Spatial and Temporal Behavior of the Plasma Parameters in a Pulsed Magnetron Discharge

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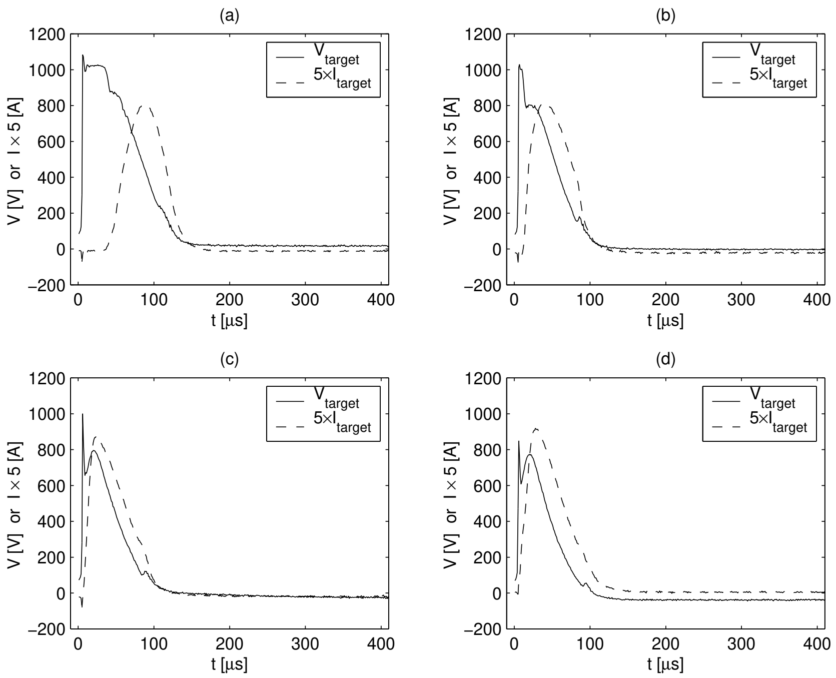
We demonstrate the evolution of the electron energy distribution and the plasma parameters in a high density plasma in a unipolar pulsed magnetron discharge

Experimental apparatus

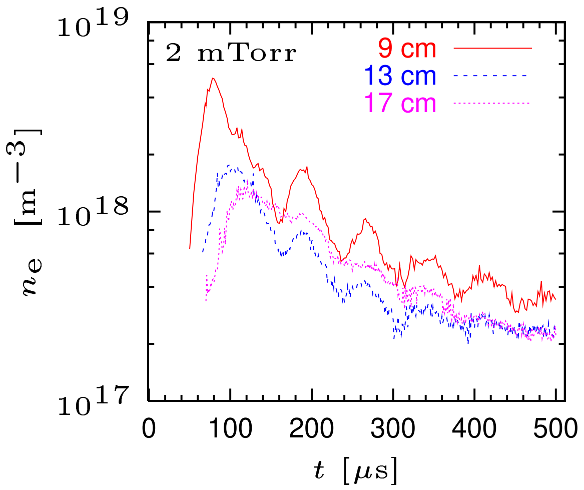
- Standard balanced planar magnetron source with a tantalum target in a stainless steel sputtering chamber of radius $R = 60$ cm and height $L = 75$ cm
- Argon pressure was varied from 0.5 – 20 mTorr
- A cylindrical Langmuir probe which is a cylindrical tungsten rod of length $l_{\mathrm{pr}} = (5.0 \pm 0.5)$ mm and radius $r_{\mathrm{pr}} = (50 \pm 1)$ μm

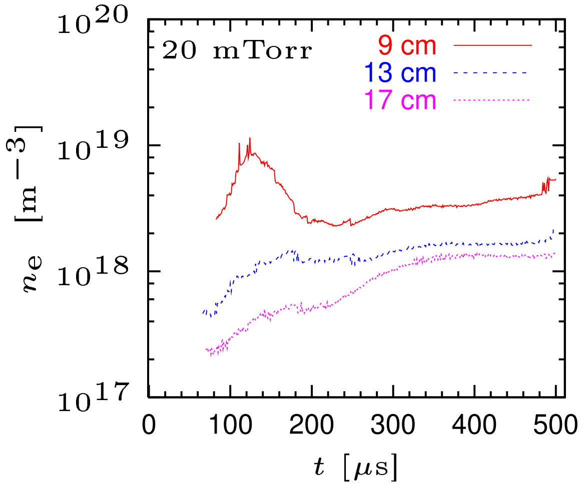
Experimental apparatus



- The magnetron cathode was driven by a unipolar pulsed power supply that can deliver peak power pulses of up to 2.4 MW (2000 V and 1200 A) at repetition frequency of 50 Hz and pulse width in the range of 50 – 100 μs.
- For the measurements presented here the average power was 300 W, pulse width 100 μs, and repetition frequency 50 Hz.

Electron density

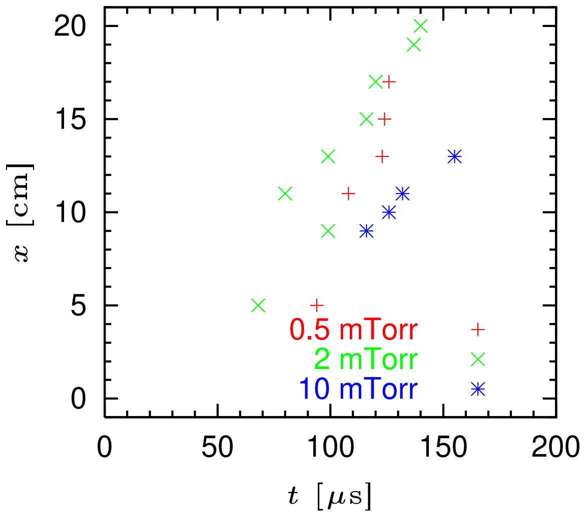




- Time evolution of the electron density depends on the discharge pressure

Distance [cm]	p [mTorr]	t [μs]	$n_{e,peak}$ [m^{-3}]
5	2	68	2×10^{19}
9	2	78	5×10^{18}
9	10	97	2×10^{19}
9	20	124	1×10^{19}

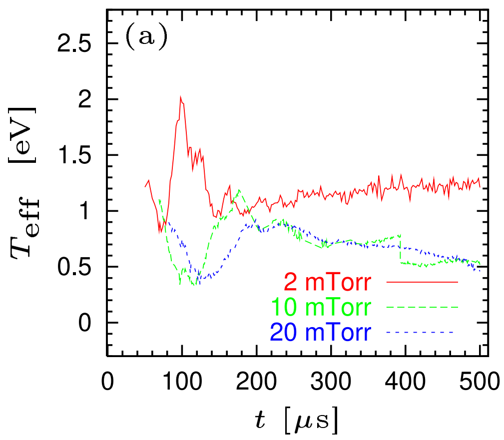
Electron density



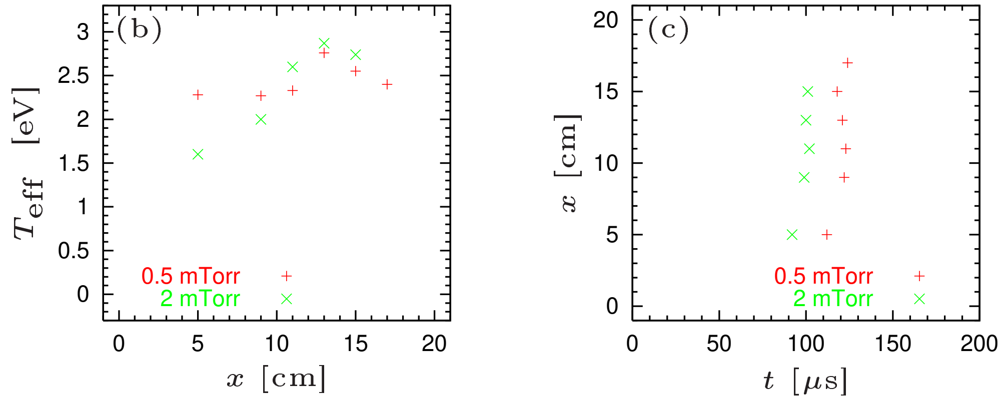
- The distance from the target versus the time difference from initiation of the pulse until the electron density peak appears
- A best fit through the data gives traveling velocity of the electron density peak

p [mTorr]	$v_{\mathrm{e,peak}}$ [cm/s]
0.5	3.2×10^5
2	1.9×10^5
10	1.0×10^5

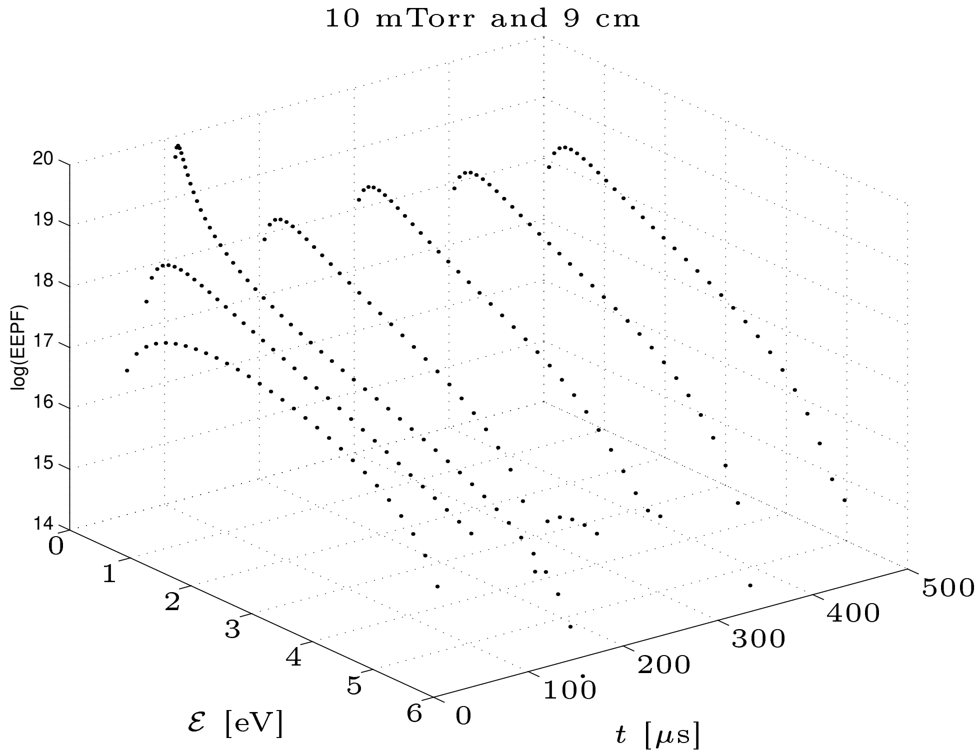
Electron temperature



- The effective electron temperature peaks at the same time independent of position in the discharge at a given pressure
- The electron energy distribution function during and shortly after the pulse can be represented by a bi-Maxwellian distribution - two energy groups of electrons



Electron energy probability function (EEPF)



- At 10 mTorr and 100 μs - a bi-Maxwellian
  - cold electron group - $T_{\rm ec} = 0.23$ eV
  - hot electron group - $T_{\rm eh} = 1.1$ eV
  - effective electron temperature - $T_{\rm eff} = 0.3$ eV
- At 10 – 20 mTorr and 200 – 400 μs a single Maxwellian with electron temperature 0.7 – 0.8 eV but depleted above 3 eV

Conclusion

- The target current and voltage waveform indicates a sputtering regime that precedes the plasma build up and subsequent decay of the plasma
- The traveling speed of the electron density peak along the axis of the discharge decreases with increased gas pressure
- The effective electron temperature peaks at the same time independent of position in the discharge at a given pressure
- The electron energy distribution function during and shortly after the pulse can be represented by a bi-Maxwellian distribution which indicates two energy groups of electrons in the plasma

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