# Spatial and temporal variation of the electron energy distribution function (EEDF) in the HiPIMS discharge

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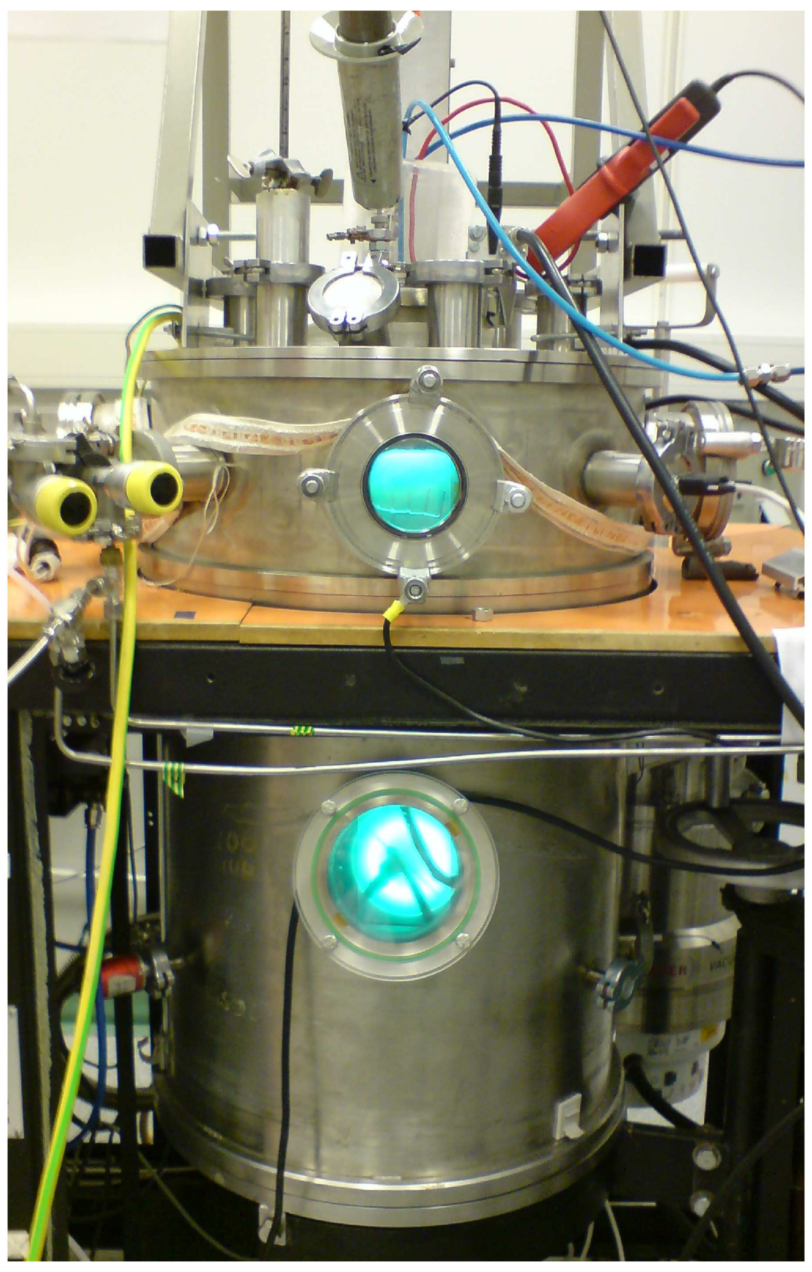
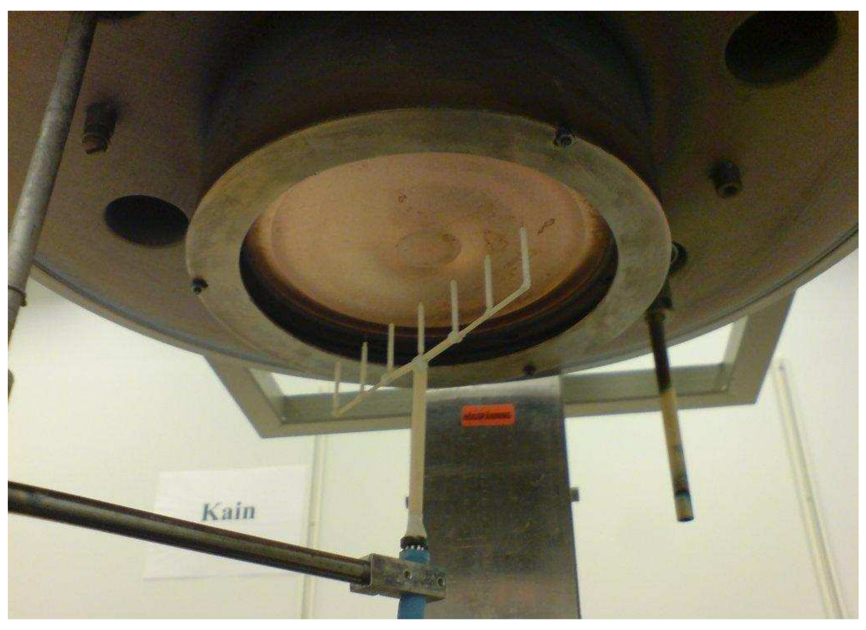
## Introduction

- In high power impulse magnetron sputtering (HiPIMS) the discharge is created by applying a high power unipolar pulse of low duty cycle to the cathode target (Helmersson et al., 2005, 2006).
- The high power pulse has a peak cathode voltage in the range 500 – 2000 V which gives peak power densities in the range 1 – 3 kW/cm$^2$.
- For the high power impulse magnetron sputtering (HiPIMS) discharge
  - Peak power ∼ kW/cm$^2$.
  - Average power ∼ W/cm$^2$, no significant target heating.
  - Repetition frequency 50 - 500 Hz.
  - Duty cycle 0.5 - 5 %
- Electron density of the order of $10^{18} - 10^{19}$ m$^{-3}$ has been reported in the substrate vicinity (Gudmundsson et al., 2001; Bohlmark et al., 2005a)
- A high fractional ionization of the sputtered vapor has been demonstrated and values higher than 90 % have been reported (Bohlmark et al., 2005b).
- Here we explore the spatial and temporal variation of the plasma parameters and the electron energy distribution in the HiPIMS discharge.

## Experimental apparatus



- Argon (Ar) of purity 99.9997 %, was used as discharge gas.
- The discharge was operated in the pressures range 3 – 20 mTorr.
- A standard planar magnetron source was operated with a 150 mm diameter copper (Cu) target inside a stainless steel chamber, 460 mm in diameter and 525 mm long.
- The average power was in the range 215 − 270 W, corresponding to pulse energy 4.3 J – 5.4 J for pulse length 80 to 90 $\mu$s, depending on the gas pressure, and repetition frequency of 50 Hz.



- An array of 7 Langmuir probes was constructed and mounted into the chamber on a movable rod, which allows for axial movement of the probe array.
- Each Langmuir probe was made of a stainless steel wire, 200 $\mu$m in diameter and 5 mm long.

## Results and Discussion

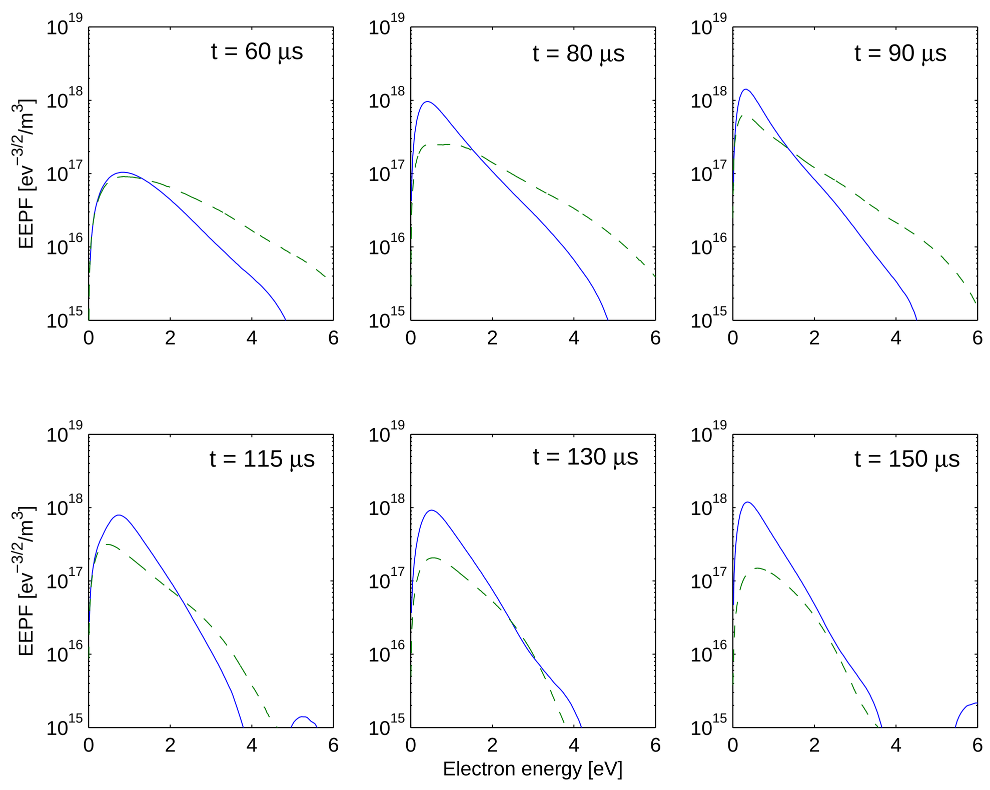



**Figure 1:** The electron energy probability function (EEPF) for various times from initiating the pulse for an argon discharge at 3 (green dotted line) and 20 (blue solid line) mTorr. The Langmuir probe is located under the race track 80 mm from the target surface.

- The EEPF is broad for the lower discharge pressure of 3 mTorr and it becomes narrower as the pulse progresses at both 3 mTorr and 20 mTorr (Gudmundsson et al., 2009).
- This indicates that the plasma cools off as the pulse progresses.
- There a significant density of metal ions in a HiPIMS discharge which is expected to cool the EEPF due to electron impact excitation and ionization of the metal atoms, that have much lower excitation thresholds and ionization potential than the argon sputtering gas.
- High electron density leads to Maxwellian-like low energy part of the electron energy distribution function. The depletion in the high energy part is partially due to escape of high energy electrons to the chamber walls.

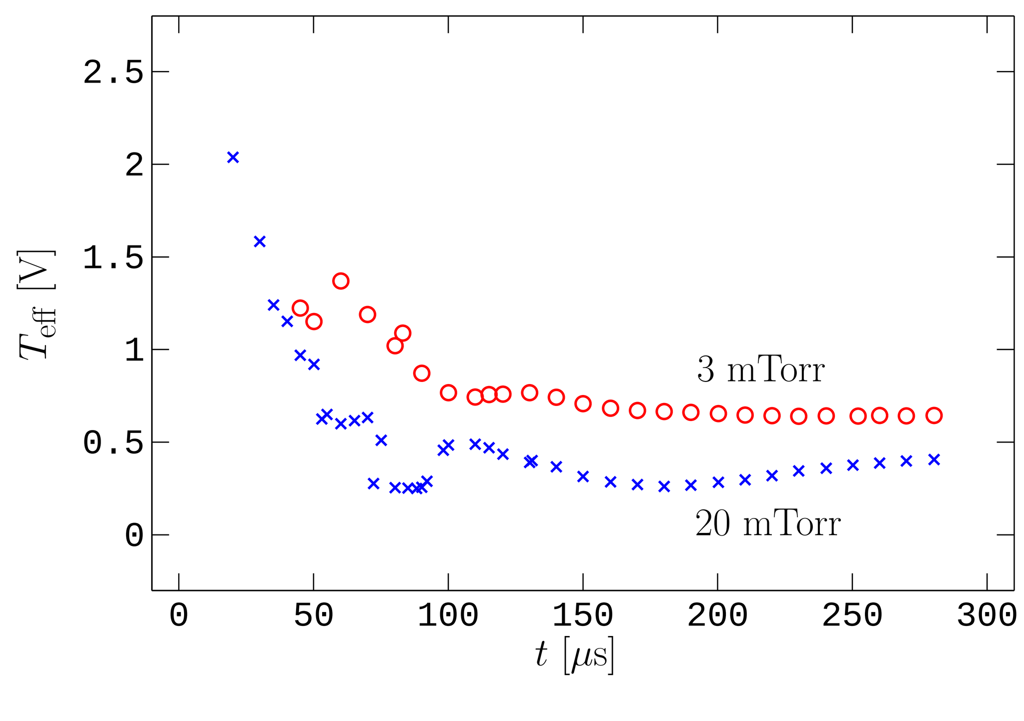



**Figure 2:** The effective electron temperature $T_{\rm eff}$ and versus time for an argon discharge at 3 and 20 mTorr.

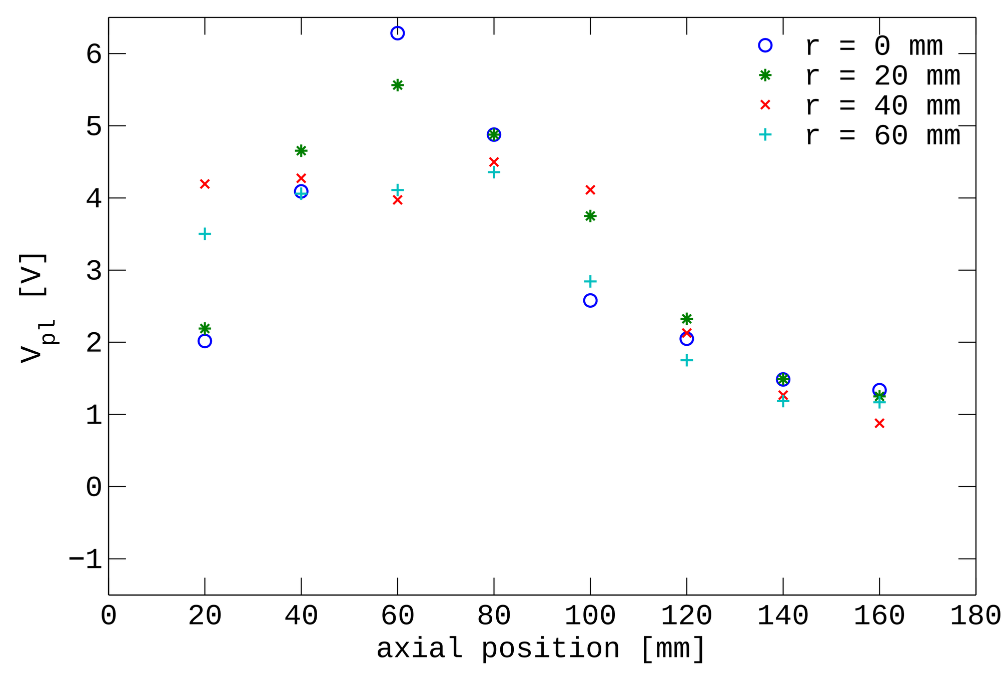



**Figure 3:** The plasma potential $V_{\rm pl}$, versus axial position for various radial positions for an argon discharge at 5 mTorr, 65 $\mu$s into the pulse.

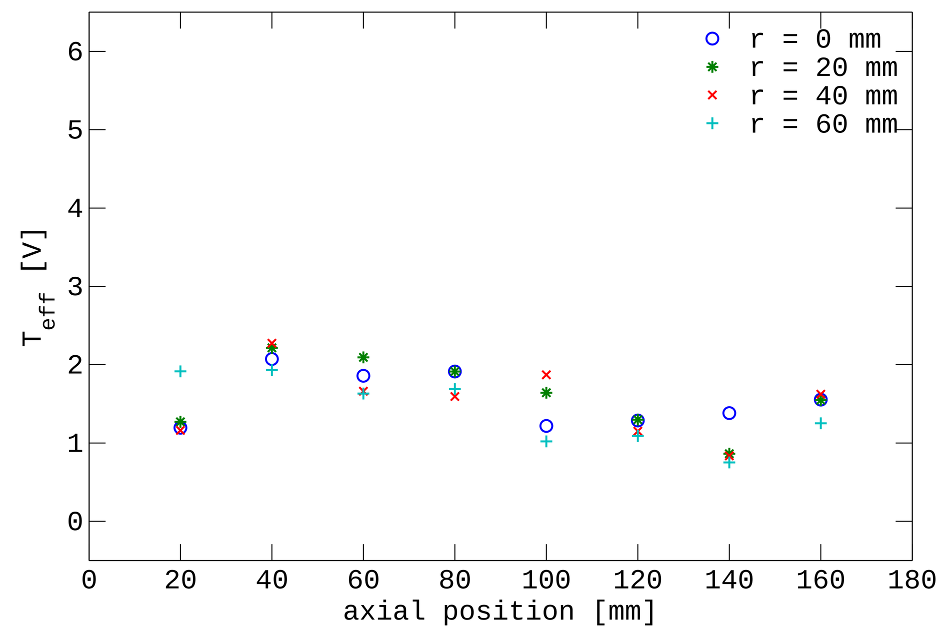



**Figure 4:** The effective electron temperature $T_{\rm eff}$, versus axial position for various radial positions for an argon discharge at 5 mTorr, 65 $\mu$s into the pulse.

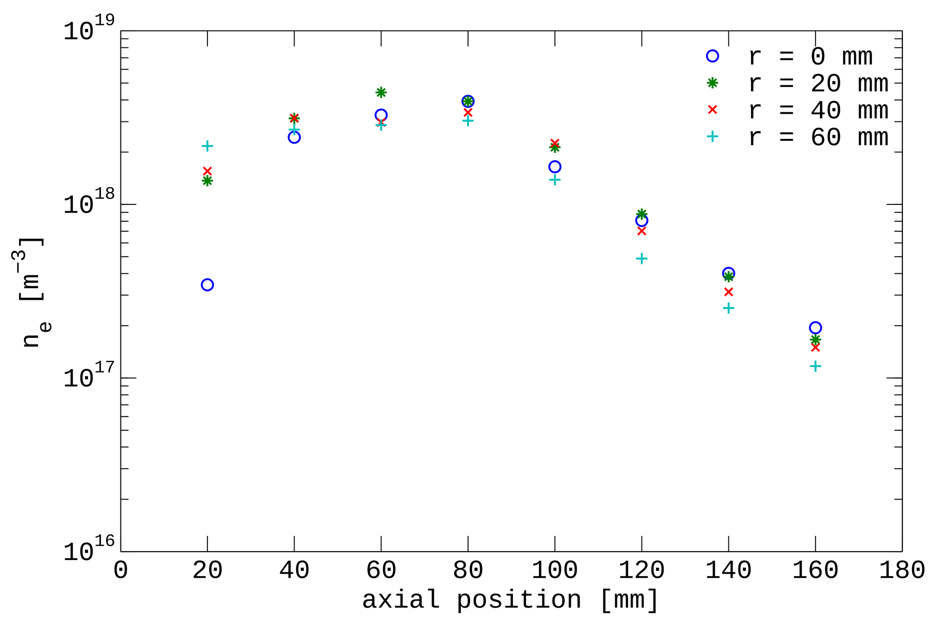



**Figure 5:** The electron density $n_{\rm e}$ versus axial position for various radial positions for an argon discharge at 5 mTorr, 65 $\mu$s into the pulse.

- The effective electron temperature is relatively constant throughout the discharge, falls slightly from 2 V 40 mm below the target to about 1.2 – 1.5 V at 160 mm below the target.
- The electron density peaks at 3 – 4 $\times 10^{18}$ m$^{-3}$ at 60 – 80 mm below the target and then falls with distance from the target.
- The electron density is uniform along the radius of the discharge (Sigurjonsson et al., 2009).

## Summary

- A Langmuir probe was applied to explore the electron density and the electron energy distribution function (EEDF), the effective electron temperature and the plasma potential during the "pulse on" period in a HiPIMS discharge.

## Acknowledgments

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