Ion sheath evolution for electrode structures in PSII*

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$$R(t) = \eta(t)\frac{d}{S} ,$$

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Abstract

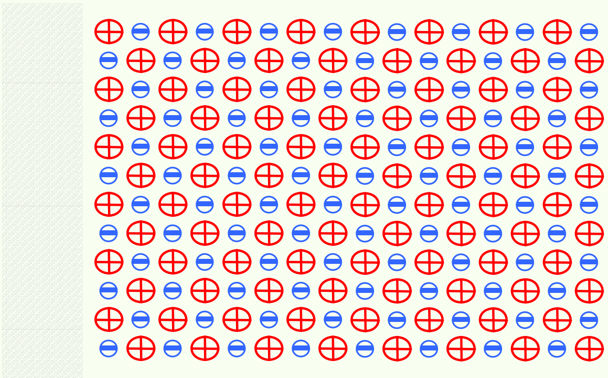
Two-dimensional spatial and temporal evolution of ion matrix sheath surrounding diverse electrodes is experimentally investigated when a sudden negative step bias is applied to electrodes.

For this experiment, the pulse modulator is used for applying a pulsed negative voltage, which is varied from 10 kV to 15 kV with a pulse width of 4 μs. In a multi-dipole plasma system of 40 cm diameter and 50 cm height, plasmas with density ranging from 10^9 cm^{-3} to 10^{10} cm^{-3} are generated by the hot filament discharge. Langmuir probes are used to determine the plasma parameters and the propagating sheath edge.

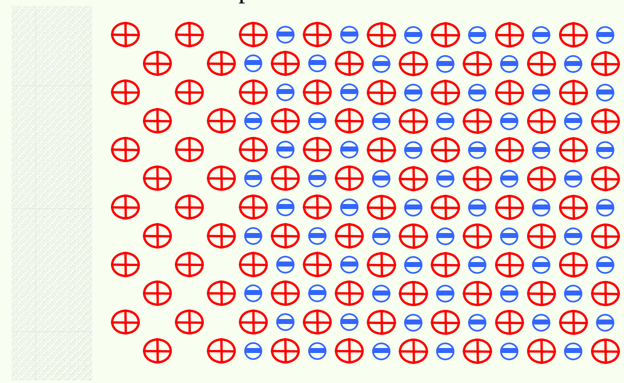
This study describes sheath evolution of the transient ion matrix sheath which forms at mesh and solid electrodes.

Behavior of transient sheath in PSII

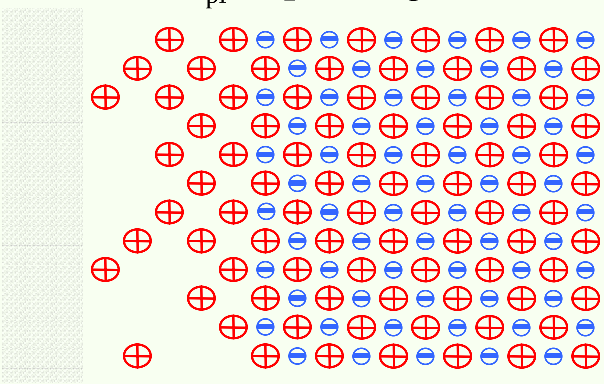
1. $t = 0$ uniform plasma



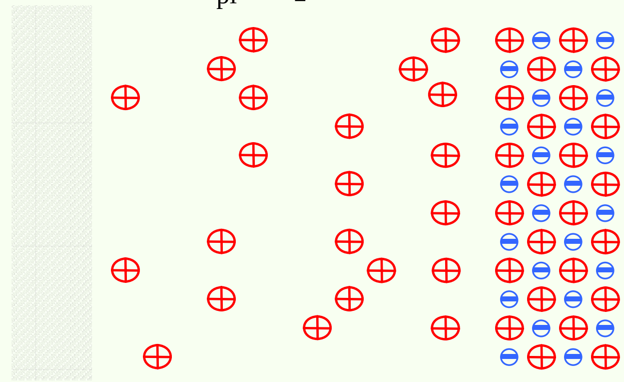
2. $t \sim 1/\omega_{pe}$ ion matrix sheath



3. $t \sim 1/\omega_{pi}$ expanding sheath



4. $t \sim 5/\omega_{pi}$ expanded sheath



Dynamic sheath propagation in PSII (1-D planar)

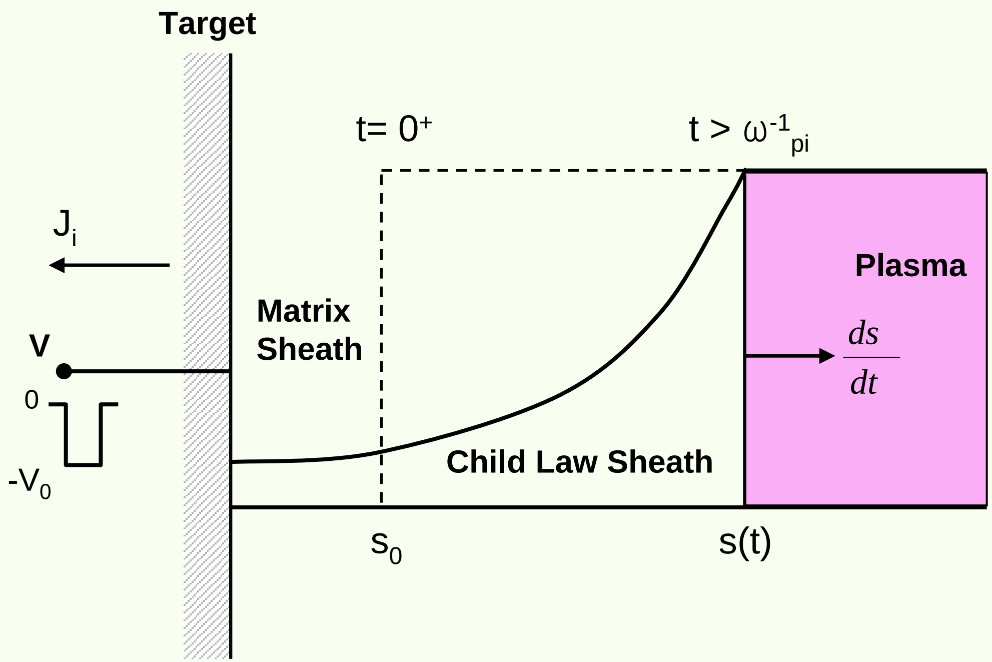
- ***Ion matrix sheath***

$$s_0 = \left(\frac{2\varepsilon_0 V}{en}\right)^{1/2} = \lambda_{De}\left(\frac{2V_0}{T_e}\right)^{1/2}$$

- ***Child-Langmuir law***

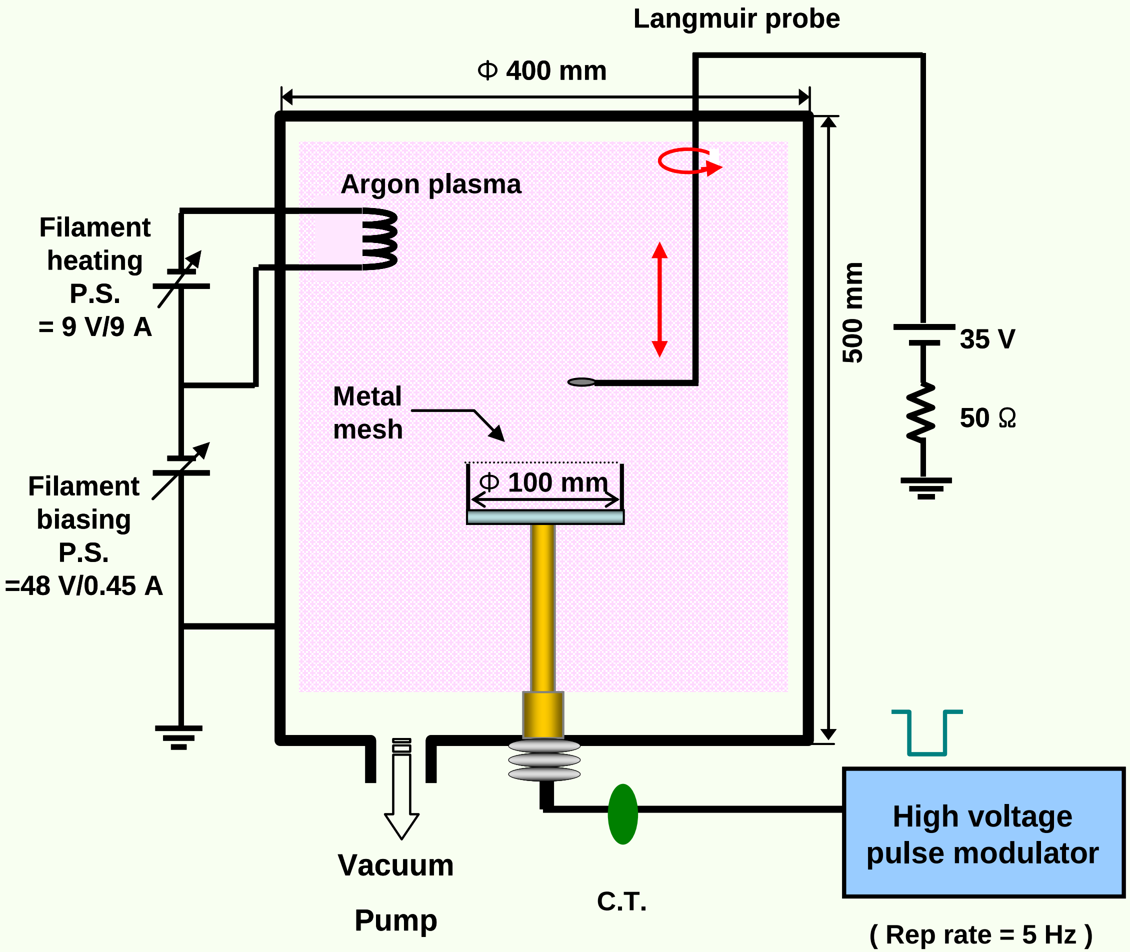
$$j = \frac{4}{9}\varepsilon_0\left(\frac{2e}{M}\right)^{1/2}\frac{V^{3/2}}{s^2}$$

$$= en\left(\frac{ds}{dt} + u_B\right)$$



Ions are implanted into the target due to the uncovering of ions at the sheath edge during sheath expansion and the ambipolar diffusion of ions toward the sheath boundary at the Bohm acoustic speed u_B=(eT_e/M).

Schematic of experimental setup



Plasma parameters

$n_e \approx 4.5X10^9 - 1.6X10^{10}\ cm^{-3}$

$T_e \approx 2.4 - 2.8\ \ eV$

$\Phi_p \approx 3 - 4\ V$

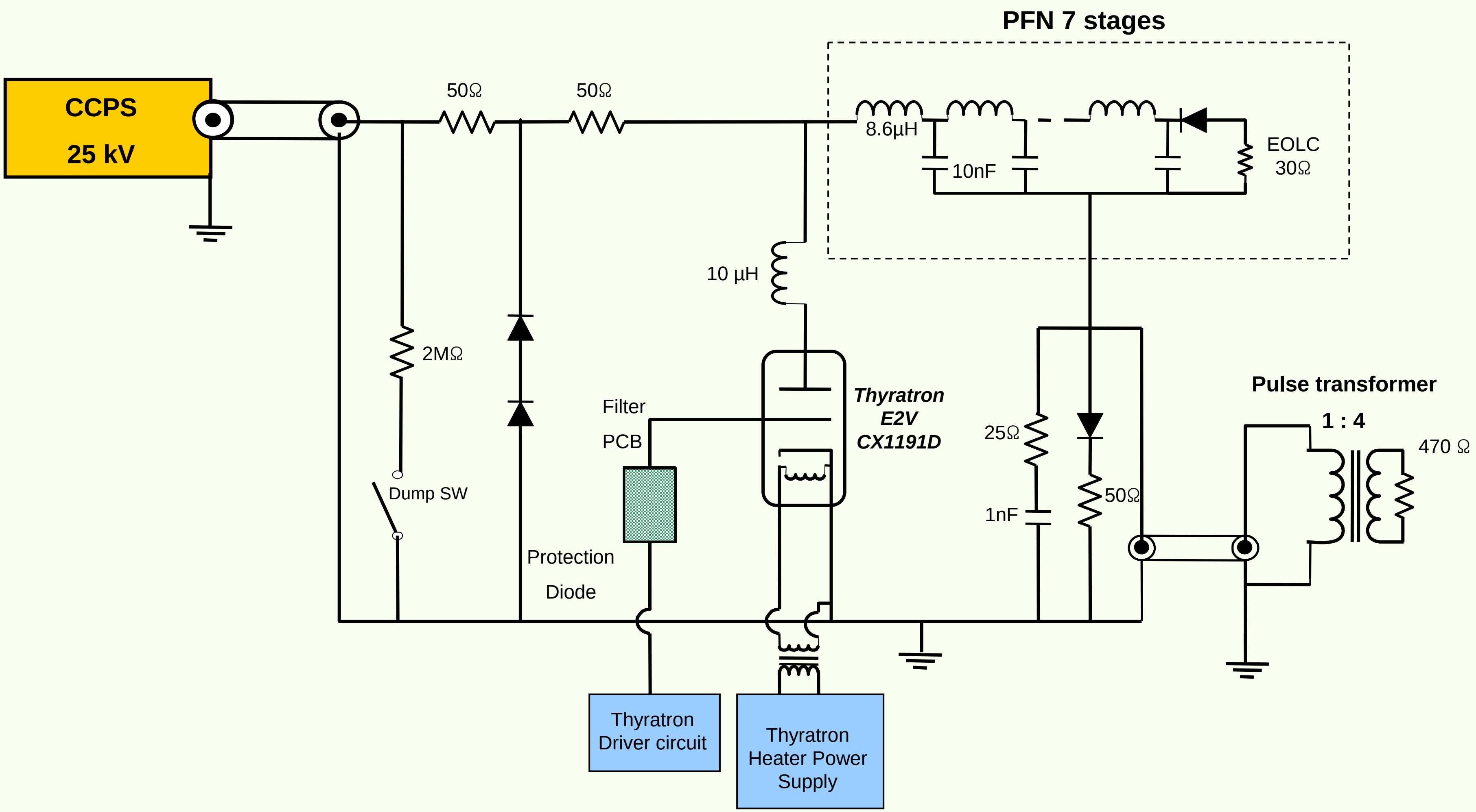
Metal mesh electrode

Wire diameter = 0.114 mm

Total diameter = 100 mm

Open area = 53.3 %

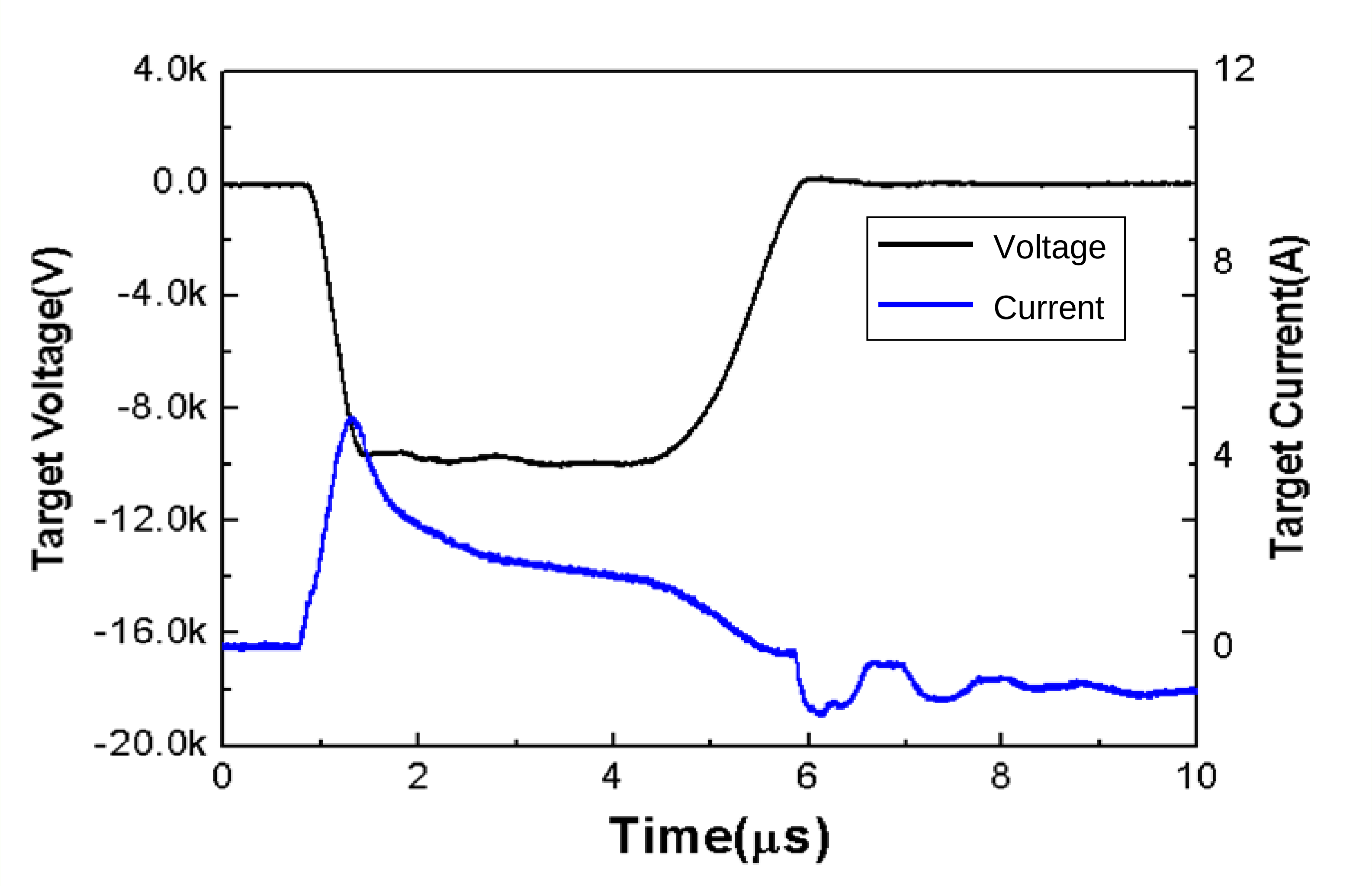
Circuit diagram of pulse modulator



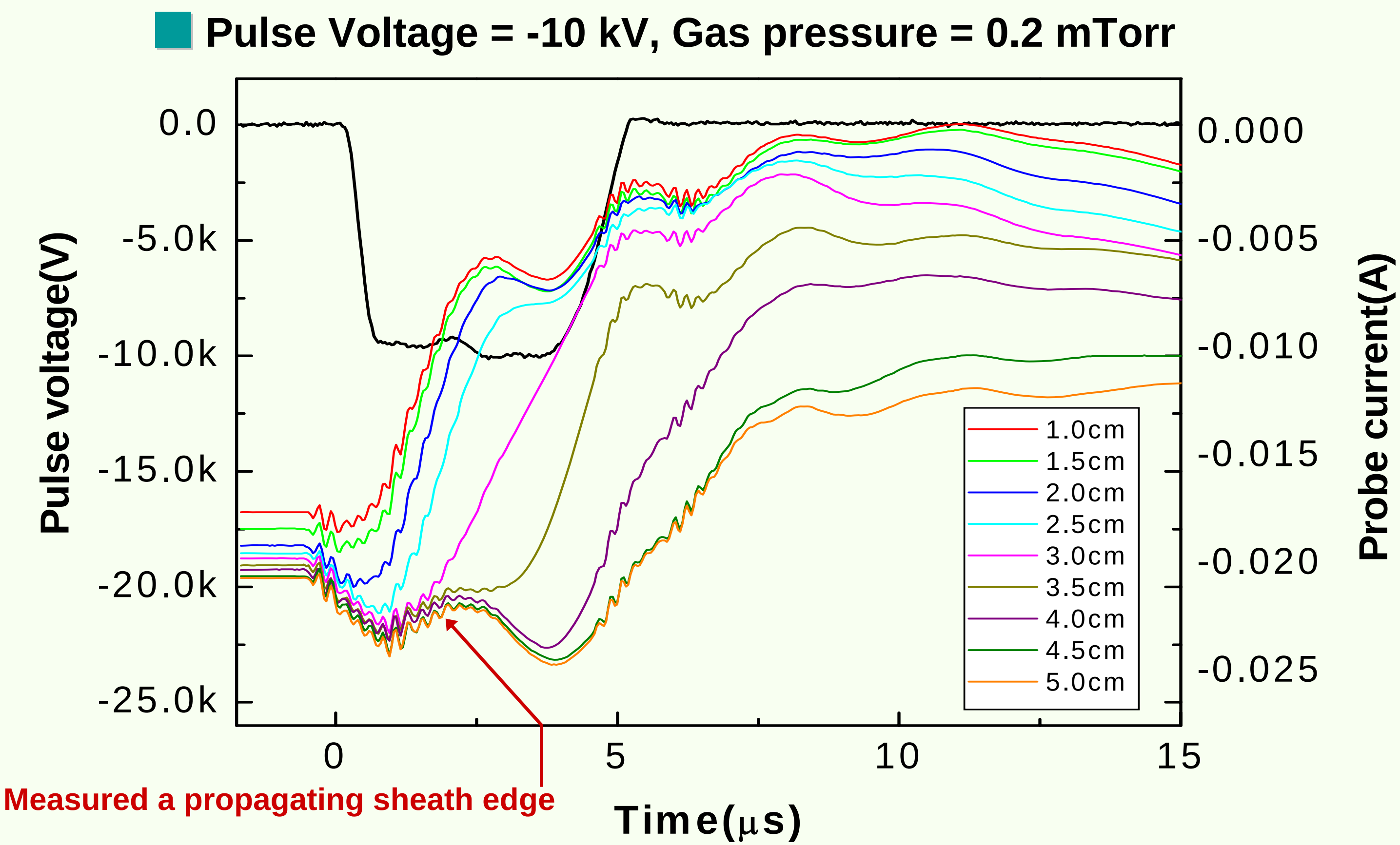
Specification of Pulse modulator

Peak voltage [kV]	45
Peak current [A]	96
Pulse energy [J]	17.3
Load impedance [Ω]	470
H.V. Pulse length [μs]	4
Max repetition rage [Hz]	200
Step-up ratio	4
PFN charging voltage [kV]	25
PFN impedance [Ω]	29.37
PFN section capacitance [nF]	10
PFN section Inductance [μH]	8.63
PFN section number	7
Charging resistance [Ω]	100
Thyratron Switch	8 MW, 35 kV, 500 A

A typical waveform of target voltage and current

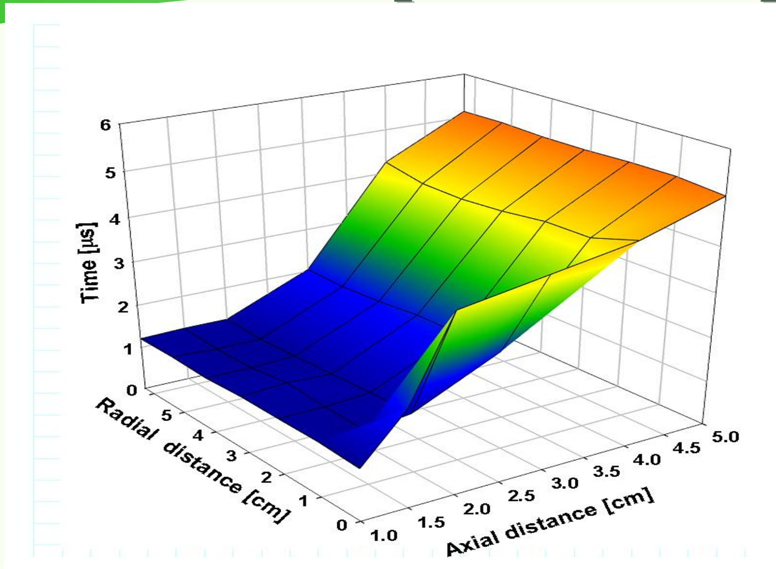


Probe currents for mesh electrode at axial distances

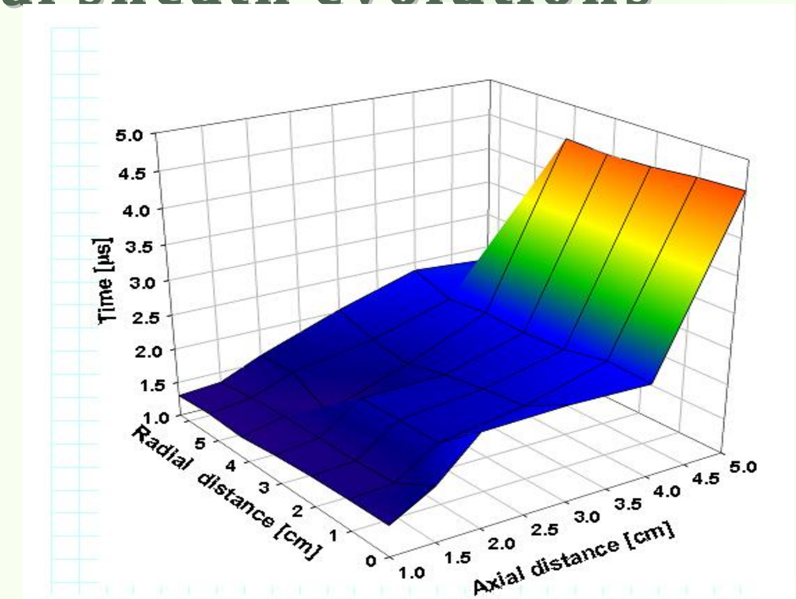


The arrival of the sheath edge to the probe is indicated by a depletion in the electron current.

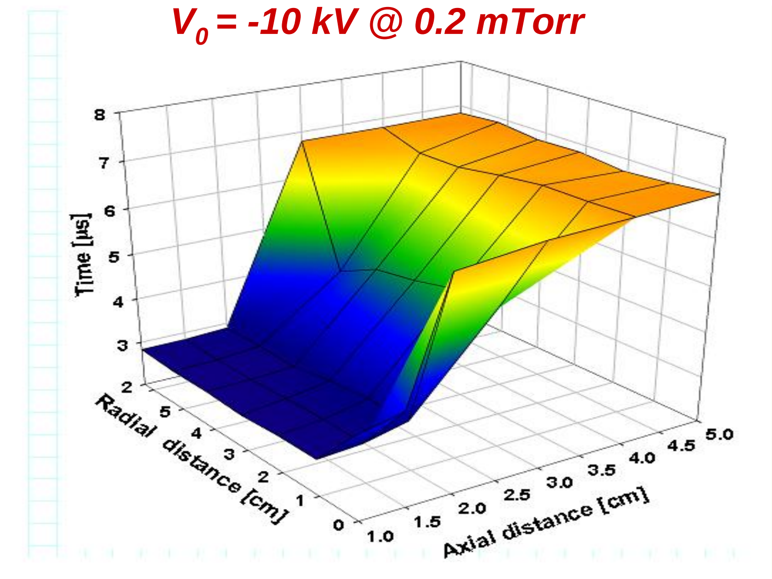
Temporal and spatial sheath evolutions



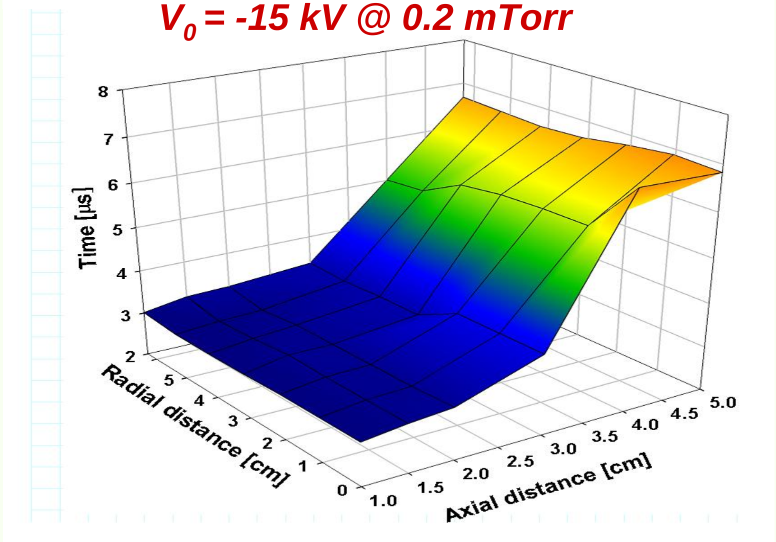
V_0 = -10 kV @ 0.2 mTorr



V_0 = -15 kV @ 0.2 mTorr



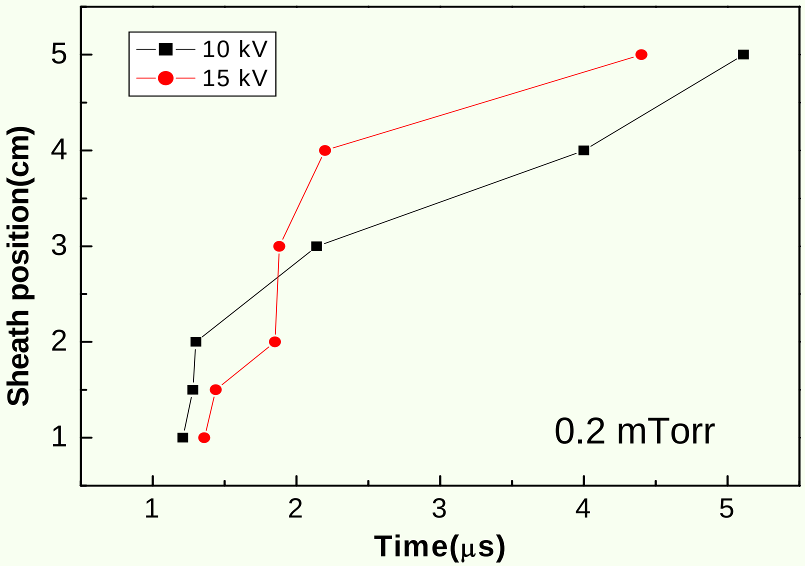
V_0 = -10 kV @ 0.3 mTorrr



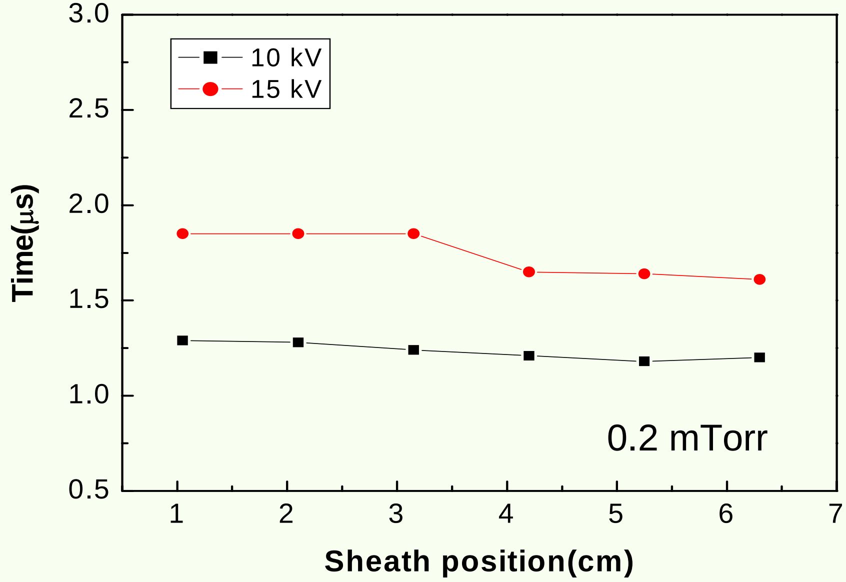
V_0 = -15 kV @ 0.3 mTorrr

Sheath expansion for mesh electrode

- **Axial direction**



- **Radial direction**



The velocity of sheath edge is 2.2~3.6 X 10^6 cm/sec in earlier stage(~ 2 μs) at axial direction. At radial direction, the sheath thickness is uniform.

Conclusion & Future work

Conclusion

Temporal and spatial dynamic analysis of sheath propagation in a collisionless argon plasma has been performed for high voltage target bias 10-15 kV. Mesh electrode of stainless steel have been used. It has been found that the sheath edge velocity was higher than ion acoustic velocity in initial stage of sheath evolution and the latter stage was comparable to the ion acoustic velocity.

Future work

- Measurement the sheath thickness for different structures by using a Langmuir probe.
- Comparison of the experimental measurements and numerical calculation of sheath evolution for diverse electrodes.