NOTES

BRIEF contributions in any field of instrumentation or technique within the scope of the journal should be submitted for this section. Contributions should in general not exceed 500 words.

End-loss analyzer for plasma diagnosis

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An end-loss analyzer to study the plasma escaping from a magnetic mirror has been constructed at low cost. It consists of 163 independently biased Langmuir probes arranged in a honeycomb array.

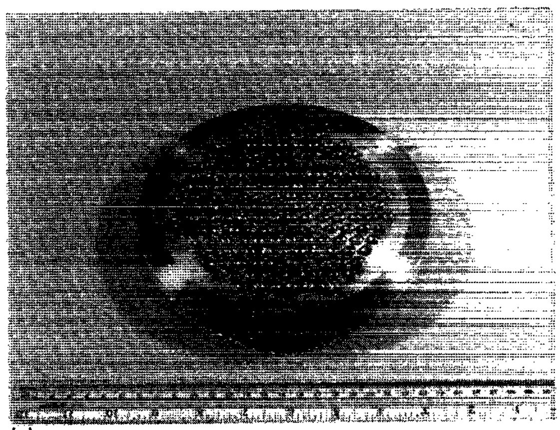
In order to study cross-field transport[1,2] and line tying of interchange modes[3–6] in a mirror trapped plasma, we have constructed an end-loss analyzer (ELA) located at the end wall of our vacuum chamber.[7] The ELA might also be used to perform axial feedback on flute modes,[8] or to excite ion-cyclotron waves.[9] The low cost of this design might make it useful for other small plasma experiments (with or without a magnetic field). The ELA is especially appropriate for pulsed, repeatable experiments where only one or two probes need be sampled at each pulse. The materials for the ELA cost about $85.

The ELA consists of 163 insulated machine screws which penetrate the vacuum system, as shown in Figs. 1 and 2. An aluminum flange of thickness 1.27 cm and diameter 15.2 cm was drilled with 163 holes of diameter 0.476 cm. The holes were spaced 0.952 cm apart in a honeycomb (hexagonal) array. A size 8-32 round head screw made of nonmagnetic 304 stainless steel serves as a Langmuir probe of area 0.45 cm^2. A viton O-ring (size AS#005) makes a vacuum seal beneath the screw head. Each screw was lathed down to a diameter of 0.32 cm near the head to accommodate the inner diameter of the O-ring. A standard nylon shoulder washer[10] insulates the brass nut from the flange. It is important not to overtorque the nut; otherwise the O-ring would be squashed out beyond the screw head where it would be exposed to the plasma.

We were unable to measure the actual leak rate of the ELA, but did obtain an upper bound by observing the rising pressure in a closed chamber. The leak rate VP/t is due to all leaks (real and virtual) in the system, where V is the volume of the chamber (44 ℓ) and P is the pressure obtained after time t.[11] Figure 3 shows that the leak rate is about 1.3×10^{-5} Torr ℓ/s, regardless of whether the ELA was in place. The leak rate appears to be lower with the ELA installed, probably because the system was pumped to a base pressure of 5×10^{-7} Torr before each measurement, so that the measurement with the ELA was made after three additional weeks of pumping. Since our vacuum chamber has a pumping speed of 196 ℓ/s, the upper-bound value of the ELA leak rate (1.3×10^{-5} Torr ℓ/s) theoretically increases the pressure by only 6.6×10^{-8} Torr.[11]

The ELA has performed satisfactorily after two years of operation. We clean lithium oxide off the ELA by immersing it is water for 20 min and scrubbing with a nylon brush. The operating pressure for most experiments is about 2×10^{-6} Torr and continues to independent of whether the ELA is in place.

The I-V characteristic of a probe resembles that of a standard Langmuir probe, except that the ion current does not completely "saturate" at negative bias. This may be


(a)

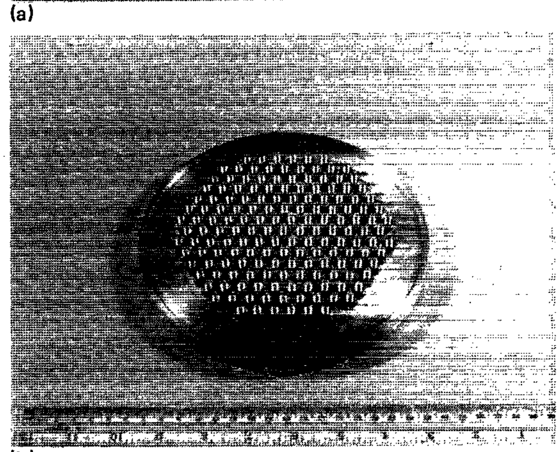

(b)

FIG. 1. Photograph of the ELA, showing 163 buttons on a vacuum flange: (a) the side facing the vacuum, (b) the air side.

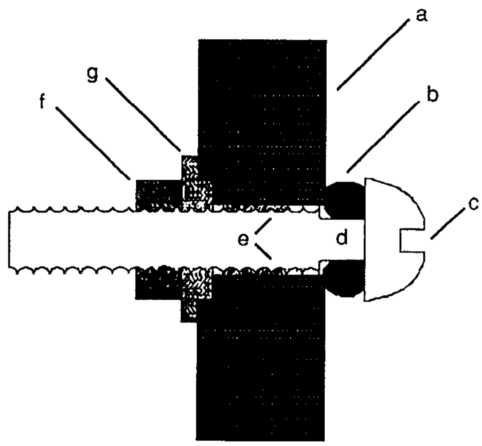


FIG. 2. Vacuum seal for each button: (a) aluminum vacuum flange, (b) viton O-ring, (c) stainless-steel screw-head facing plasma, (d) portion of screw lathed down to accommodate O-ring, (e) heat shrink tubing, (f) brass nut, (g) nylon shoulder washer.

due to the low plasma density and correspondingly long Debye length ($\sim$0.3 cm).[12] A full discussion of how the ELA interprets interchange modes is beyond the scope of this paper, and must also consider finite k-parallel effects[13] and the fact that the ion transit time is comparable to the mode evolution time.

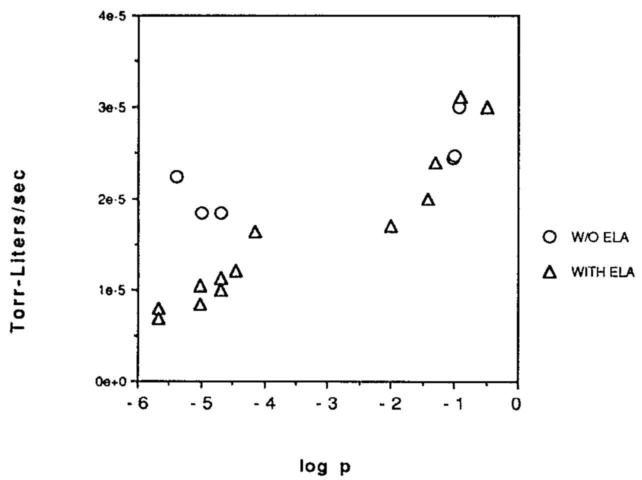


FIG. 3. Average leak rate vs the maximum pressure (measured in Torr) reached in the sealed off vacuum chamber. The triangles and circles represent the leak rate with and without the ELA, respectively.

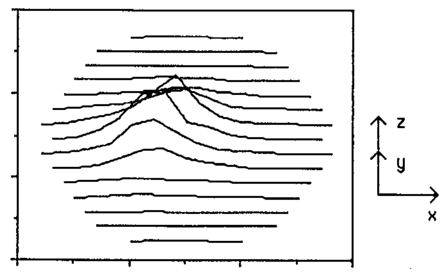


FIG. 4. Radial profile from the ELA for an argon plasma with the source in the PIG mode. The x and y axes denote the position of the button on the hexagonal array. Each curve represents a density profile obtained by moving horizontally along 6 to 14 buttons in a row. The graph can be viewed as a three-dimensional graph with plasma density plotted on the z axis, where the coordinate system is viewed in the yz plane at an angle of 20° from the z axis. The peak density at the center corresponds to an "ion saturated" current of 6×10^{-6} A to ground, which yields an estimated plasma density of 2×10^{7} cm^{-3}.

Figure 4 shows a steady-state density profile of a low-density source operated in the "PIG" mode.[7] Since this plasma has a large negative space potential, we obtained the profile by grounding the probes through a 56 kΩ resistor and measuring the current. We also made a 20 frame "movie" of a pulsed plasma produced by the source in the "contact ionization mode."[7] The plasma was pulsed off 60 times per second while recording the ion-saturation signal on an oscilloscope. A video camera recorded the signal from each button for about 10 s. The signals were then converted into a 25 frame "movie" on a VCR tape using an Omega video computer.

[1] M. Rosenbluth and A. Simon, Phys. Fluids **8**, 1300 (1965).
[2] Miguel Galvez and Christopher Barnes, Phys. Fluids **31**, 863 (1988).
[3] G. Vandegrift and T. Good, Phys. Fluids **29**, 550 (1986).
[4] J. C. Glowienka, W. C. Jennings, and R. L. Hickok, Phys. Fluids **31**, 2704 (1988).
[5] Yutaka Kadoya and Hirotada Abe, Phys. Fluids **31**, 894 (1988).
[6] G. Vandegrift, Phys. Fluids B **1**, 2414 (1989).
[7] G. Vandegrift, Kathy Donahue, and Debra Velat (unpublished).
[8] M. A. Lieberman and S. K. Wong, Plasma Phys. **19**, 745 (1977).
[9] R. McWilliams, M. K. Okubo, and N. S. Wolf, Phys. Fluids **29**, 3031 (1986).
[10] The stainless-steel screws and nylon shoulder washers were purchased from McMaster-Carr, P.O. Box 440, New Brunswick, NJ 08903-0440.
[11] Saul Dushman and J. M. Lafferty, *Scientific Foundations of Vacuum Technique* (Wiley, New York, 1962).
[12] I. H. Hutchinson, *Principles of Plasma Diagnostics* (Cambridge University, New York, 1987), pp. 50–86.
[13] M. Whickam and G. Vandegrift, Phys. Fluids **25**, 52 (1982).