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Measurement of the sheath thickness in single and dual capacitively coupled radio frequency discharges

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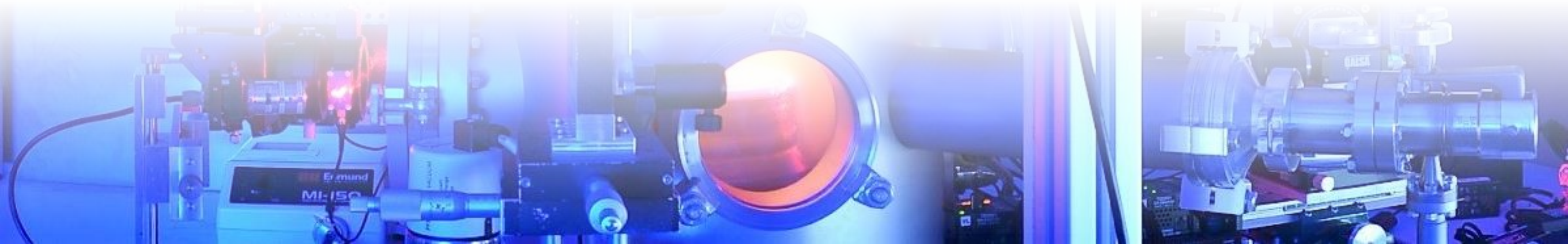
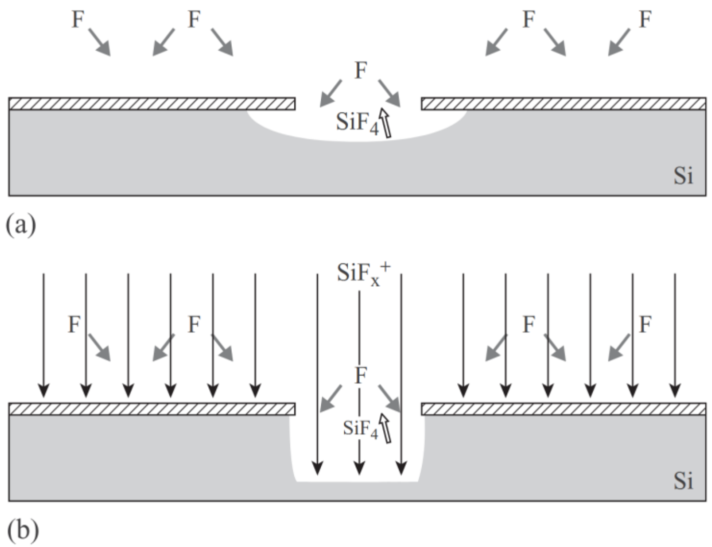
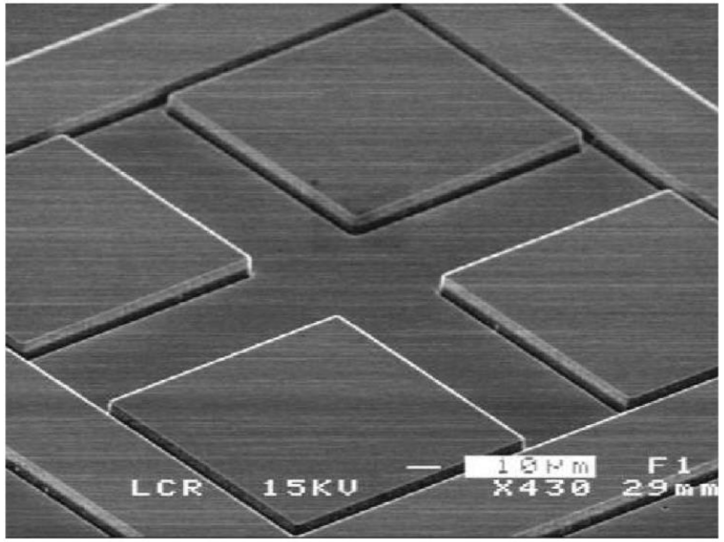


I. Introduction

- Widespread industrial applications of capacitively coupled radio frequency (CCRF) discharges
  - ➢ Surface processes
    - Ion flux determines rate
    - Ion energy determines process
    - ➢ Dependent on RF-amplitude

- Decoupling of ion flux and ion energy threw electrical-asymmetry-effect (EAE) in dual frequency discharges





P. Chabert, N.Braithwaite, „Physics of Radio-Frequency-Plasmas“, 2011

Goals

- Diagnostic to deepen understanding of plasma processes

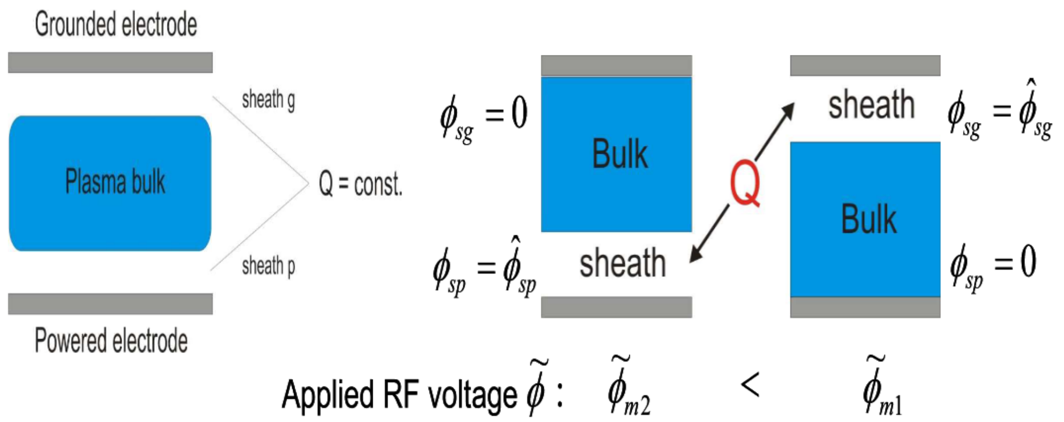
- Goals:
  - Investigation of the plasma sheath behavior in 1f and 2f (EAE) discharges
    - Which plasma parameters can be determined from that?
      - Electron densities
      - Discharge symmetries
  - Is a photometric diagnostic suitable for that?

- Sheath extension measurements
    - photometric (noninvasive)
- Langmuir probe measurements

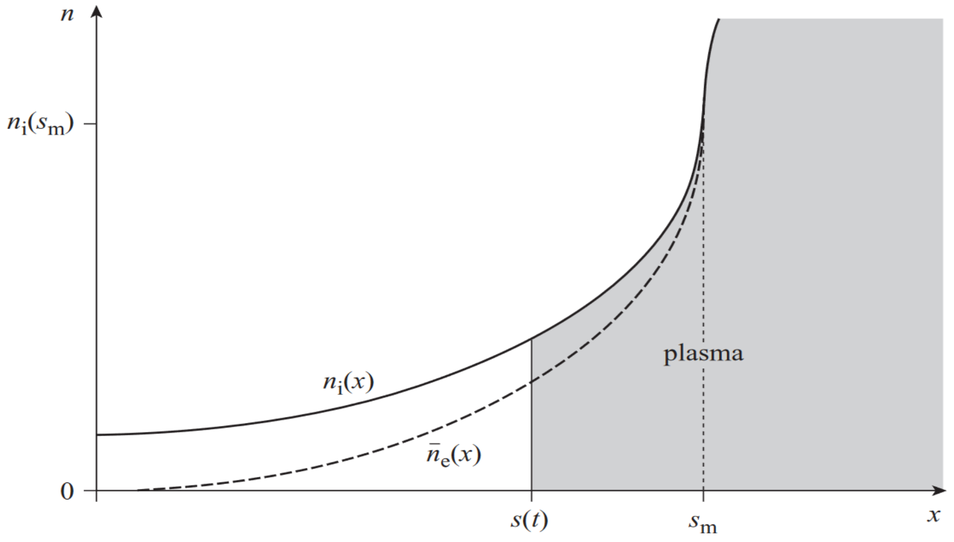
II. Theoretical Background

Child-Langmuir sheath

- Plasma boundary sheath where plasma is in contact with objects (probes, chamber walls, etc.)
  - Positive space charge region
- In RF-discharges sheath oscillates
  - Electrons periodically flood the sheath region



U. Czarnetzki, B. G. Heil, J. Schulze, Z. Donkó, T. Mussenbrock, and R. P. Brinkmann, “The electrical asymmetry effect - a novel and simple method for separate control of ion energy and flux in capacitively coupled rf discharges,”Journal of Physics: Conference Series, vol. 162, p. 012010, 2009



P. Chabert and N. Braithwaite, Physics of radio-frequency plasmas. Cambridge: Cambridge University Press, 2011

- Can be described by the Child-Langmuir law:

$$d \sim \left(\frac{1}{j_i}\right)^{\frac{1}{2}} \bar{V}^{\frac{3}{4}} \text{ (collisionless)}$$

$$d \sim \frac{\lambda_i^{\frac{1}{5}}}{j_i^{\frac{2}{5}}} \bar{V}^{\frac{3}{5}} \text{ (collisional)}$$

Electrical-asymmetry-effect

- 2f discharge driven by superposition of 2 harmonic signals:

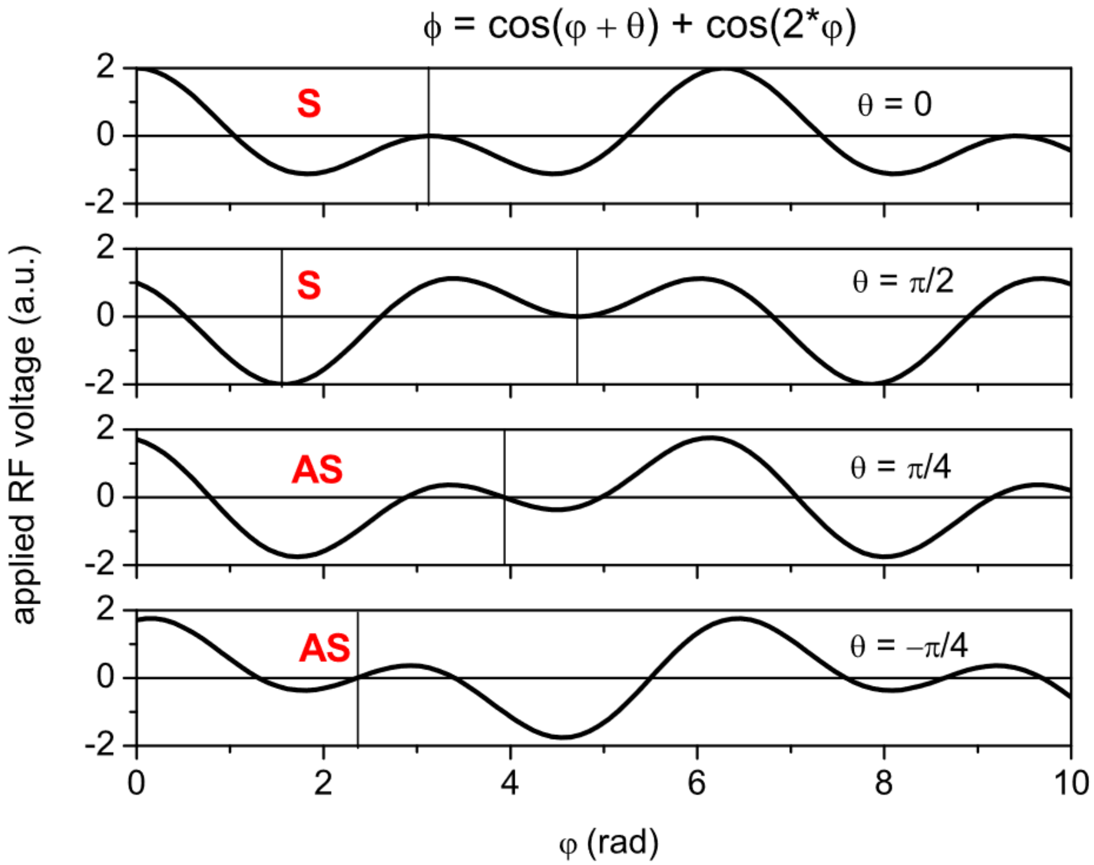
$$V_0 = V_1 \cos(2\pi f t + \theta) + V_2 \cos(4\pi f t)$$

- DC-Self Bias in general given by:

$$\eta = -\frac{V_{0,\max} + \epsilon V_{0,\min}}{1+\epsilon}$$

- Symmetry parameter ϵ:

$$\epsilon = \left|\frac{V_{\mathrm{sp}}}{V_{\mathrm{sg}}}\right|,$$



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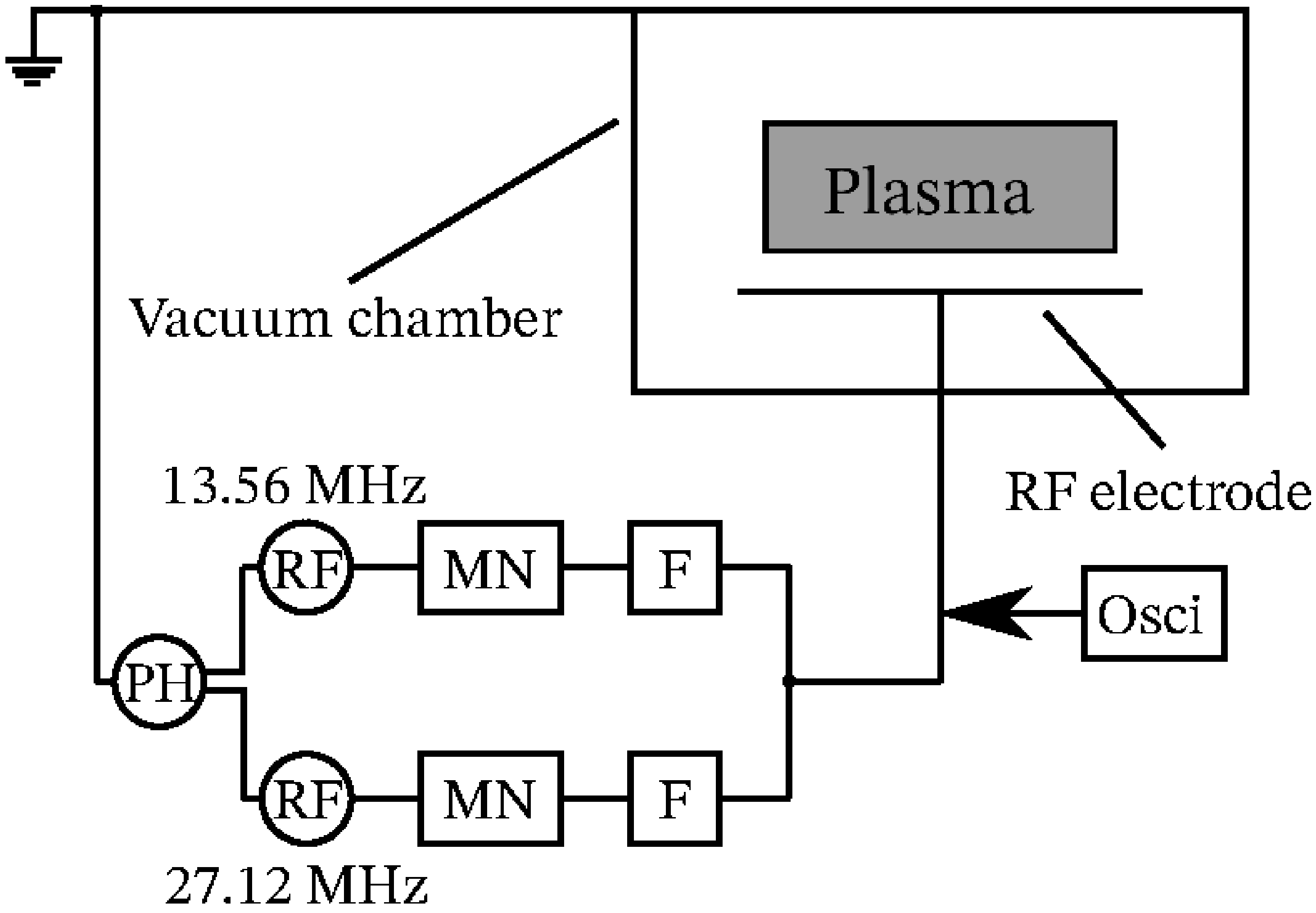
III. Experiment

Plasma chamber



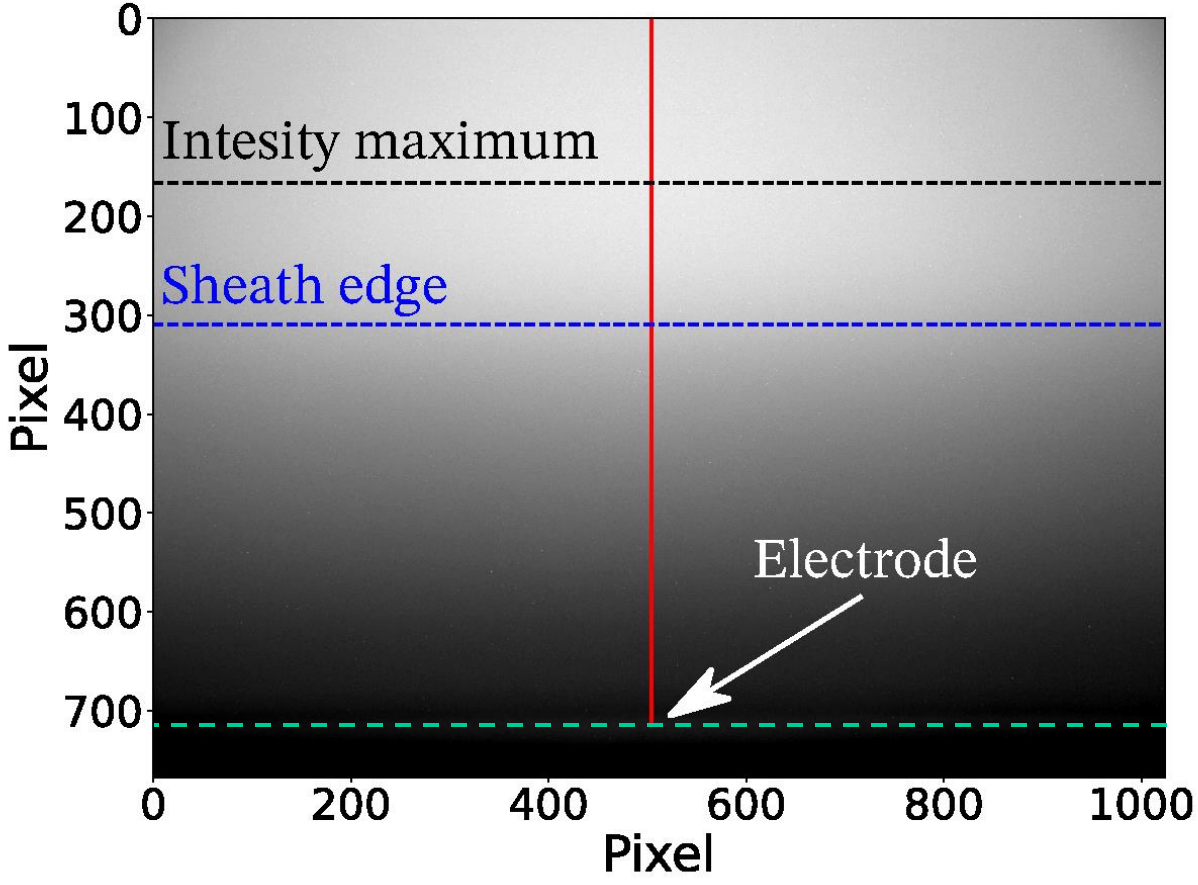
MN: Matching network, RF: RF-generator, PH: Phase shifter, Osci: Oscilloscope, F: Filter

Execution

- Argon plasma

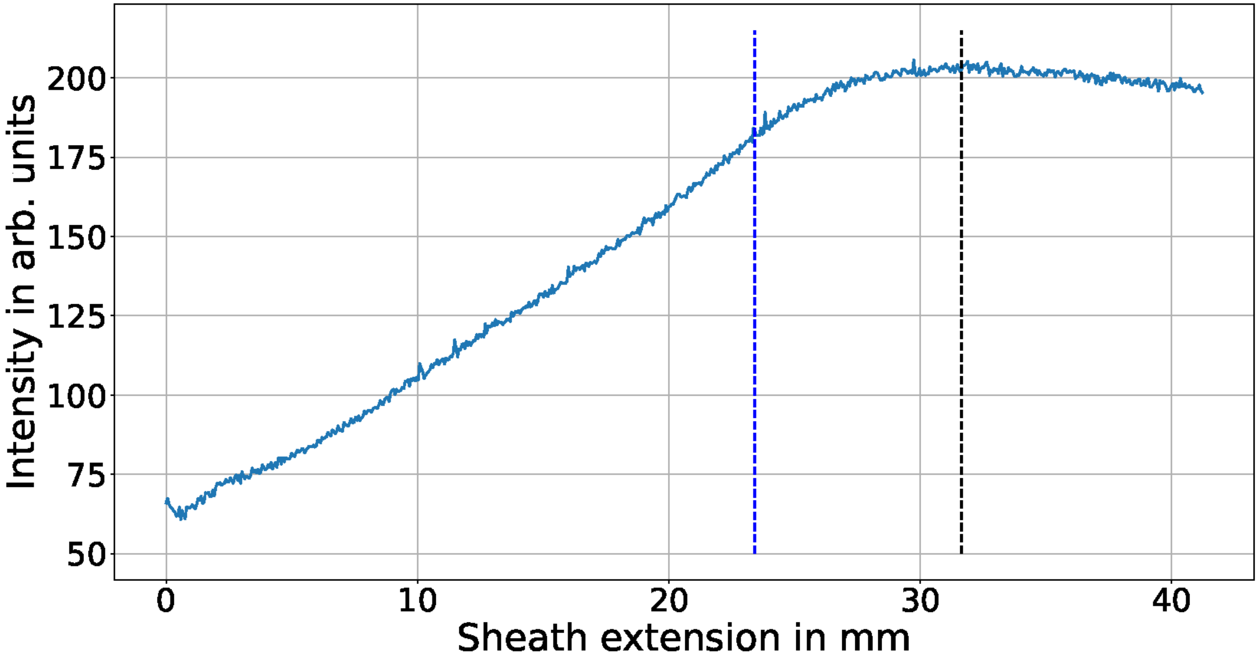
- Sheath extension measurements:
  - Photo of sheath region
    - 1f (13.56 MHz, 27.12 MHz)
    - 2f
    - Pressure variation

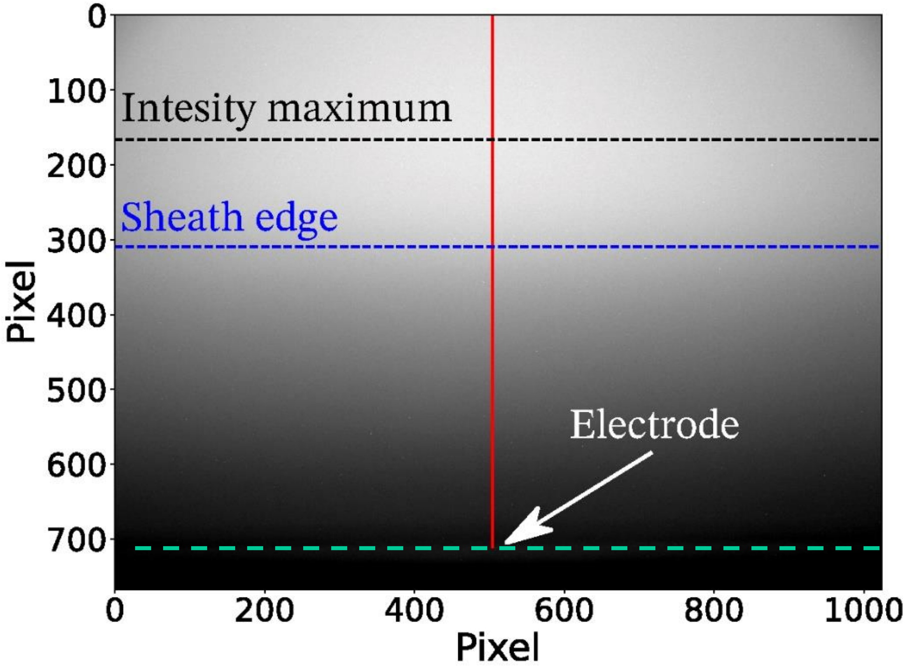
- Langmuir-probe measurements:
  - 1f 27.12 MHz
  - 2f
  - Pressure variation



Execution

- Evaluation of the pictures intensity profiles
- **Assumption:** plasma-sheath edge is located at 75% of the distance to the intensity maximum





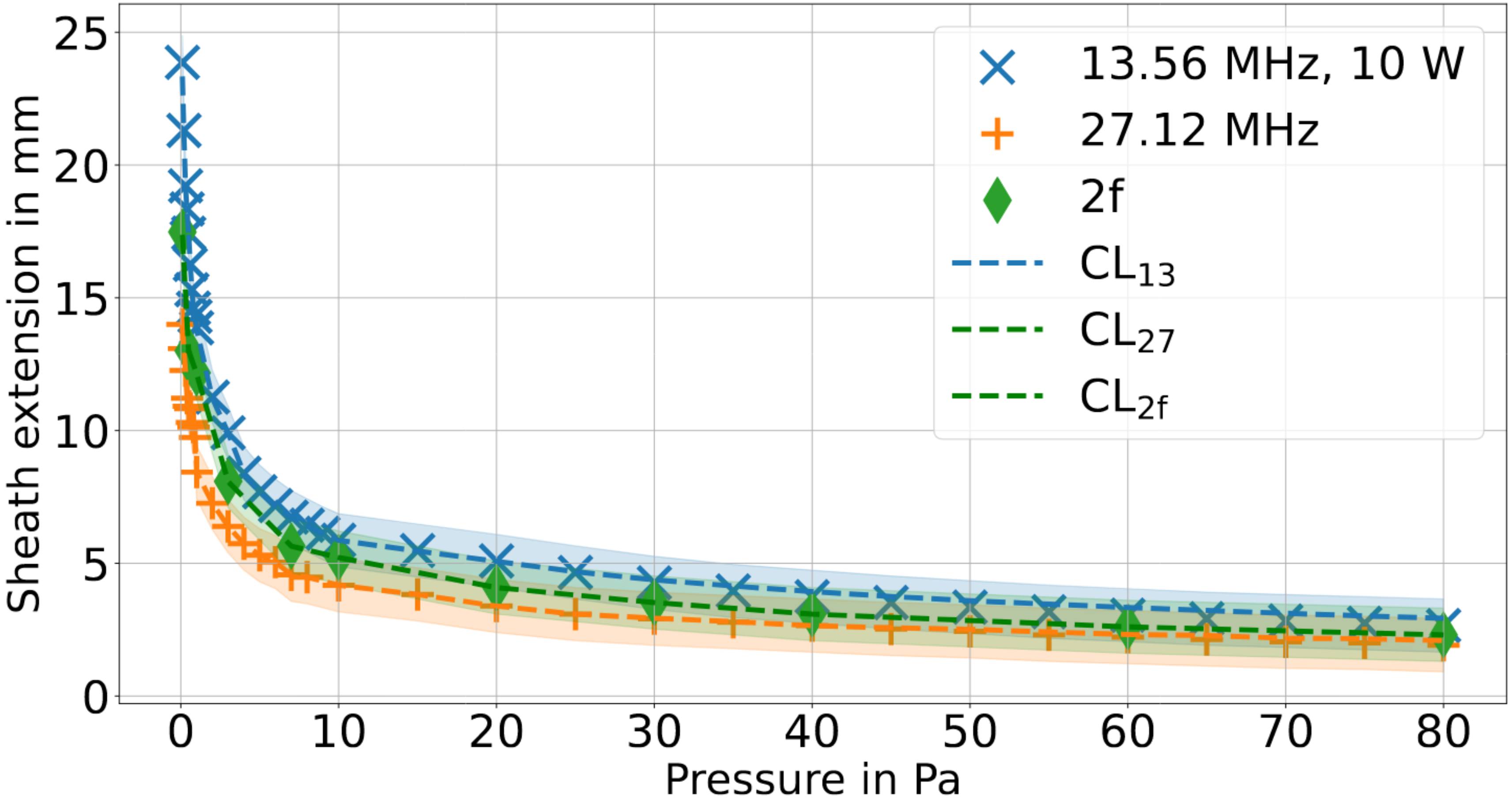
IV. Results

Boundary sheath

Sheath thickness

- Decrease with rising pressure
    - Because of rise in collisions
- Smaller for higher frequencies
- Equalize at 10 – 20 Pa
    - Because collisions dominate

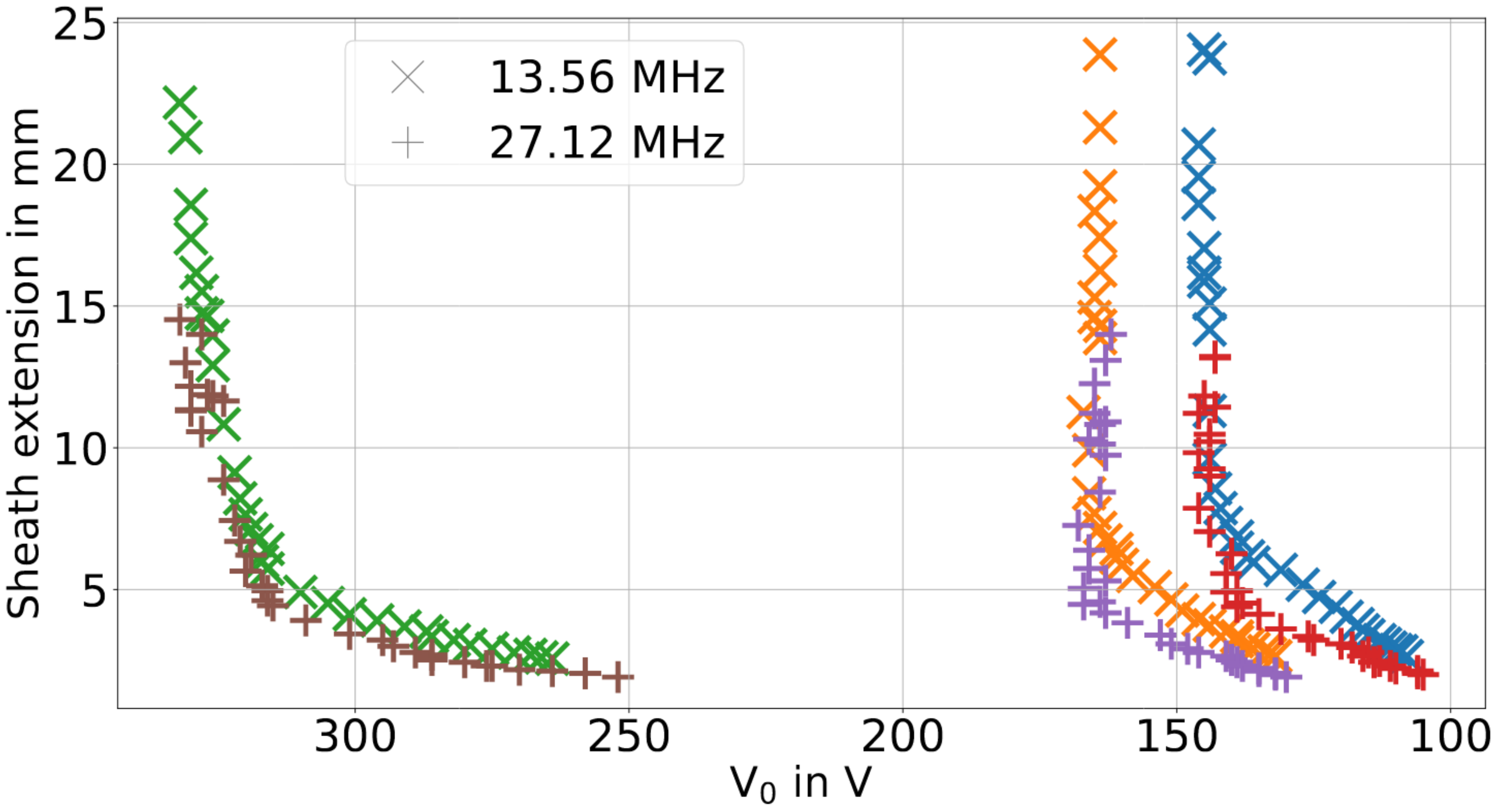
2f sheath influenced by both frequencies



Bopundary sheath

- Sheath thickness almost independent of P and V_0
- Critical parameter is f

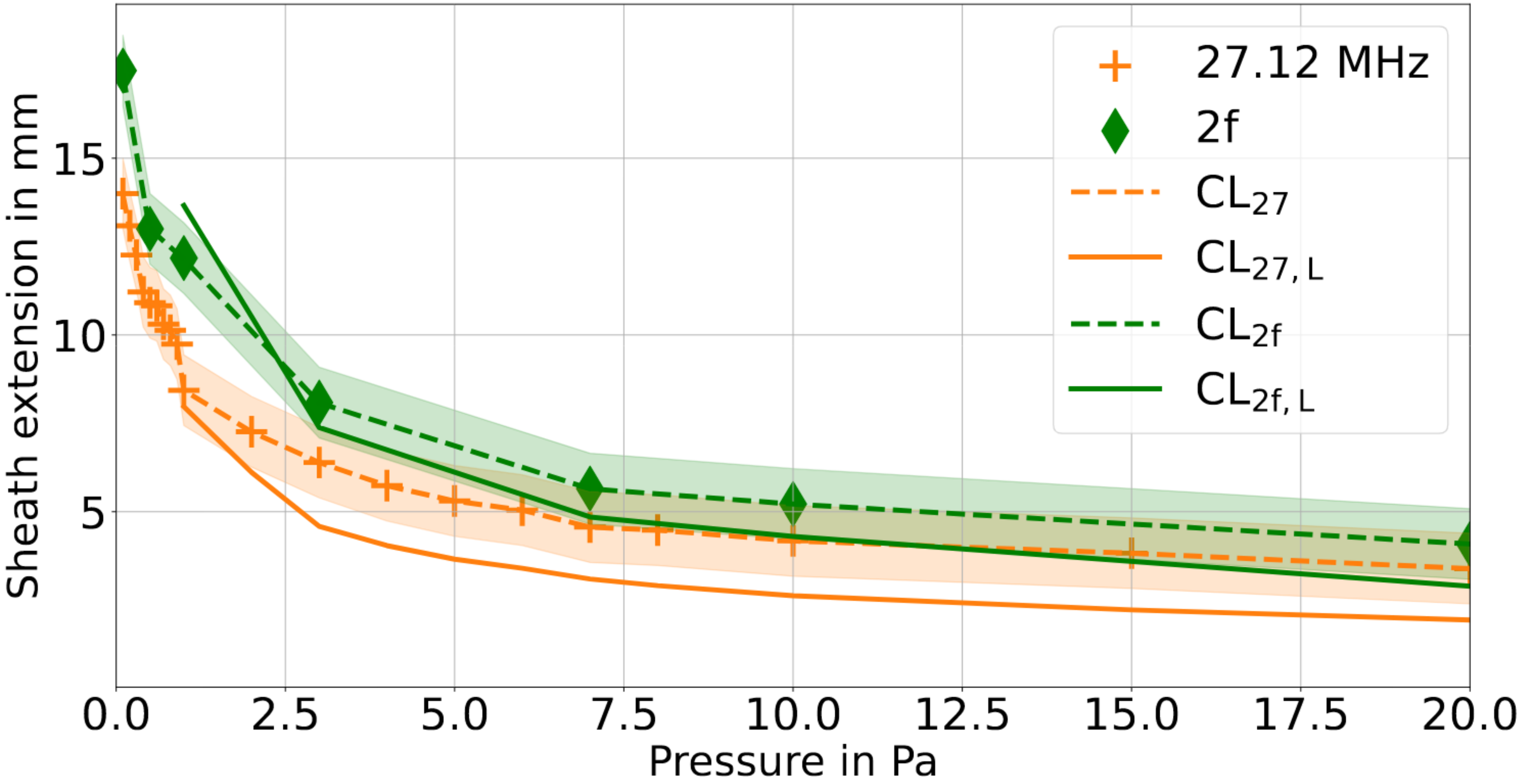
$$d \sim \frac{\lambda_{\mathrm{i}}^{\frac{1}{5}} \bar{V}^{\frac{3}{5}}}{0.61 e n_{\mathrm{e}} \sqrt{\frac{k_{\mathrm{B}} T_{\mathrm{e}}}{m_{\mathrm{i}}}}}$$



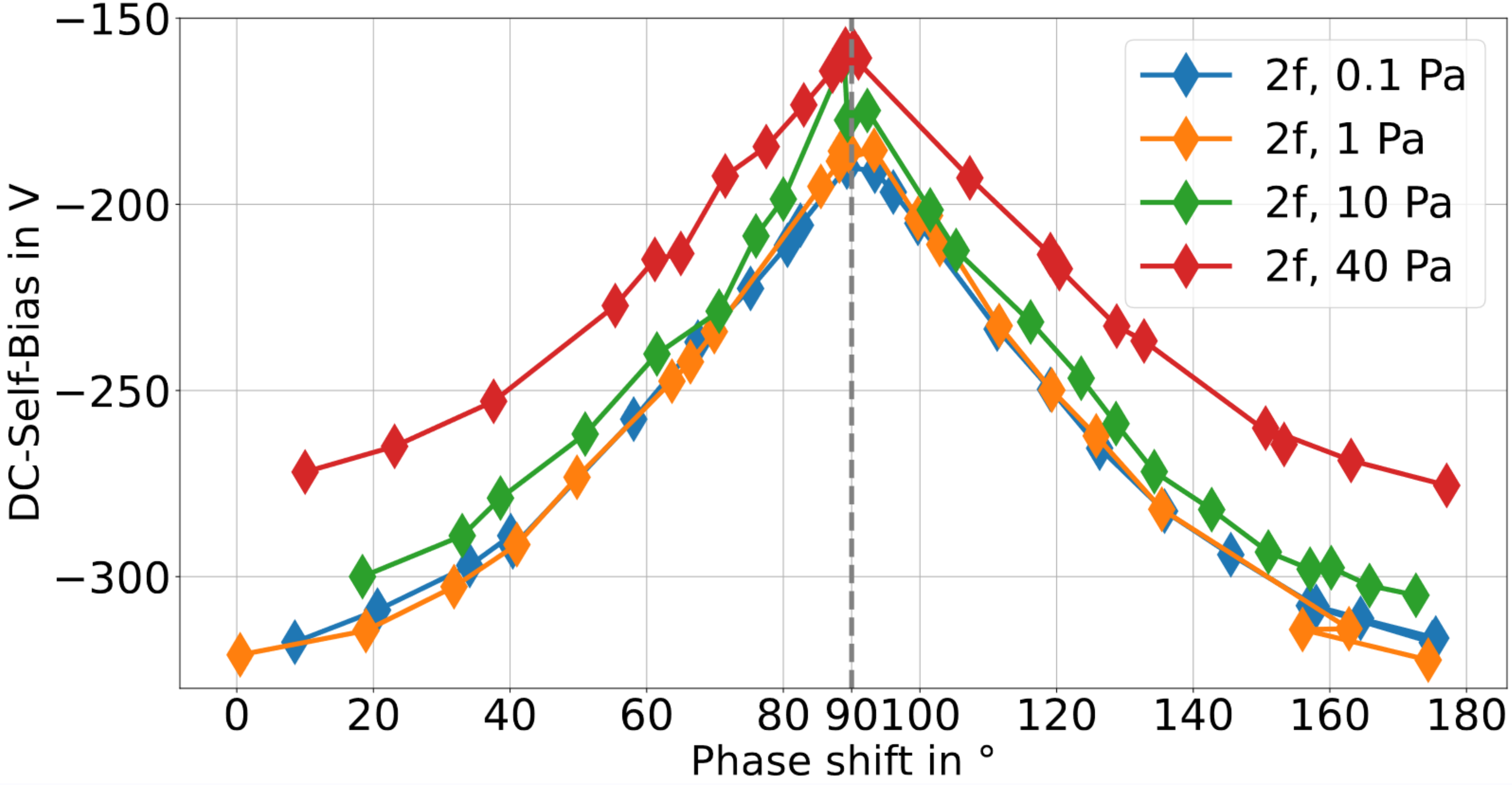
Electron density

- Higher frequency leads to higher densities
    - ➢ Smaller sheath
- 2f density is highest
- Child-Langmuir sheath smaller for measured n_e, T_e

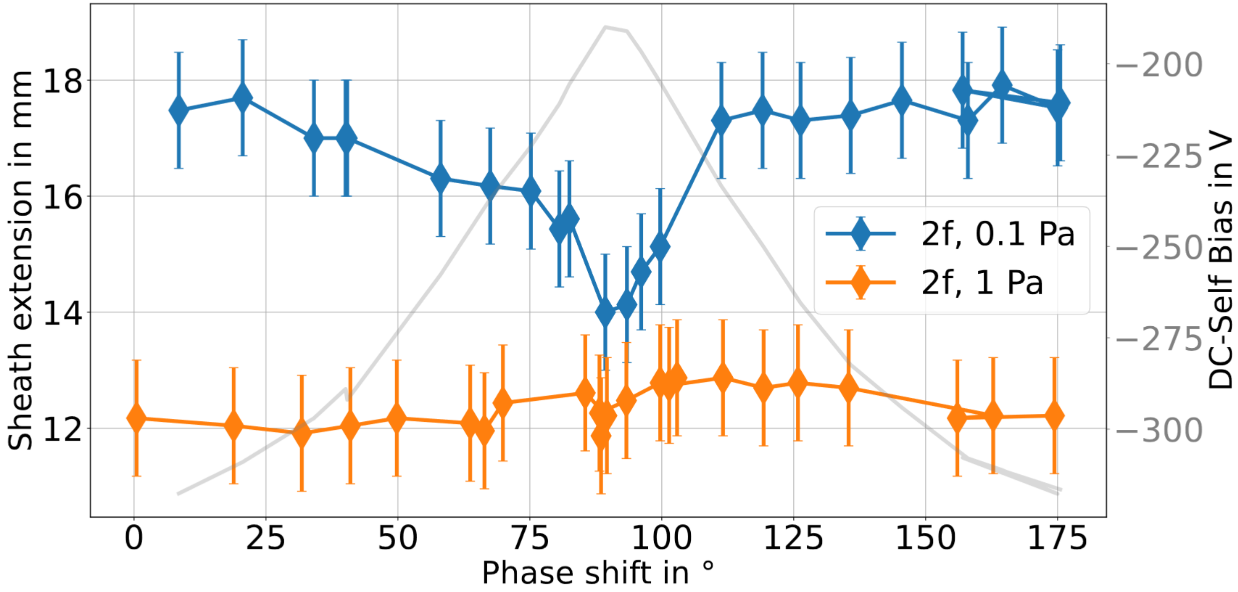
➢ Trends agree well, but absolute values deviate



2f DC-Bias

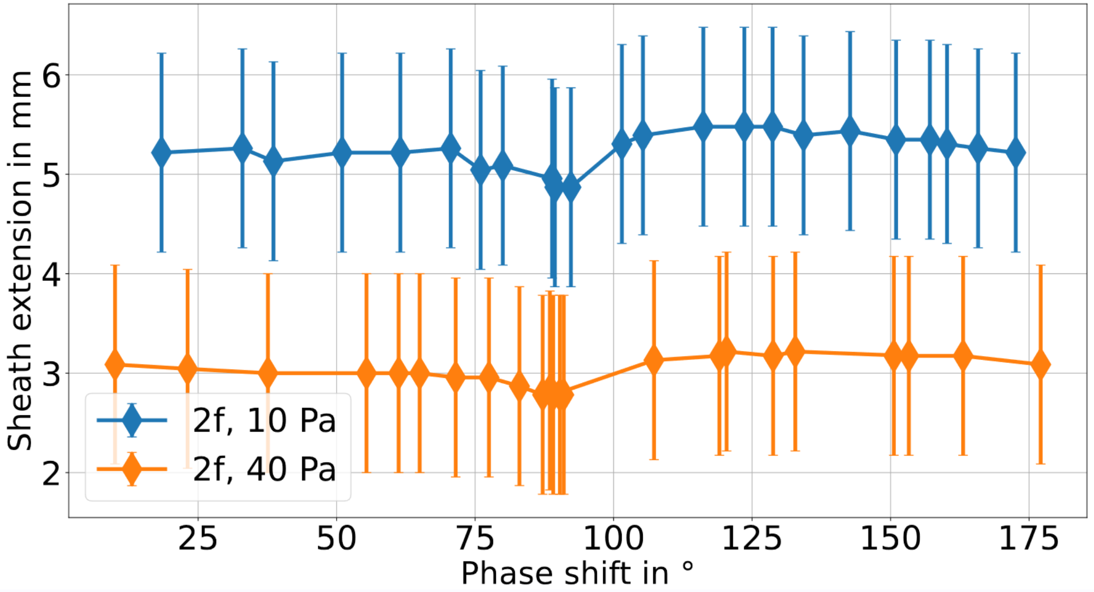

−150
−200
−250
−300
DC-Self-Bias in V
0
20
40
60
80
90
100
120
140
160
180
Phase shift in °
2f, 0.1 Pa
2f, 1 Pa
2f, 10 Pa
2f, 40 Pa

2f boundary sheath

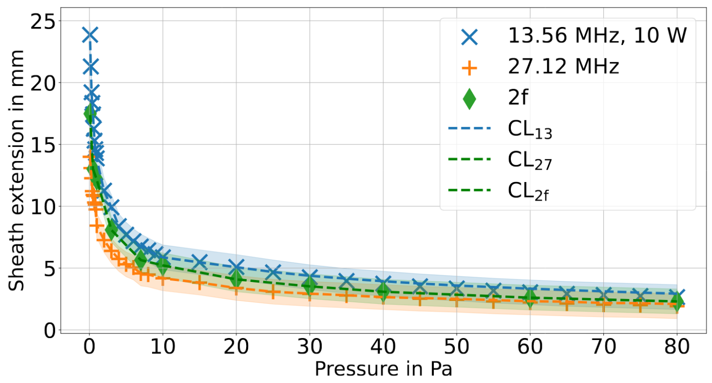


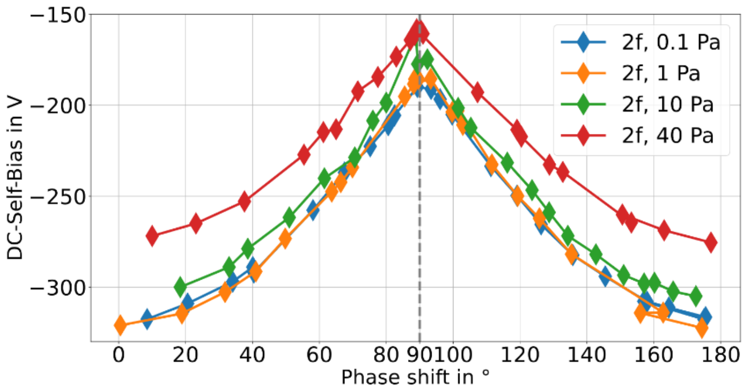
- Expression of sheath thickness minima decrease with rising pressure

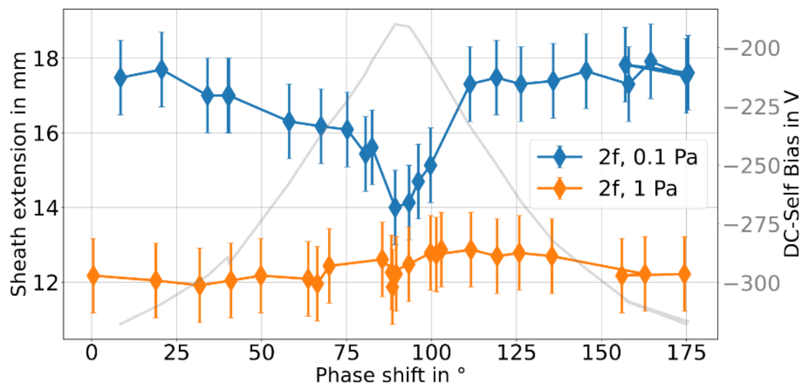
- Asymmetry of the sheath thickness at 90°



V. Conclusion







Boundary sheath

- Decreases with rising pressure
- Is almost independent of power/RF-amplitude
- Is dependent on RF-frequency
- 2f trend resembles 1f trend
- Asymmetry at 90°
- Child-Langmuir law gives trend, but absolute values deviate

Bias

- As expected strongly dependent on the phase
  - With a symmetry at 90°

Photometric diagnostic

➢ Photometric method suitable for estimation of certain parameters and discharge asymmetries

Thank you for your attention