Z-Pinch Discharge in Laser Produced Plasma

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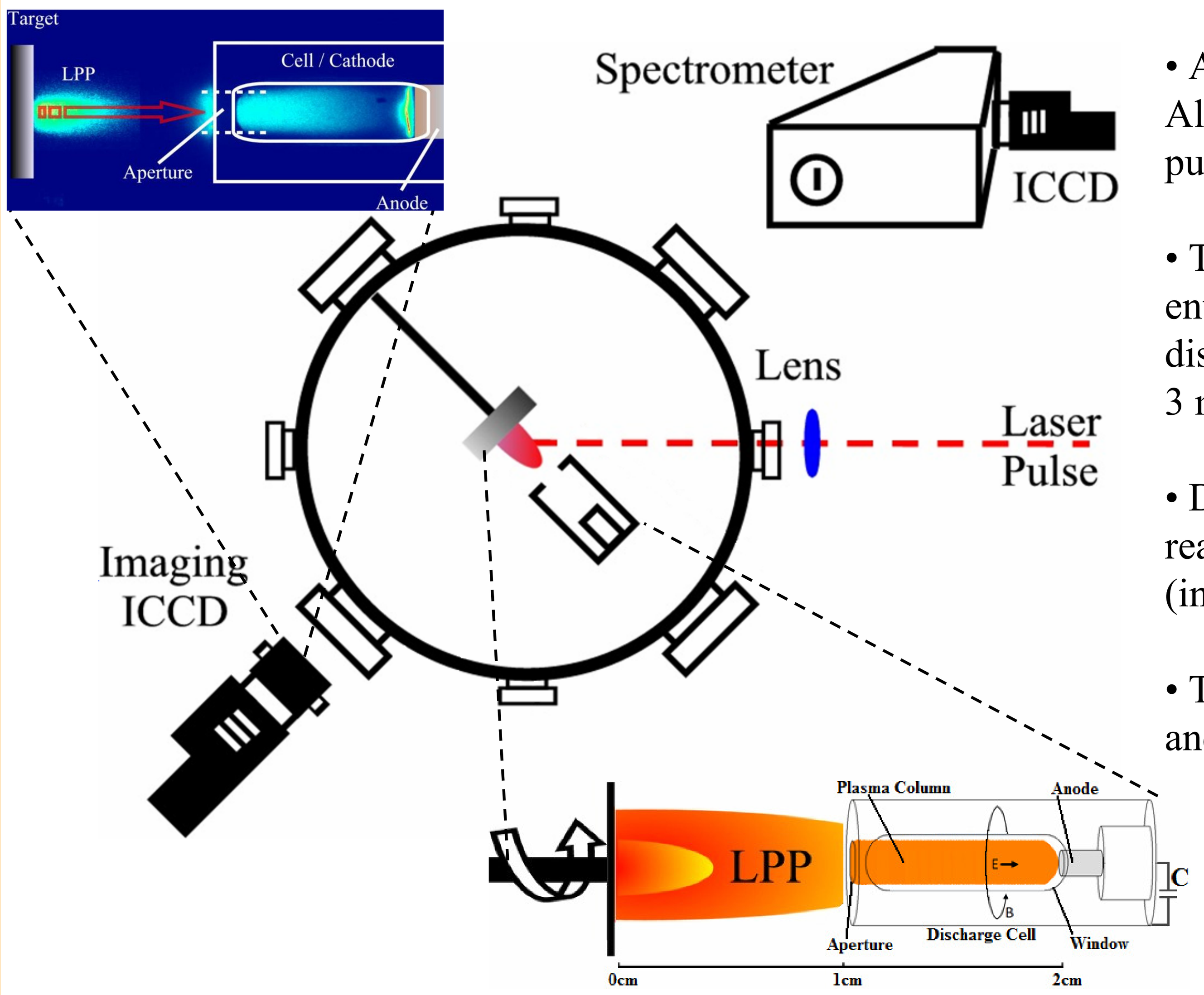
A fast coaxial discharge is used to produce a Z-pinch in a laser produced aluminum plasma. A 3mm aperture was used to collimate the plasma plume as it enters the discharge cell. Z-pinch dynamics were recorded using time-resolved imaging and time- and space-resolved spectroscopy. Ion density profiles were derived from Langmuir probe signals using self-similar transforms. The behaviour of the pinch is compared and with the predictions of the slug model*.

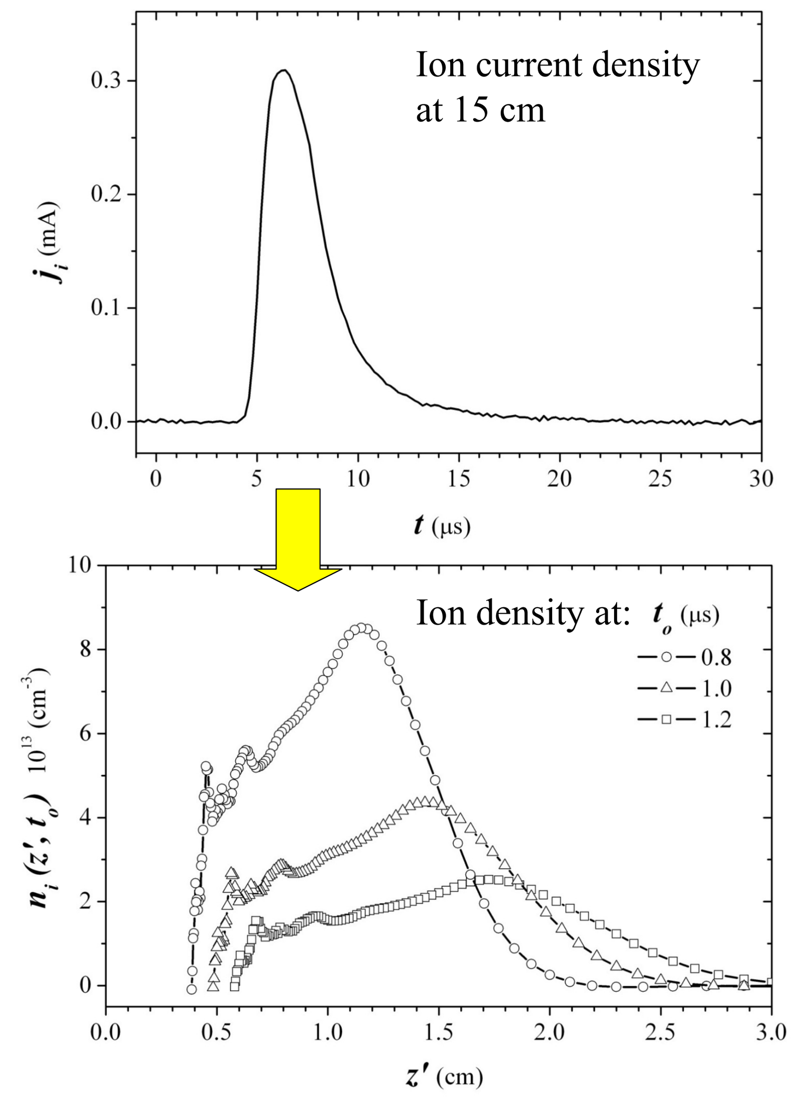
*D. Potter, *Nuclear Fusion*, **18**, 813–823 (1978).

Experimental Setup



- A laser plasma is produced from an Al rotating target using an excimer pulse, λ = 248 nm.
- The laser plasma is collimated as it enters the electrically grounded discharge cell, 1 cm away, producing a 3 mm plasma column.
- Discharging ensues as plasma column reaches the inner "live" electrode (inter-electrode gap is 1 cm).
- Time- and space- resolved imagine and spectroscopy.

Langmuir Ion Probe Analysis



The ion current on the probe is given by:

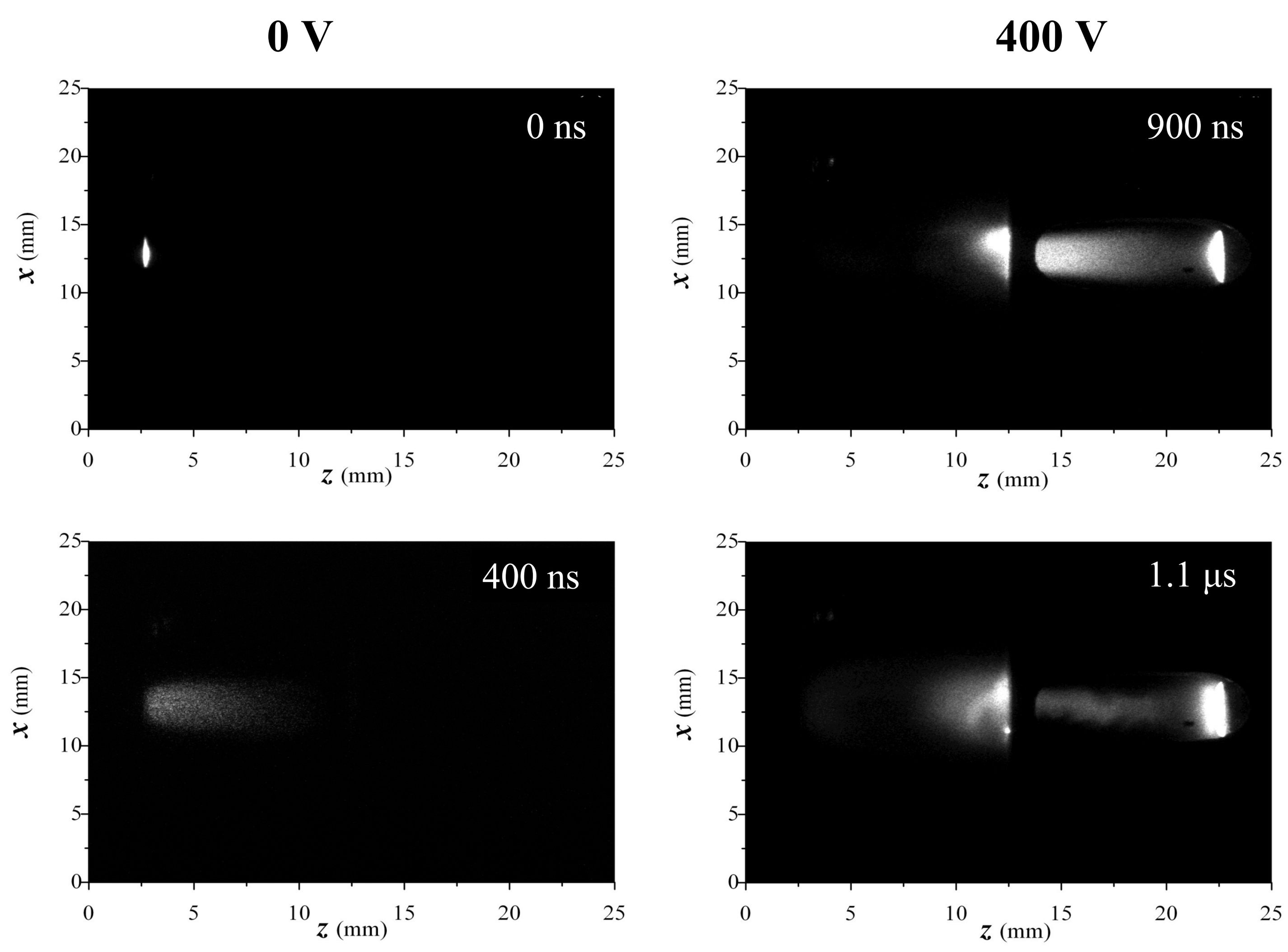
$$I_i(t) = n_i(z_p, t) A_p v_i e$$

Assuming the plume expansion is self-similar the ion current density at time, $t = t_0$, is given by:

$$n_i(z', t_0) = n_i(z_p, t) \times (t/t_0)^3$$

$$z' = z_p\,(t_0/t)$$

ICCD Imaging and Spectroscopy



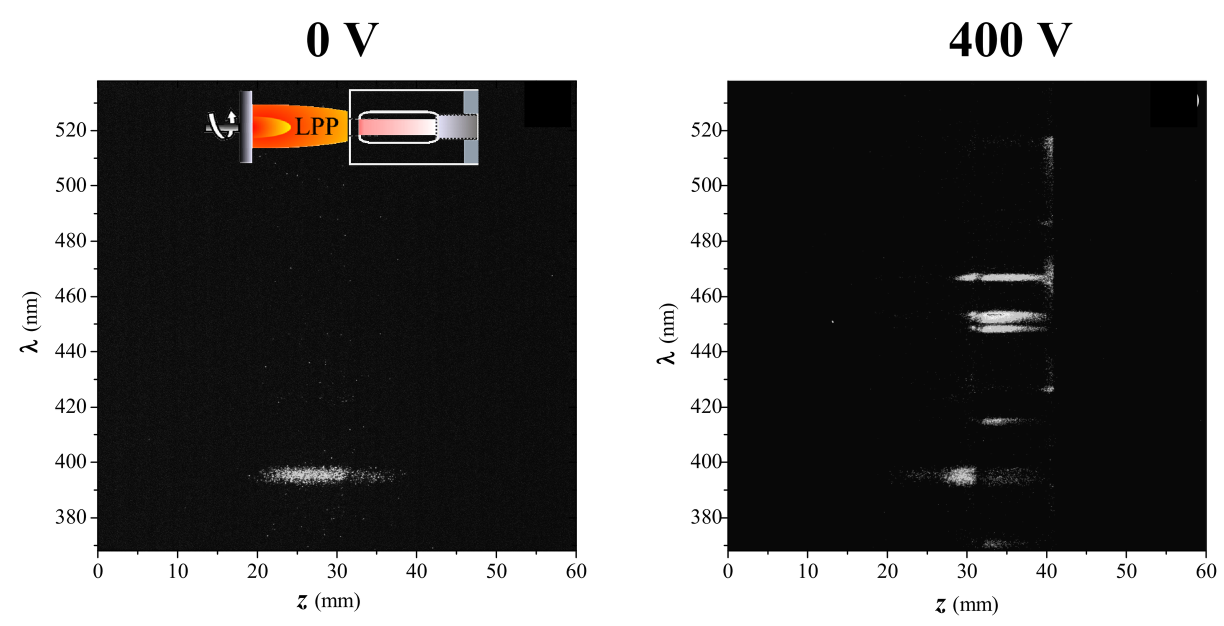
Laser pulse arrives at Al target at Δt = 0.

Expanding laser plasma enters cell at ~600 ns through a 3 mm aperture.

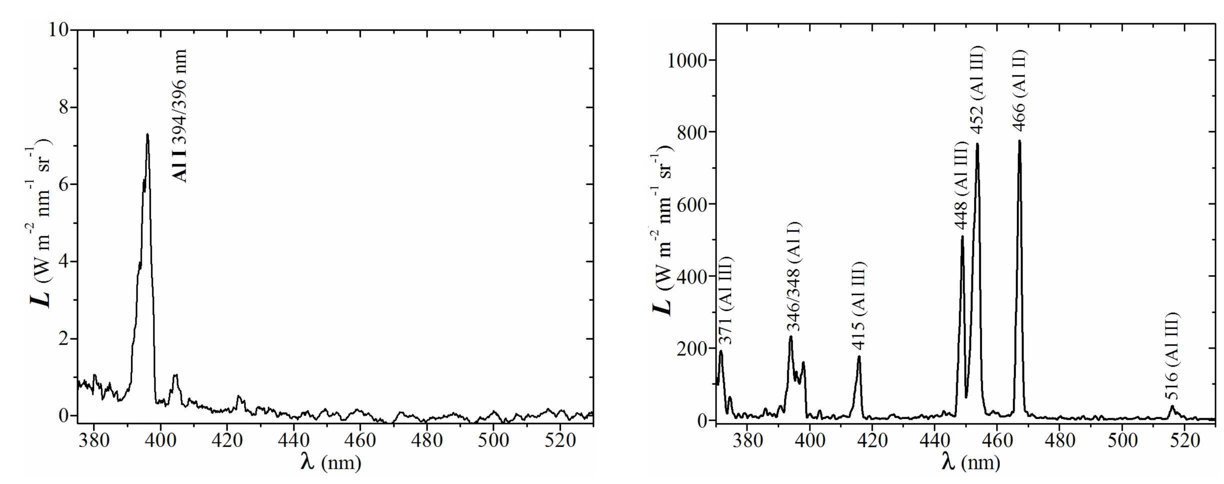
Discharge is triggered at ~800 ns, igniting the 3 mm diameter plasma column.

A highly emissive plasma is observed at 900 ns, followed by radial constriction of the column and the development of an MHD instability at 1.1 μs.

Final discharge radius is ~1 mm.



ICCD spectrum image



Lineout from inside of cell

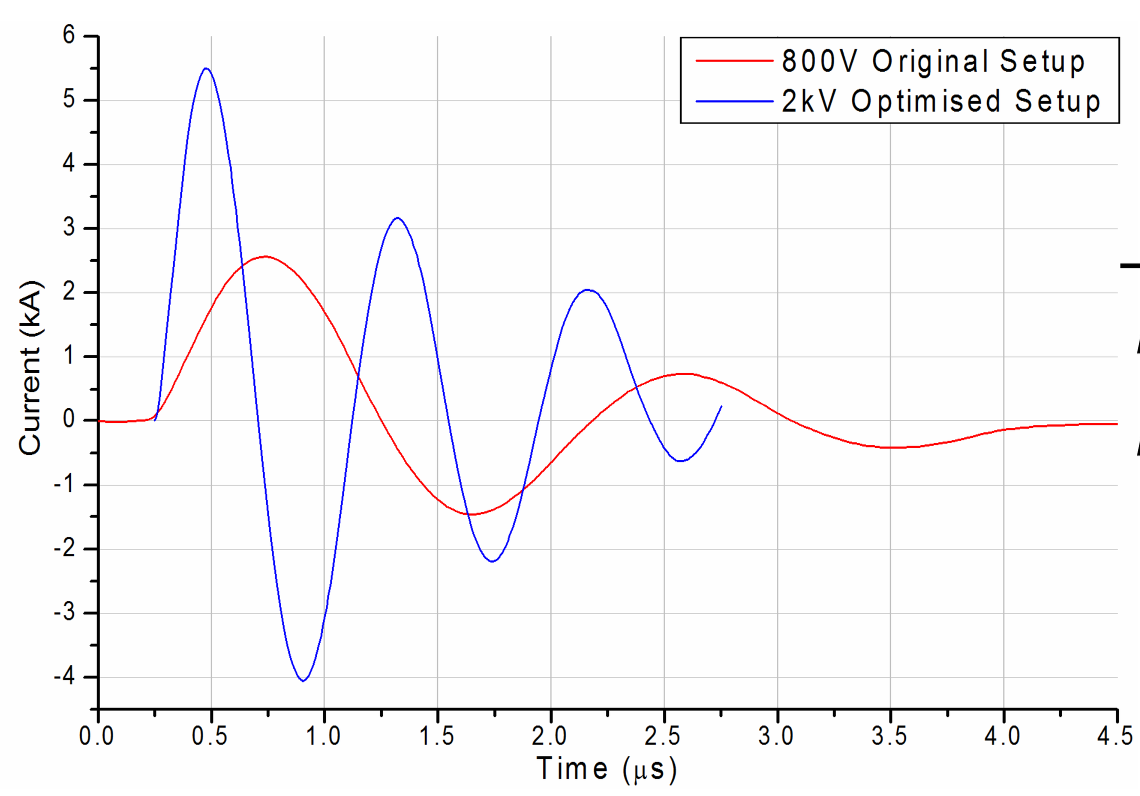
For laser plasma without discharge emission is mainly on Al I 394/396 nm lines.

With the discharge the plasma is heated to emit Al II and Al III lines.

Emission at anode shows accumulation of plasma on surface.

Faster Discharge

- By decreasing the length of the circuit loop the inductance is significantly decreased, estimates from PSPICE models show the total circuit inductance was decreased from ≈ 65 nH to ≈ 40 nH.
- The capacitance was also decreased from 1.47 μF to 0.47 μF, but using capacitors with higher voltage rating.
- Faster, higher current discharge obtained.



	Period (μs)	Temperature (eV)
Original Discharge	1.95	2.2*
Faster Discharge	0.85	3.5*

*at t = 1.1 μs in the centre of the discharge cell

Z-pinch Analysis and

Slug Model*estimates:

Time to pinch

$$t_p = 0.377\left(\frac{\rho_0}{\mu_0}\right)^{\frac{1}{2}} \frac{4\pi R_0^2}{I}$$

Final pinch radius

$$R_{\min} = R_0\left(\frac{\gamma}{\gamma+1}\right)^{\gamma/\gamma-1} = \frac{1}{3}R_0$$

γ = 5/3 – adiabatic constant; R_0 – initial column radius; ρ_0 – ion mass density; μ_0 – free space permeability

	Model	Exp.
t_p (ns)	50	200
R_0 (mm)	0.75	0.75

- Plasma density profiles at the position of the discharge cell were derived from Langmuir probe signals using self-similar transforms.
- Radial compression due to the azimuthal magnetic field was observed. The final pinch radius agrees with the prediction of Potter's slug model.
- Substantial plasma heating is observed, with the appearance of Al II and III ions for a 400 V discharge.

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