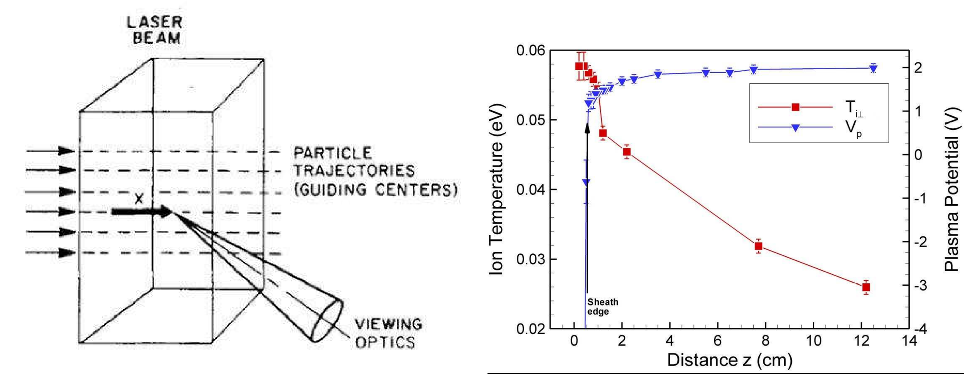


FIGURE 5: The plasma potential profile and the transverse ion temperature as a function of the position z. The sheath edge is detected at $z = 0.45 \pm 0.05cm$.The transverse ion temperature associated with the ion motion perpendicular to the surface normal is $0.026 \pm 0.001eV$ in the bulk, and $0.058 \pm 0.002eV$ at the sheath edge, an increase of slightly more than a factor of 2.

Other experiments and simulations agree when perpendicular elastic scattering (which increases as kT_e diminishes) is taken into account.

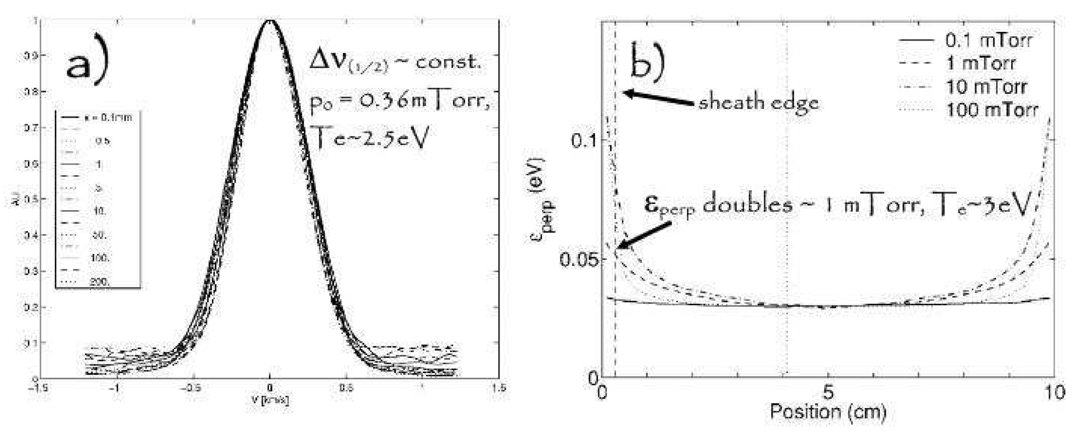


FIGURE 6: (a) Claire[?], et al., showed that in an Ar+, multipolar DC, 0.36mTorr, $kT_e \sim 2.5eV$plasma, $T_{i\perp}$ unchanged throughout the presheath. (b) The PIC simulation of Meige[1], et al., estimates how the $T_{i\perp}$ increase depends of neutral pressure (0.1-100mTorr). It would appear that both simulation and experiment suggests that we should've seen a smaller increase in $T_{i\perp}$. But it both of these cases, the higher kT_e leads to higher ion flow speeds and thus lower perpendicular elastic scattering.

References

[1] A. Meige, O. Sutherland, H. B. Smith, and R. W. Boswell, Phys. Plasmas, 14, 032104 (2007)

[2] N. Claire, G. Bachet, U. Stroth, and F. Doveil, Phys. Plasmas, 13, 062103 (2006)

[3] M.A. Lieberman and A.J. Lichtenberg, p2, in *Principles of Plasma Discharges and Materials Processing*, Wiley, New York

[4] R. A. Stern, Phys. Fluids 21, 1287 (1978)

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