Zeitaufgelöste Einzelsondenmessung an einer gepulsten Magnetronentladung

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Outline:

- Introduction
- Theoretical Basics
- Experimental Setup
- Results and Discussion
- Conclusion

Introduction

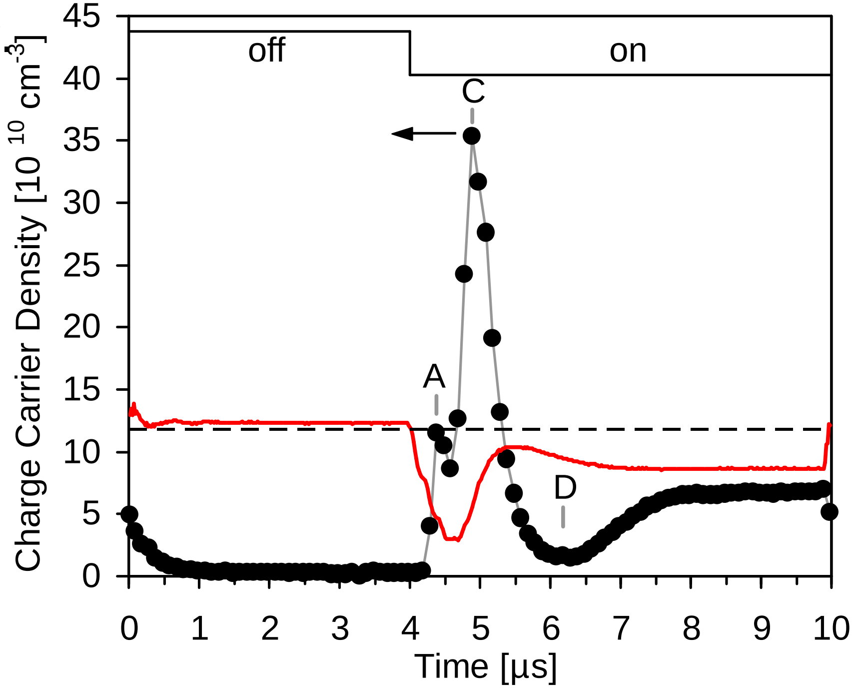
Results of time-resolved double probe measurements:

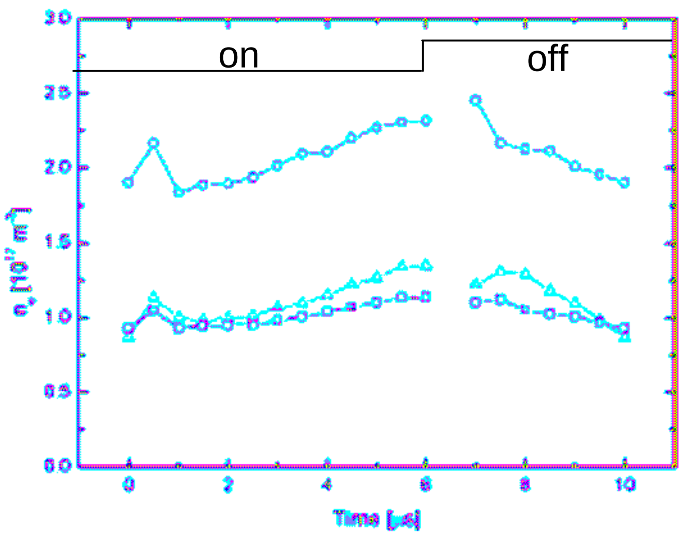
- confirmed by optical emission spectroscopy

"on" phase:

- typical double peak structure (A, C)
- transition into the stationary state (D → E)

"off" phase: fast decay (≈ 0.5 µs)



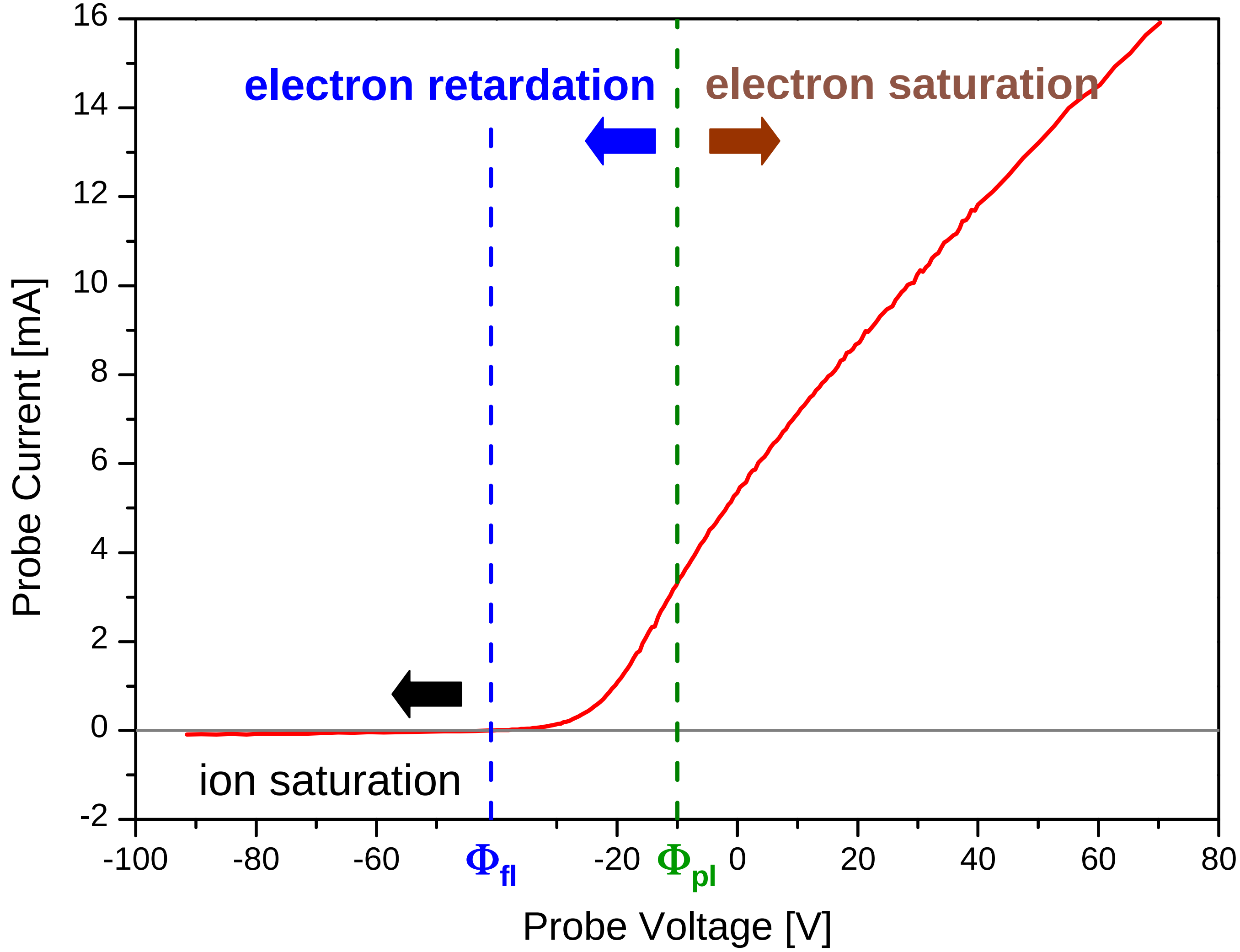


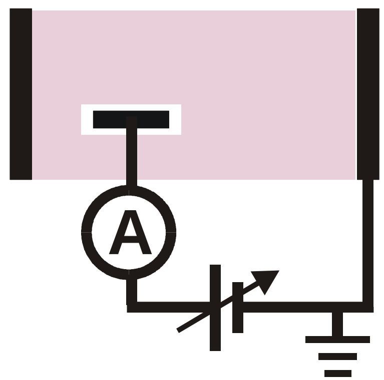
I. Swindells, P. Kelly, J.W. Bradley, NJP 8 (2006) 47.

Our results are not in agreement with results of single probe measurements of other authors (e.g. J.W. Bradley and co-workers)!

Verification by using a single probe desirable.

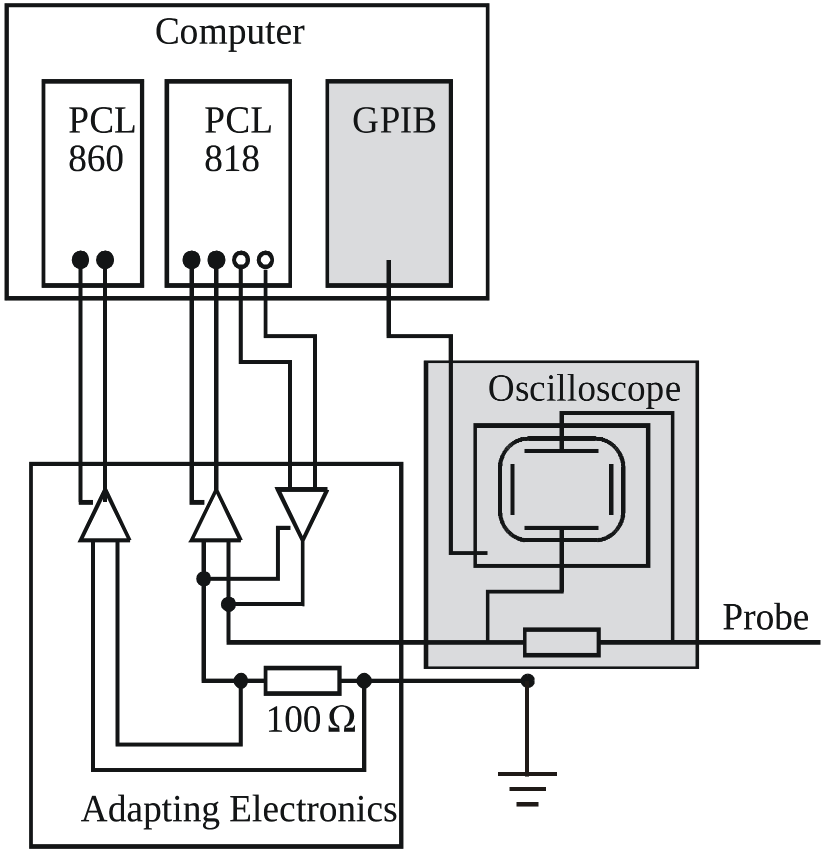
Langmuir Single Probe





- electron saturation: $f(n_e, T_e, \ldots) \rightarrow n_e$
- electron retardation : f(eedf) $\sim \exp(-eU_p/kT_e) \rightarrow T_e$
- ion saturation: $f(n_i, T_i, \ldots) \rightarrow n_i$

Time-Resolved Probe Setup



electrodes

- tungsten
- ∅ = 0.5 mm, l ~ 10 mm

current measurement $I_p(t)|_U$

- external 100 Ω resistor
- potential drop measured vs. time by digitising oscilloscope
- averaged over 20 cycles

measurement of “asymmetric” characteristics in pulsed discharges:

→ enhanced requirements on power supply

- current range: -10 … 200 mA
- voltage range: -100 …100 V
  (Φ_{pl} ~ 400 V (not accessible)

Theoretical Time Resolution

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Is the probe in equilibrium with the potential variations of a pulsed plasma?

- transit time of an average charge carrier through the sheath
- determined by the plasma frequency ω_P of each type of charge carriers

$$\omega_{p,x} = \sqrt{\frac{e^2 \cdot n_x}{\varepsilon_0 \cdot m_x}}$$

e … elementary charge
ε_0 … vacuum permittivity
n_x … charge carrier density
m_x… particle mass
x … electron or ion

Example: argon plasma, $n_i \approx n_e = 10^{10}$ cm^{-3}

$\omega_{p,I} \approx$ 20 MHz, $\omega_{P,e} \approx$ 5.6 GHz
$\tau_i \approx$ 300 ns, $\tau_e \approx$ 1 ns

electron region: yes
ion saturation: most of the pulse period
fast transients can not be followed

Response Time of the Probe Setup

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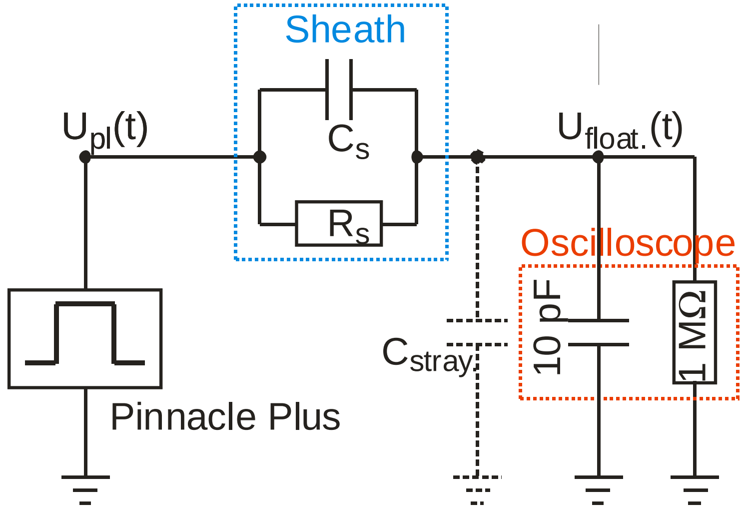
$\Rightarrow$ determined by:
- sheath resistance
- stray capacitance



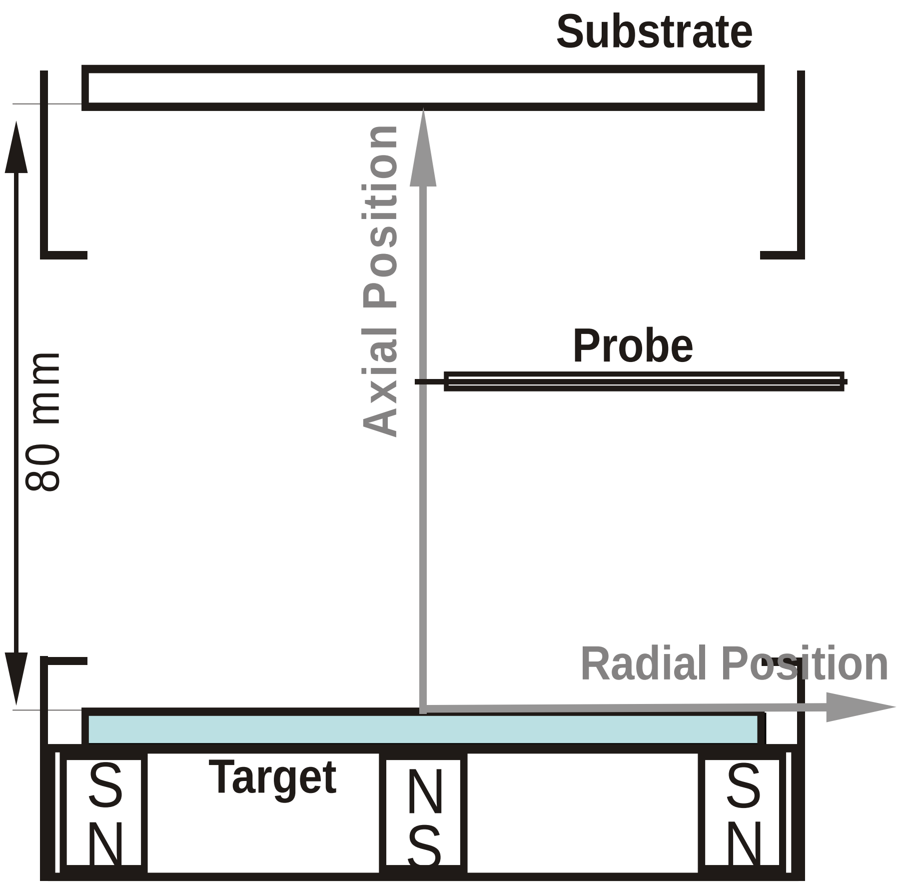
$$\tau = \frac{R_S \cdot Z_S}{(R_S + Z_S)} \cdot C_{stray} \approx R_S \cdot C_{stray}$$

<u>ion part:</u>
- typical values should be about 100 µA
- high impedance of the probe sheath
  $\rightarrow$ bad response time of the probe
- increase of probe area can improve it slightly

<u>electron part:</u>
- high probe currents measured (40 – 100 mA)
- low impedance of the „probe sheath“
- good response time to follow changes in the plasma

further improvements:
- decrease of the stray capacitance $\rightarrow$ careful wiring (difficult) **Tested!**
- decrease of the sheath resistance $\rightarrow$ increase of the probe area
  but: limited by electron saturation currents and power of the power supply

Experimental Setup



depositon system:

- target: Ti (∅ = 100 mm)
- unbalanced magnetic field configuration
- floating substrate
- d_{TS}= 80 mm
- gas: 50 sccm Ar + 10 sccm O_2
- pressure: 0.40 Pa

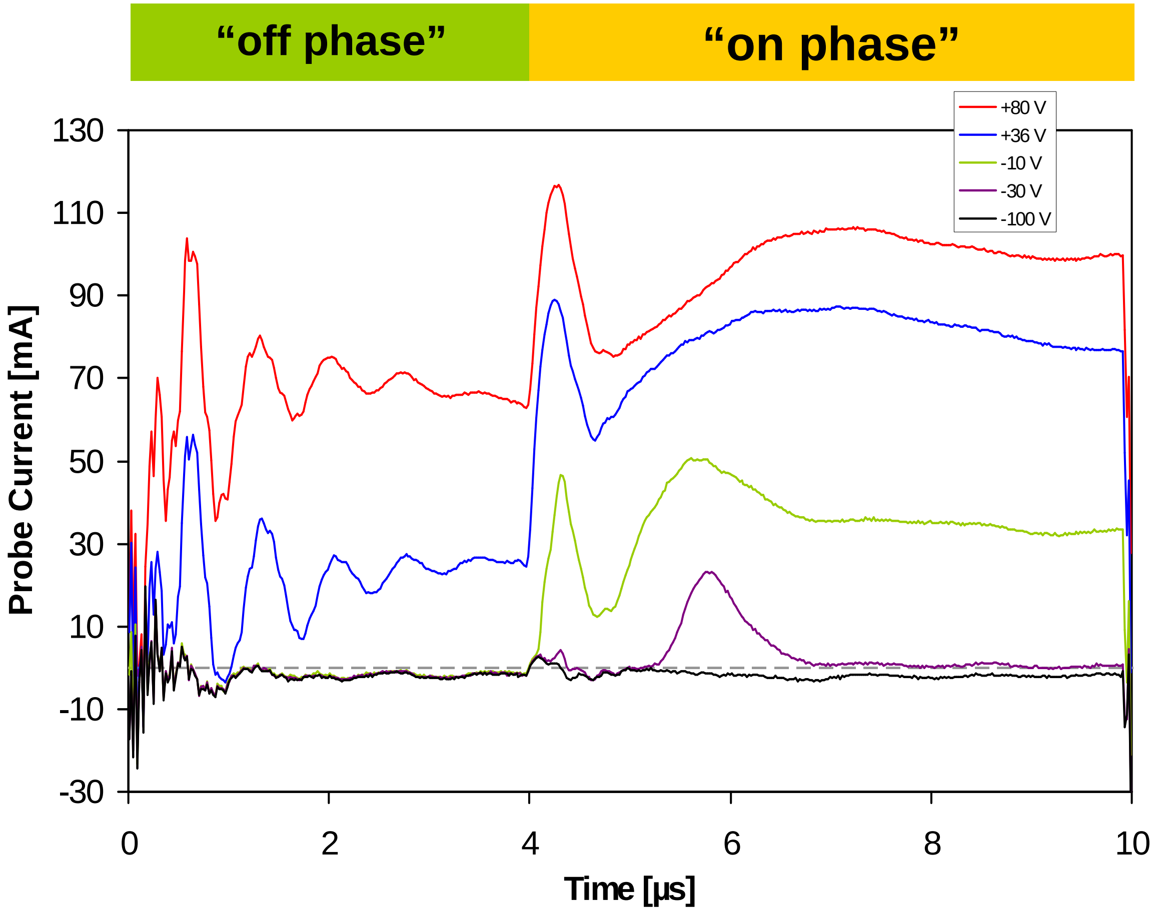
power supply: (Pinnacle Plus, AE)

<P> = 200 W, f = 100 kHz, τ_{rev} = 4 µs

spatial probe position:

- centre of the discharge
- approx. 50 mm above the target

Attempt: Time-resolved Measurements



Ti, 200 W, 100 kHz, 4.0 µs, 0.4 Pa

- “on” and “off phase” can be distinguished

Most of the pulse time:
positive electron current and **negative** ion current are observed

Electron current:
- shows rapid changes
- range: 30…110 mA

Ion current:
- blurred and delayed
- range: -3…0 mA

Typical Probe Characteristics

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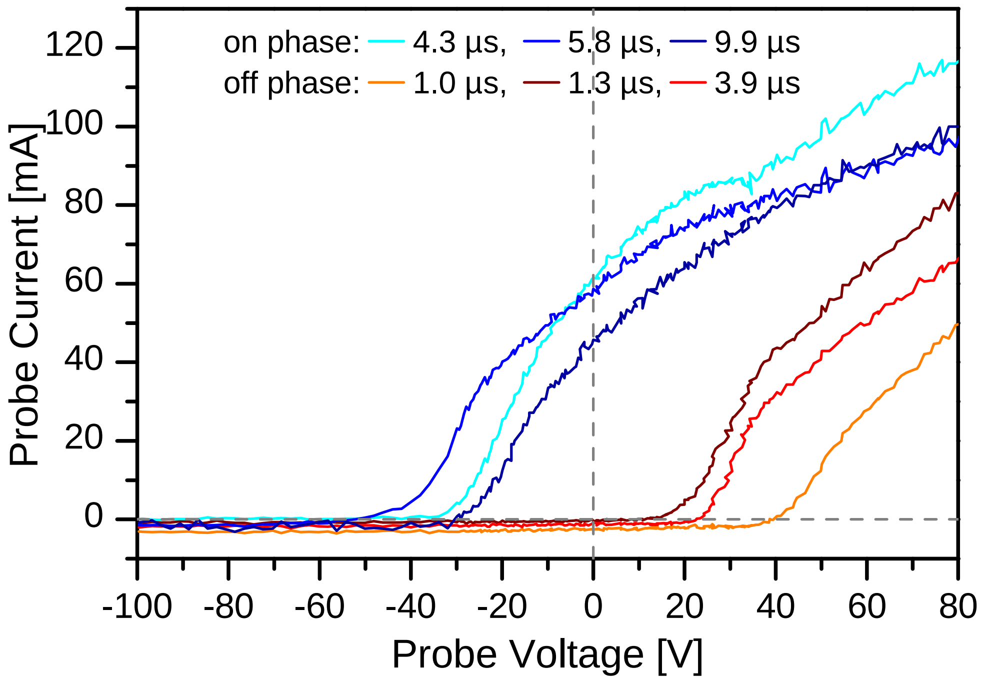


Discharge pulsed: Φ_{pl}, $\Phi_{fl} \rightarrow f(t)$

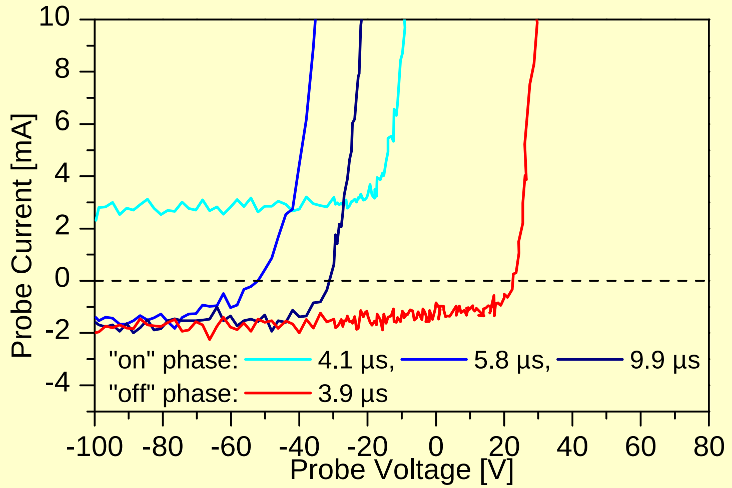
<u>electron saturation:</u> $\rightarrow n_e$
differences between “on” and “off”

<u>electron retardation:</u> $\rightarrow T_e$
changes of T_e can be guessed

<u>ion saturation:</u> $\rightarrow n_i$
unexpected high absolute values

<u>Positive ion current?</u>

- displacement currents due to rapid potential changes (4.3 µs)
- high-energetic secondary electrons? (5.8 µs)



Assignable Floating Potential

- .Φ_{fl} of the probe tip: similar temporal development as the substrate plate

- slightly higher absolute values
- delayed transients
  - different positions $d_{TP} \approx 45$ mm; $d_{TS} = 80$ mm

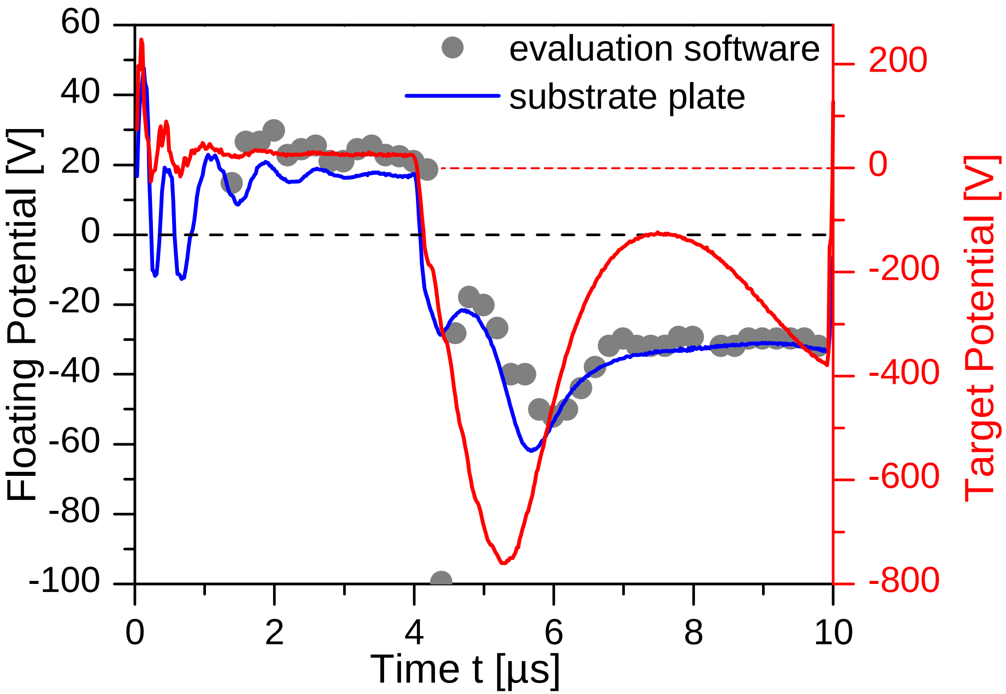
<u>t < 1 µs:</u> $\Phi_{fl} > 80$ V?
- strong positive overshoot of the target potential
- .Φ_{pl} up to 400 V are observed by emissive probe studies [2]

<u>4 µs < t < 4.5 µs:</u>
- determination not possible

→probe current always positive

[2] Th. Welzel, ICPIG, 2007.

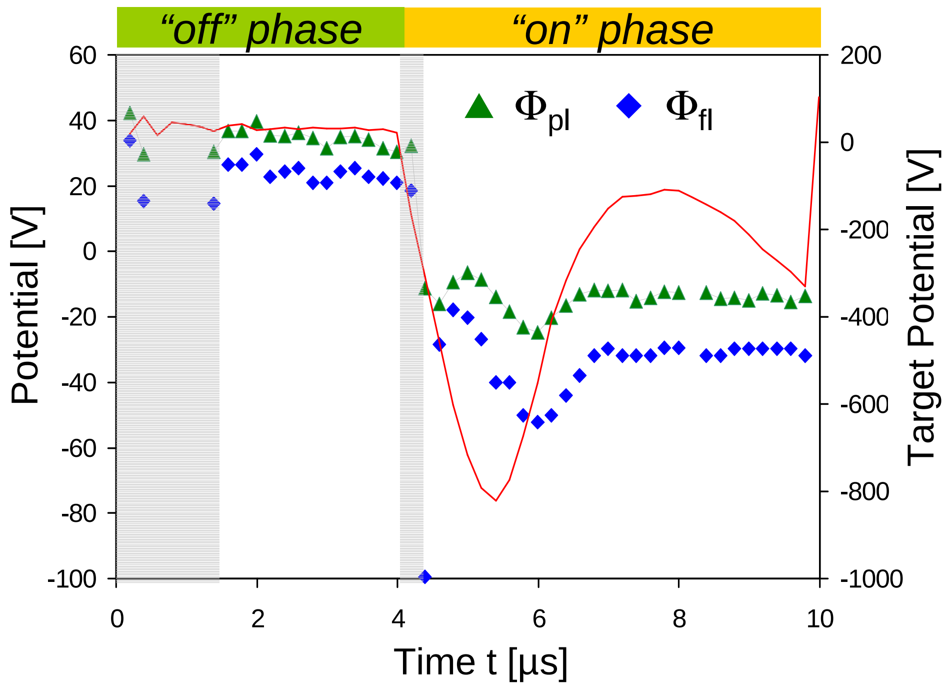
Ti, 200 W, 100 kHz, 4.0 µs, 0.4 Pa



➡ Φ_{fl} follows variations most of the pulse time (mainly supported by electron mobility)

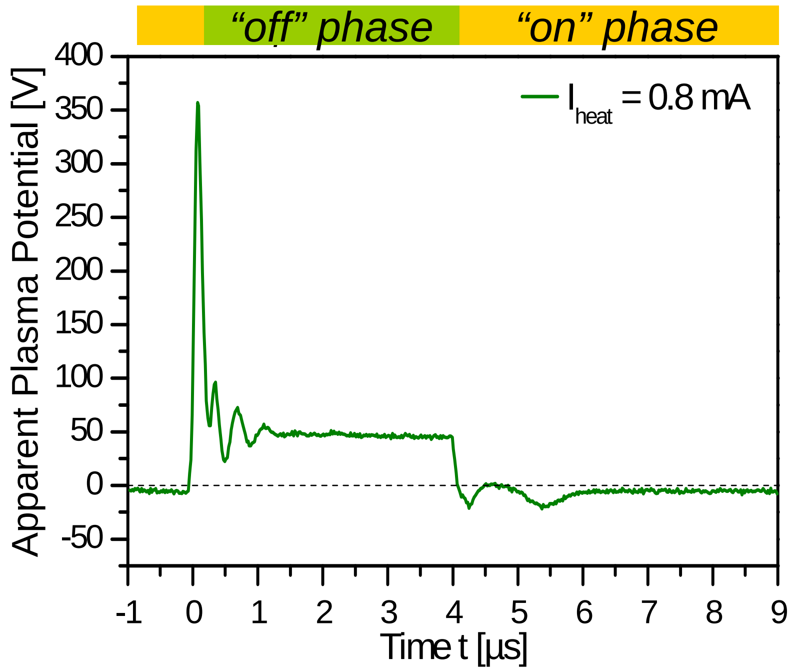
Results: Floating and Plasma Potential

Time-resolved Single Probe



Time-resolved Emissive Probe

(C, 400 W, 100 kHz, 4.0 µs 0.46 Pa Ar)

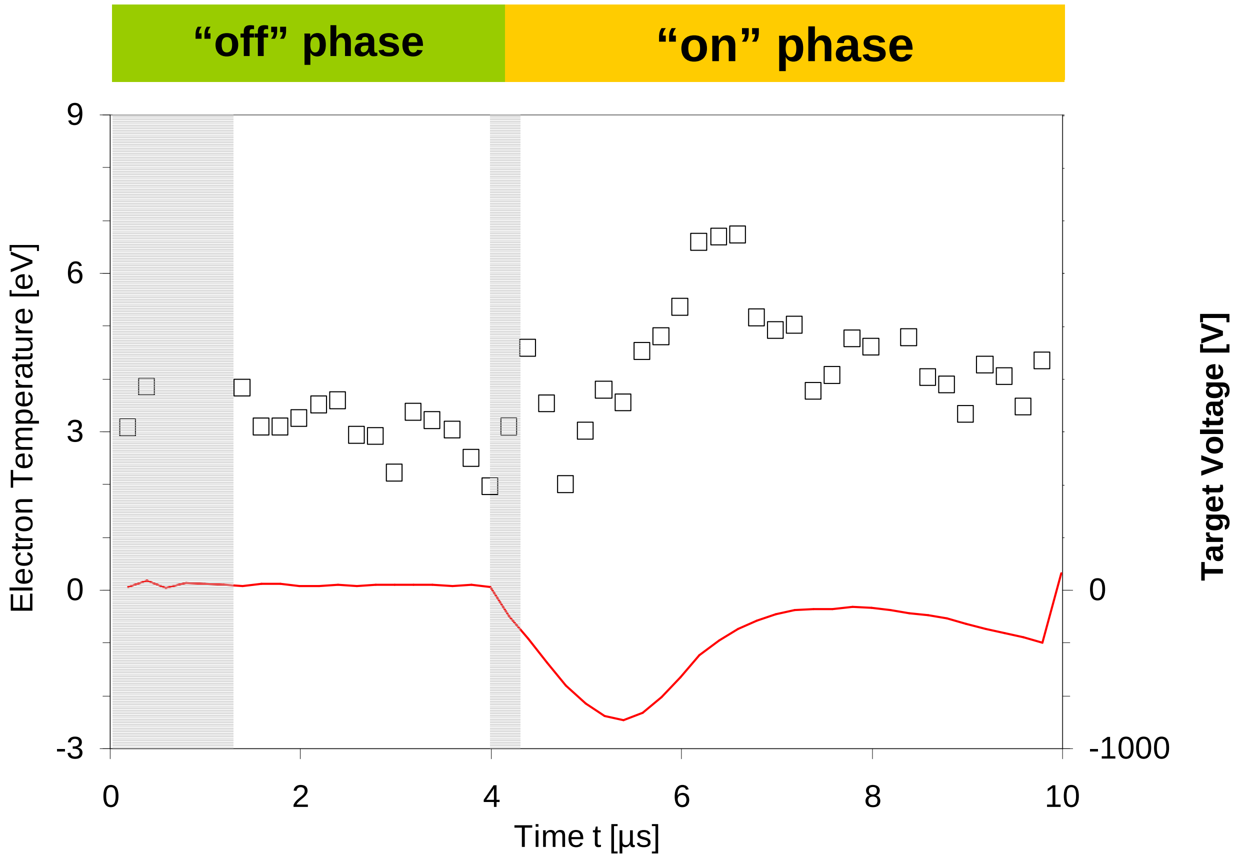


- Φ_{pl} similar to Φ_{fl}, but higher
- gray regions: evaluation not possible

- confirm the observed $\Phi_{pl}(t)$ obtained by a single probe
- here, higher absolute values

⇒ geometry, target material …

Results: Electron Temperature



- typical values of T_e for a magnetron discharge
- no evidence of high energetic electrons (ion current subtraction necessary)

<u>"on" phase:</u>

- increase of T_e from 3 to 7 eV at 6.5 µs
- decrease of T_e to the end of the on phase

<u>"off" phase:</u>

- almost constant 3 eV

gray marked region: evaluation not possible

Results: Charge Carrier Density

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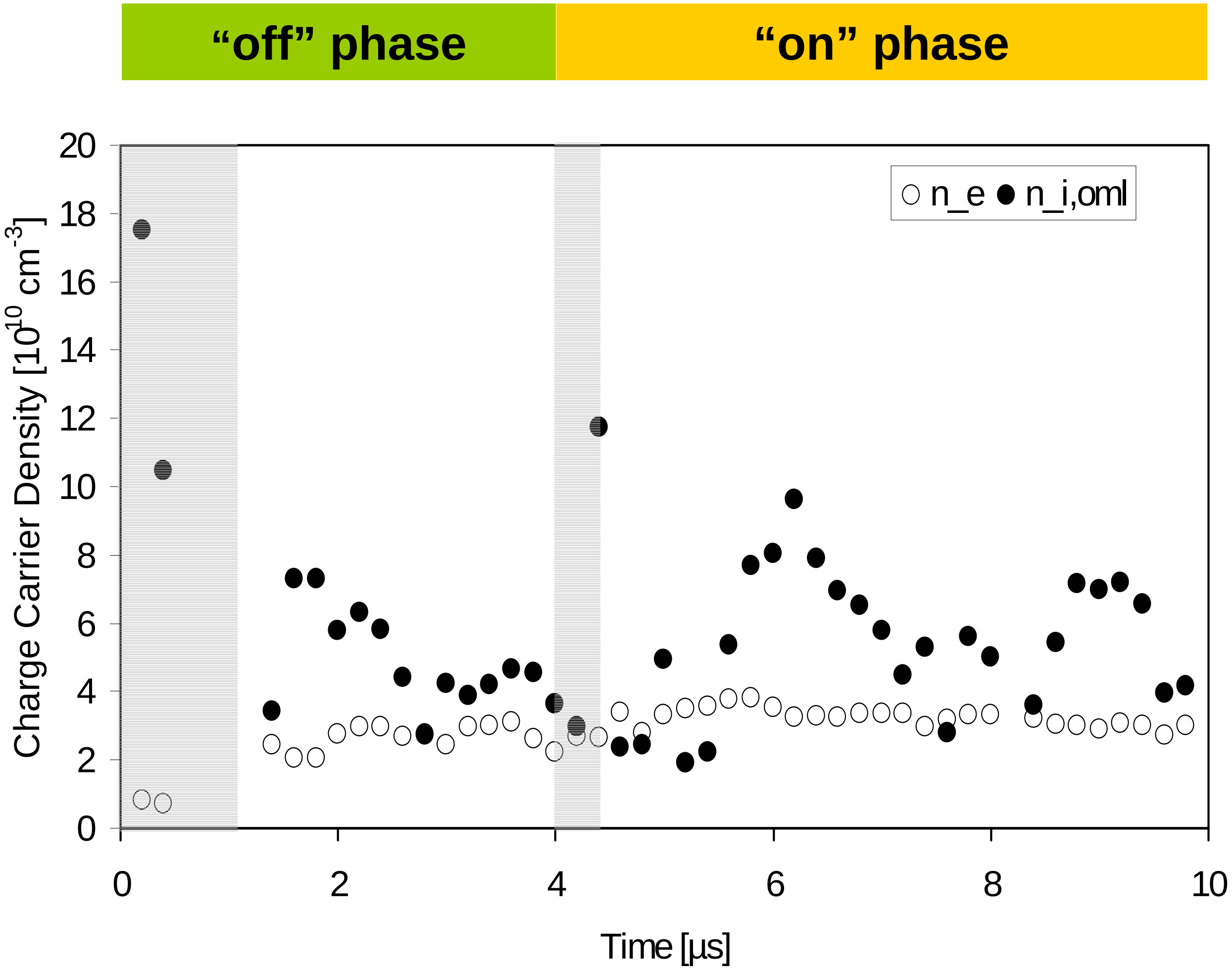

gray marked region: evaluation not possible

electron density (n_e)
- no significant changes observed
- $n_e \approx 3 \cdot 10^{10}$ cm^{-3}

ion density (n_i)
- shows temporal changes (OML theory)

but:
- theory not valid
- serious determination not possible
- results of different evaluation procedures are not consistent to each other

Conclusions

- First setup of a time-resolved single probe has been developed. Time-resolved characteristics can be measured.
- Response time of the probe looks good enough to follow the plasma potential variation in of the period.
- Variations are observed for T_e and Φ. n_e is almost constant?
- The results show the difficulties of the measuring technique and are useful to understand the published results by other authors.
- The review of the double probe results on the basis of these investigations could not be done yet.

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Thank you for your attention!