The plasma parameters in a high power impulse magnetron sputtering discharge (HiPIMS)

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Introduction

- In the 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 $\sim$ kW/cm^2.
  - Average power $\sim$ W/cm^2, no significant target heating.
  - Repetition frequency 50 - 500 Hz.
  - Duty cycle 1 - 5 %
- Electron density of the order of $10^{18} - 10^{19}$ m^{-3} has been reported in the substrate vicinity (Gudmundsson et al., 2001; Pajdarová et al., 2007)
- A high fractional ionization has been demonstrated and values higher than 90 % have been reported (Bohlmark et al., 2005).

Experimental apparatus

- Argon (Ar) of purity 99.9997 %, was used as discharge gas.
- 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 discharge was operated in the pressures range 3 – 20 mTorr.

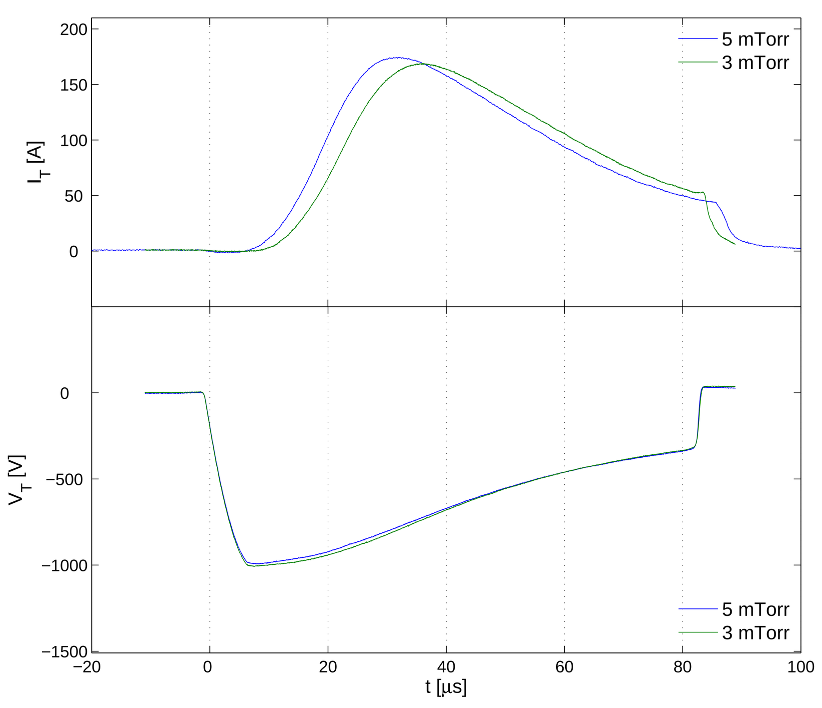

Figure 1: The target current and target voltage versus time for an argon discharge at 3 and 5 mTorr, pulse frequency 50 Hz and average power 240 W. The target current peaks at 32 μs for 5 mTorr and at 36 μs for 3 mTorr.

- The Langmuir probe current-voltage (I-V) characteristic was recorded and the second derivative was obtained by numerically differentiating and filtering (Magnus and Gudmundsson, 2002) the measured curve to determine the electron energy distribution function (EEDF) from Druyvesteyn formula.
- The electron energy probability function (EEPF) is

$$g_{\rm P}(\mathcal{E}) = \mathcal{E}^{-1/2} g_{\rm e}(\mathcal{E}) \tag{1}$$

- The electron density was found by

$$n_{\rm e} = \int_0^\infty g_{\rm e}(\mathcal{E}) d\mathcal{E} \tag{2}$$

where $\mathcal{E}$ is the electron energy.
- The average electron energy is then

$$\langle \mathcal{E} \rangle = \frac{1}{n_{\rm e}} \int_0^\infty \mathcal{E} g_{\rm e}(\mathcal{E}) d\mathcal{E} \tag{3}$$

- The effective electron energy is defined as

$$T_{\rm eff} = \frac{2}{3} \langle \mathcal{E} \rangle \tag{4}$$

- The plasma potential was determined from the zero point of the second derivative of the electron probe current and the floating potential was determined from the zero value of the total probe current.

Results and discussion

- The time evolution of the electron energy probability function (EEPF) is shown in figures 2 and 3 for discharge pressure 3 and 20 mTorr, respectively.
- The Langmuir probe was located under the racetrack, 80 mm from the target surface.
- The pulse was roughly 80 μs long, the frequency 50 Hz and the average power 135 W at 3 mTorr and 170 W at 20 mTorr.

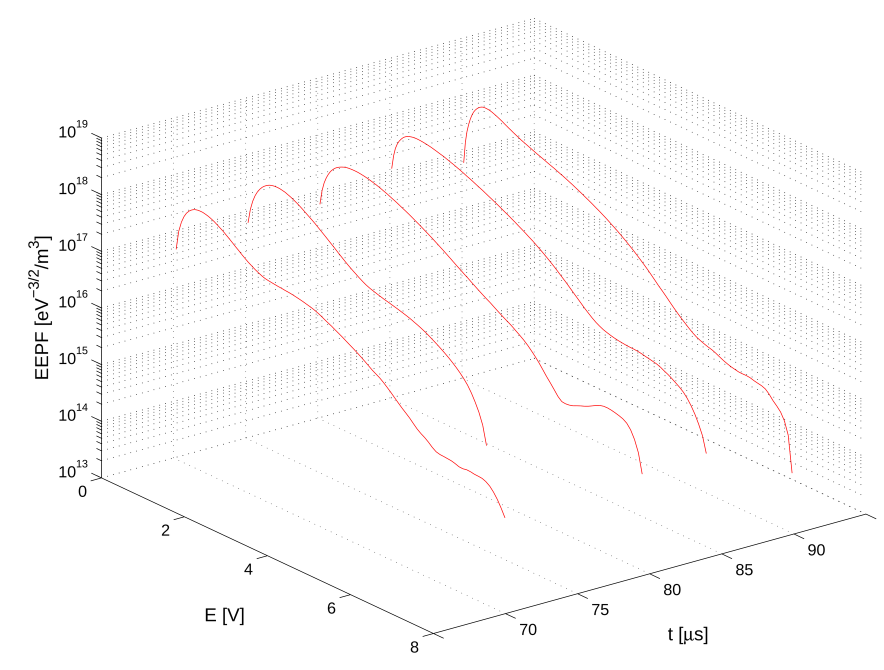

Figure 2: The time evolution of the electron energy probability function (EEPF) under the racetrack, 80 mm from the target surface, for an argon discharge at 3 mTorr.

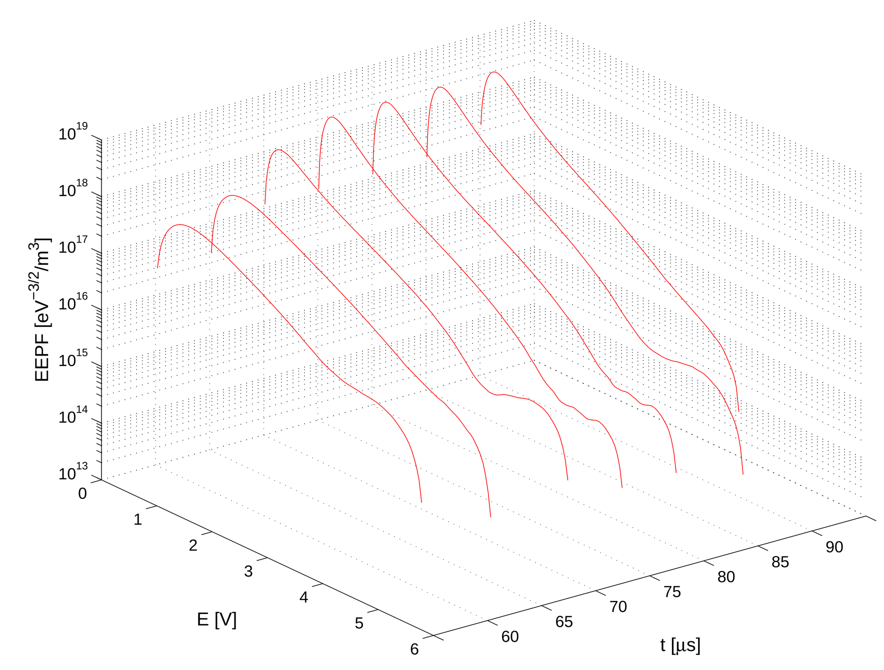

Figure 3: The time evolution of the electron energy probability function (EEPF) under the racetrack, 80 mm from the target surface, for an argon discharge at 20 mTorr.

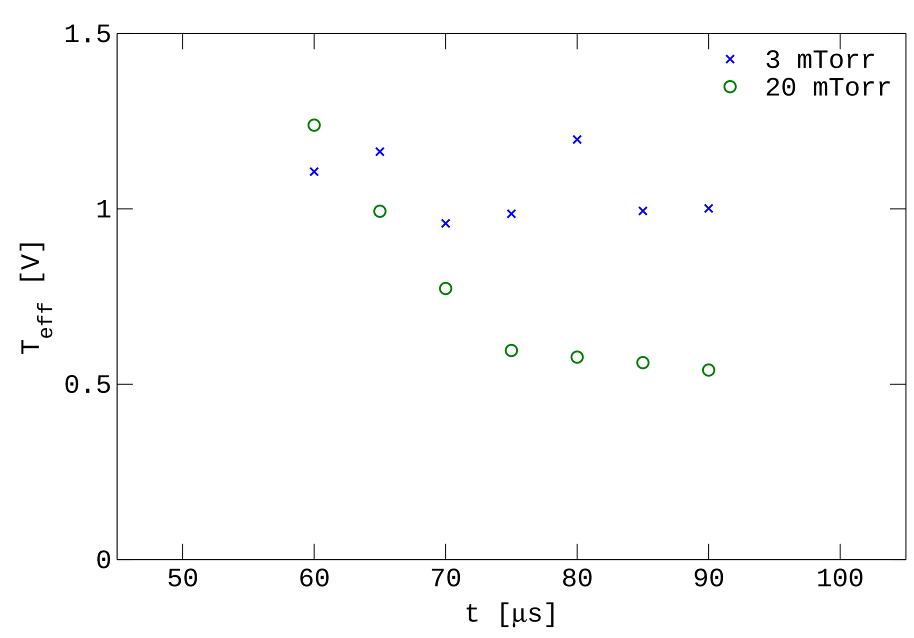

Figure 4: The effective electron temperature $T_{\rm eff}$ versus time under the racetrack, 80 mm from the target surface, for an argon discharge at 3 and 20 mTorr.

- The effective electron temperature towards the end of the pulse calculated using equations (3) and (4) is shown in figure 4 and is in the range 0.5 – 1.5 V.
- The electron density peaks 78 μs into the pulse at 5 mTorr and 74 μs into the pulse at 3 mTorr. The high plasma density wave travels faster at lower discharge pressure (Gylfason et al., 2005).
- The negative peak in the floating potential at the beginning of the pulse has been related to high energy electrons that are repelled from the target by the rapid drop of the target potential at the initiation of the pulse (Pajdarová et al., 2007).

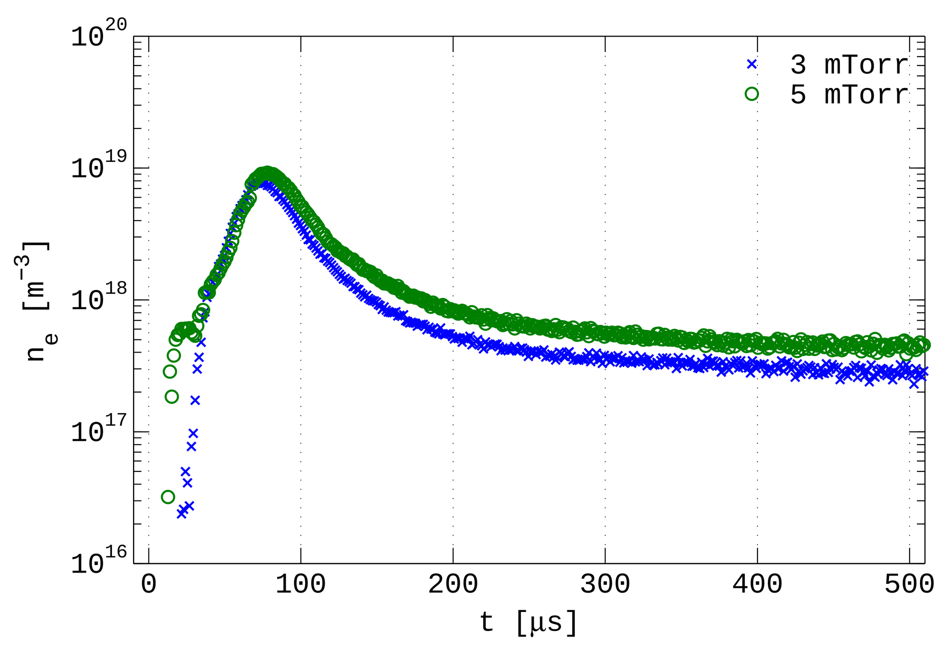

Figure 5: The electron density versus time for an argon discharge at 3 and 5 mTorr. The Langmuir probe was located under the racetrack, 100 mm from the target surface, the pulse was roughly 80 μs long, the frequency 50 Hz and the average power 240 W.

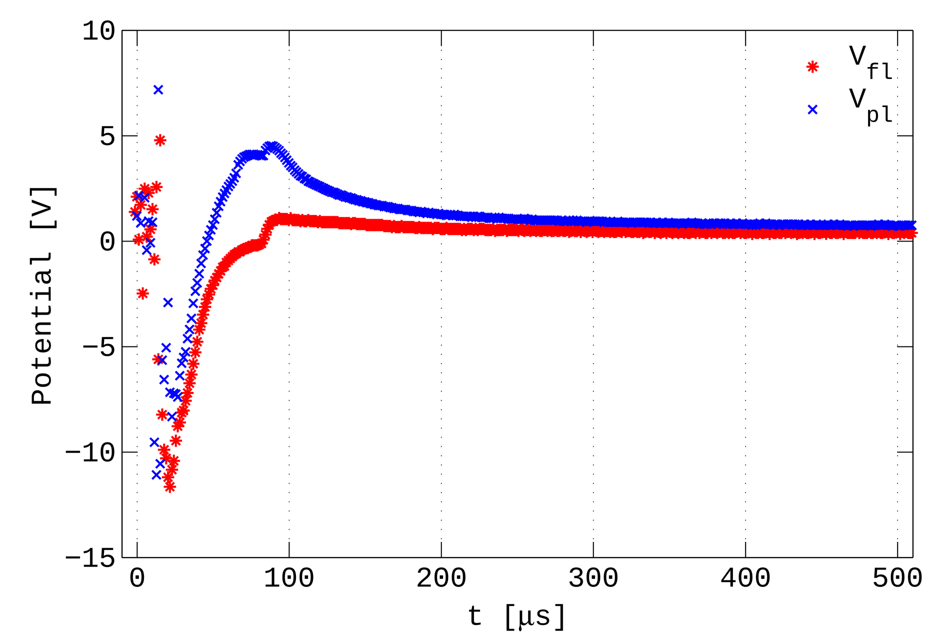

Figure 6: The plasma potential and the floating potential versus time for an argon discharge at 3 mTorr. The Langmuir probe was located under the racetrack, 100 mm from the target surface, the pulse was roughly 80 μs long, the frequency 50 Hz and the average power 240 W.

Conclusions

- The electron density in the substrate vicinity peaks at 1×10^{19} m^{-3}.
- The effective electron temperature during the pulse on period is in the range 0.5 – 1.2 V and falls with time.

Acknowledgments

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References

J. Bohlmark, J. Alami, C. Christou, A. P. Ehiasarian, and U. Helmersson, Journal of Vacuum Science and Technology A **23**, 18 (2005).

J. T. Gudmundsson, J. Alami, and U. Helmersson, Applied Physics Letters **78**, 3427 (2001).

K. B. Gylfason, J. Alami, U. Helmersson, and J. T. Gudmundsson, Journal of Physics D: Applied Physics **38**, 3417 (2005).

U. Helmersson, M. Lattemann, J. Alami, J. Bohlmark, A. P. Ehiasarian, and J. T. Gudmundsson, in *48th Annual Technical Conference Proceedings* (Society of Vacuum Coaters, Denver, CO, USA, 2005), pp. 458 – 464.

U. Helmersson, M. Lattemann, J. Bohlmark, A. P. Ehiasarian, and J. T. Gudmundsson, Thin Solid Films **513**, 1 (2006).

F. Magnus and J. T. Gudmundsson, *Digital smoothing of the I − V Langmuir probe characteristic*, Technical Report RH-20-02, Science Institute, University of Iceland (2002).

A. D. Pajdarová, J. Vlček, P. Kudláček, J. Lukáš, and J. Musil, in *Proceedings of the XXVIII International Conference on Phenomena in Ionized Gases*, edited by J. Schmidt, M. Šimek, S. Pekárek, and V. Prukner (Institute of Plasma Physics AS CR, v.v.i., Prague, Czech Republic, 2007), pp. 1960 – 1962.