XXIV. Erfahrungsaustausch - Oberflächentechnologie mit Plasma- und Ionenstrahlprozessen
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Measurements on a high voltage pulsed substrate (PBII) in a HiPIMS process

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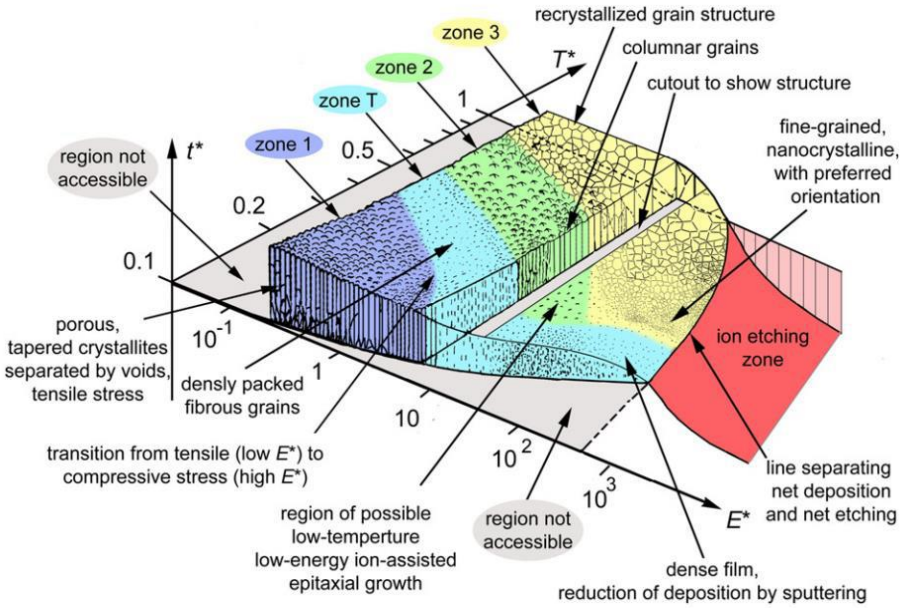
2. Experimental Setup
3. Theory and Method
   - Calorimetric probe (PTP)
   - High voltage pulsed grid
4. Proof of Concept
5. Variation of PBII Parameters
6. Conclusions

Motivation

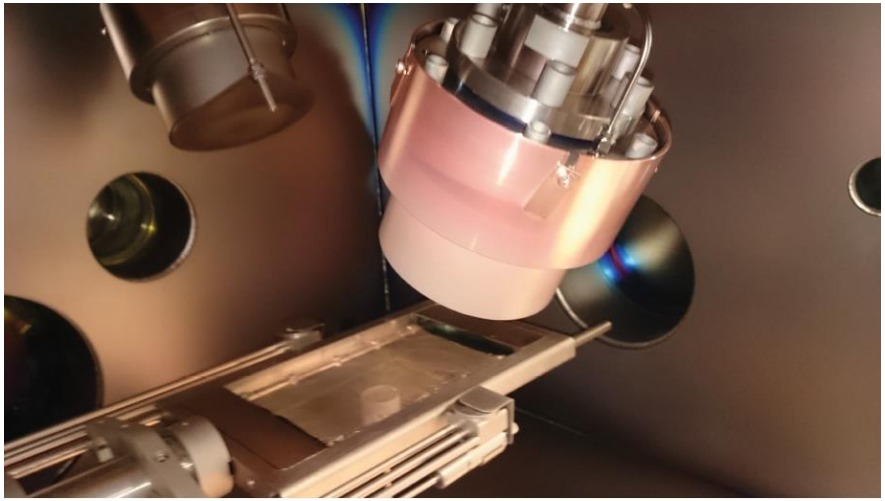
- HiPIMS (High ionization degree of sputtered particles) + PBII (synchronized high voltage substrate pulsing) = versatile system for simultaneous coating and doping
  - Efficient cleaning and deposition in one process
  - Enhanced adhesion
  - Reduction of stress
- Adjustment of delay between HiPIMS and PBII pulse allows tuning of ion flux to the substrate
- Energy flux to the substrate is a crucial process parameter

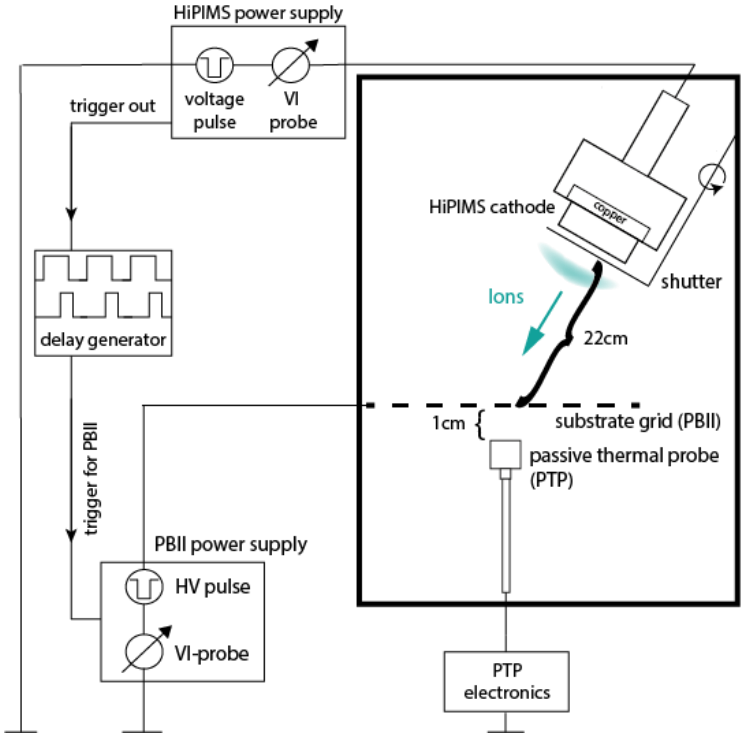
Lattemann, M. et al., Surface and Coatings Technology, 200(22–23), 6495–6499, 2005
Ehiasarian, A. P. et al., (2007), Journal of Applied Physics, 101(5)



A. Anders, Thin Sold Films, Vol. 518, 2010
J. A. Thornton, J. Vac. Sci. Technol. Vol. 11, No. 4, 1974
B. A. Movchan and A. V. Demshishin. Phys. Met. Metallogr. (Engl. Trans.), 28(4):83–90, 1969.

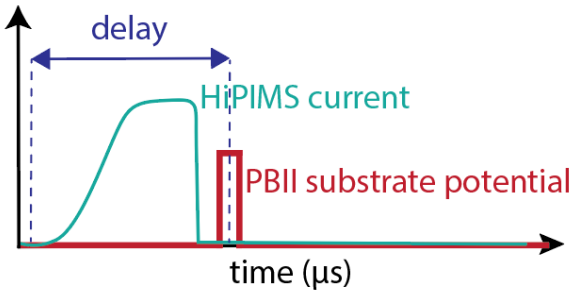
Experimental Setup





HiPIMS: 100 Hz, 200 µs, planar circular 4" magnetron, Cu – target,
P ≈ 800 W (≙0.88kW/cm²), PBII 100 Hz

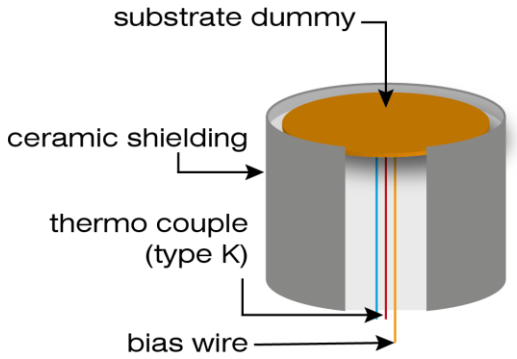
	HiPIMS parameters		PBII parameters	
Variation of PBII pulse duration	Voltage (V)	600	Voltage (kV)	-3
	Peak power density (kW/cm^2)	0.88	Delay (μs)	10 - 1030
	Pressure (Pa)	1.5	On-time(μs)	**20-60**
Variation of PBII voltage	Voltage (V)	580	Voltage (kV)	**-3 - -15**
	Peak power density (kW/cm^2)	1.15	Delay (μs)	2 - 1002
	Pressure (Pa)	1	On-time(μs)	5



Theory and Method – Calorimetric probe (PTP)

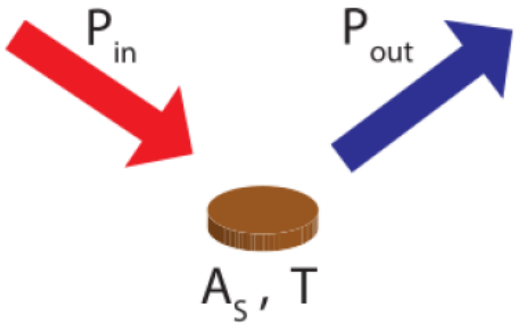
Relation between derivative of the substrate enthalpy H_s and derivative of the substrate temperature T_s :

$$\dot{H}_s = C_s \frac{dT_s}{dt} = P_{in} - P_{out}$$



$$\text{power source on :} \quad C_s \frac{dT_{s_{heat}}}{dt} = P_{in} - P_{out}$$

$$\text{power source off :} \quad C_s \frac{dT_{s_{cool}}}{dt} = -P'_{out}$$



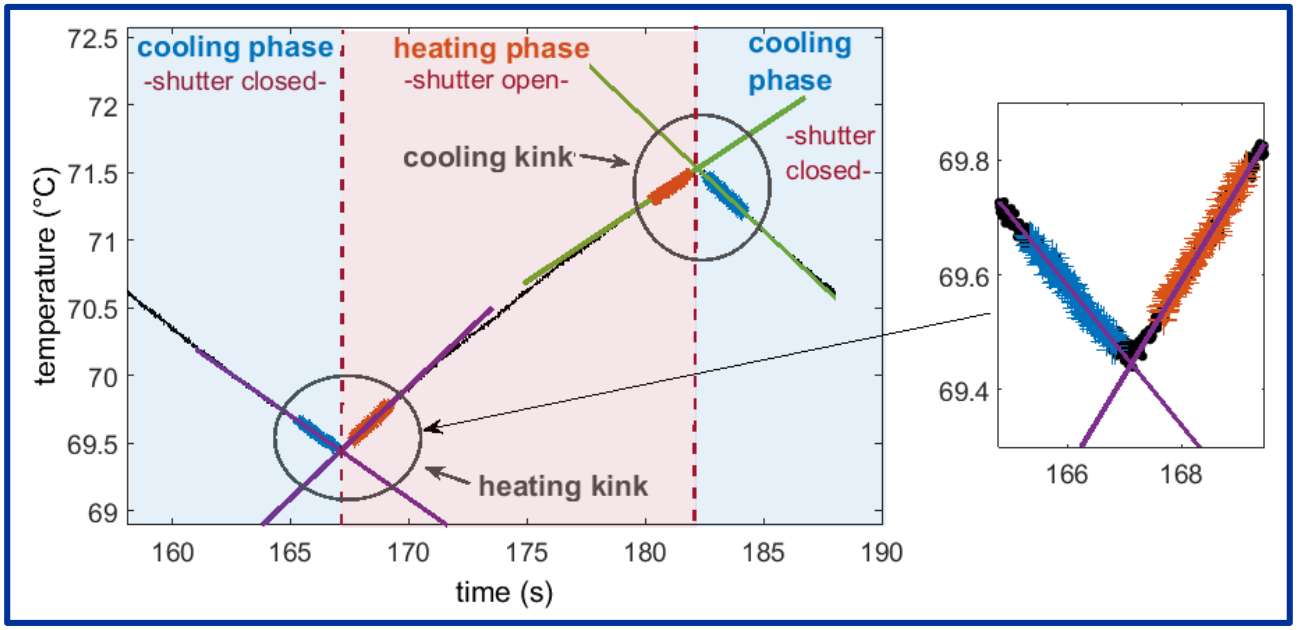
Theory and Method – Calorimetric probe (PTP)

$$\text{power source on :} \qquad C_s \frac{dT_{s_{heat}}}{dt} = P_{in} - P_{out}$$

$$\text{power source off :} \qquad C_s \frac{dT_{s_{cool}}}{dt} = -P'_{out}$$

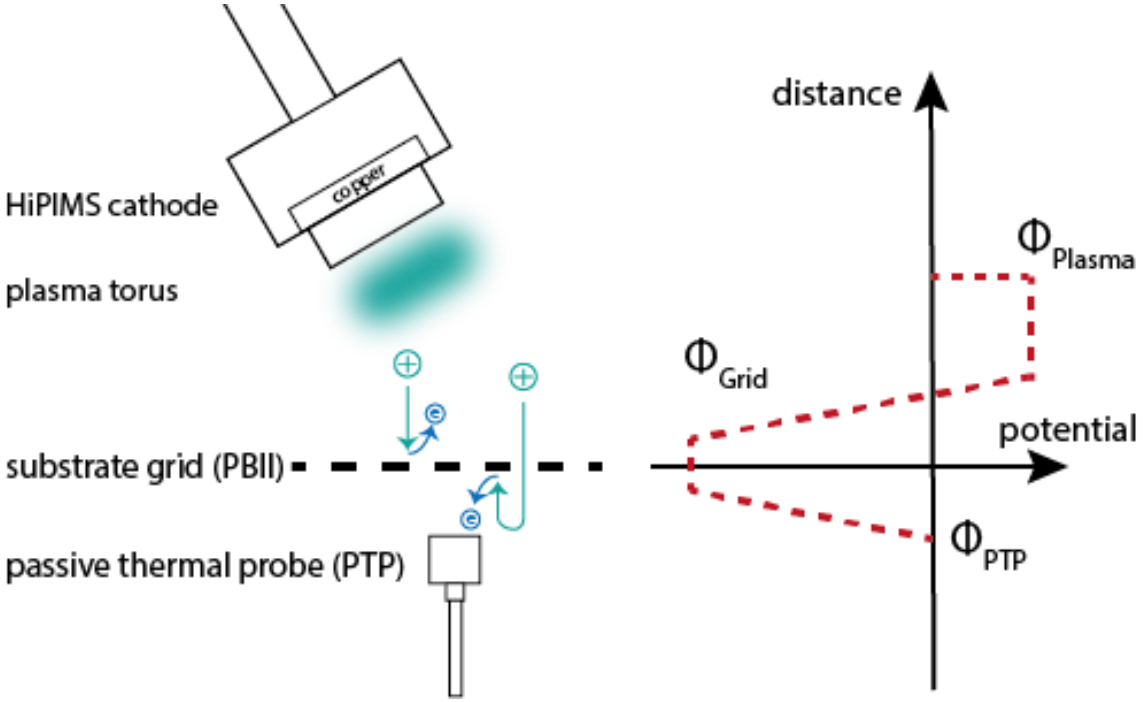
Assumption for small changes of temperature: $P_{out} = P'_{out}$

$$P_{in} = C_s \cdot \left(\frac{dT_{s_{heat}}}{dt} - \frac{dT_{s_{cool}}}{dt} \right) \qquad J_{in} = \frac{P_{in}}{A_s}$$



Delay 100 µs, 5 µs PBII pulse duration, 3 kV PBII voltage, 1 Pa, 580 V HiPIMS voltage, 200 µs pulse at 100 Hz

Theory and Method – High voltage pulsed grid

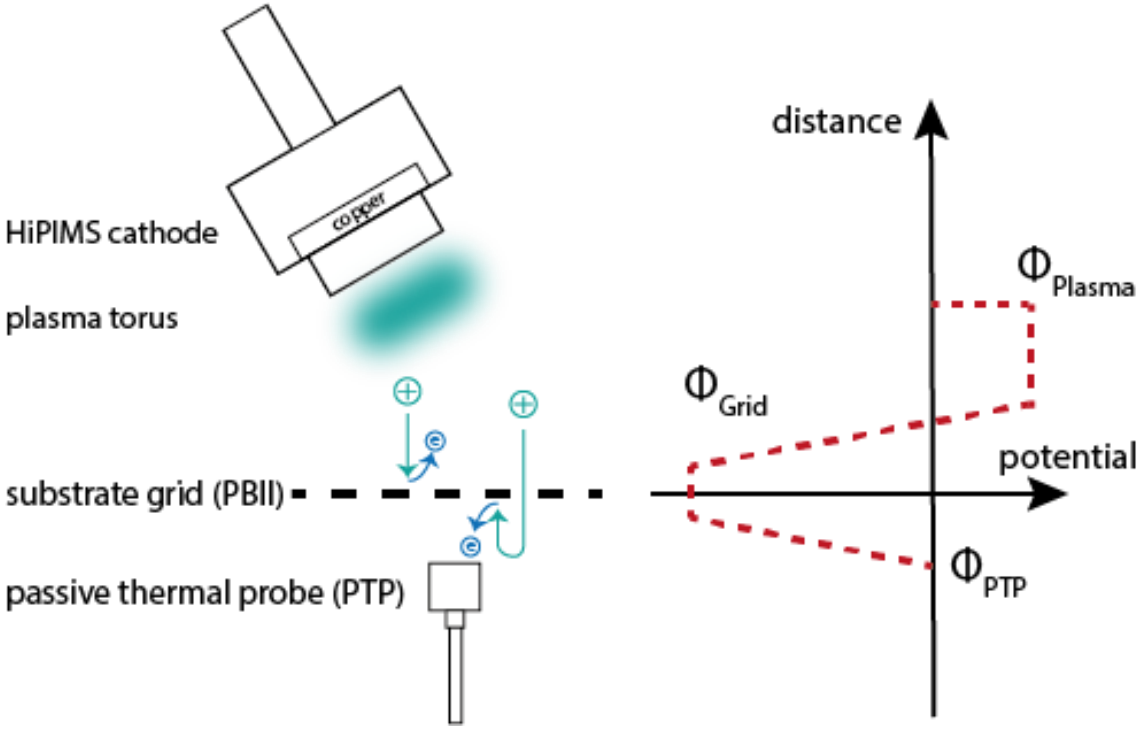


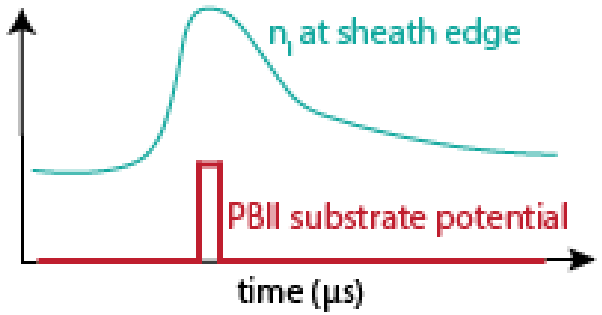
- Sheath transit time < 3 µs, Child-Langmuir
- Ions can oscillate in grid potential
- Ions hitting the grid create secondary electrons
- Energy flux and electric power on grid is composed of
  - SEE with full grid potential
- Energetic Ions released from grid potential at PBII switch off

$$t_{sheath} = 3 \cdot \sqrt{\frac{m_{Cu}}{2e \cdot U_{PBII}}} \cdot d_{sheath}$$

→ PTP measurement can be used to obtain information about energy flux onto PBII substrate grid

Theory and Method – High voltage pulsed grid

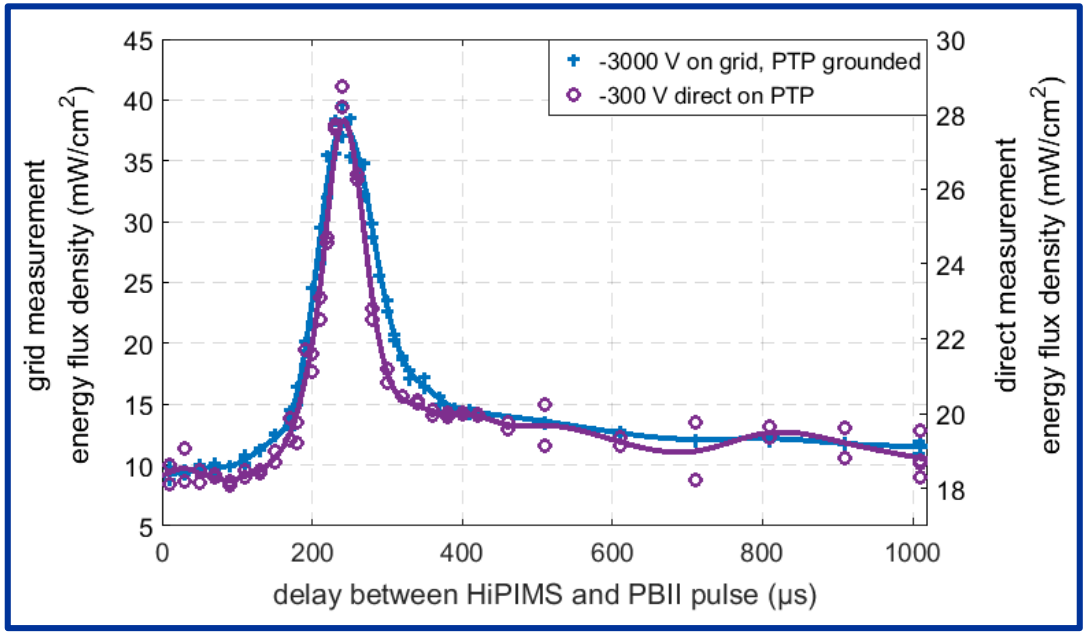




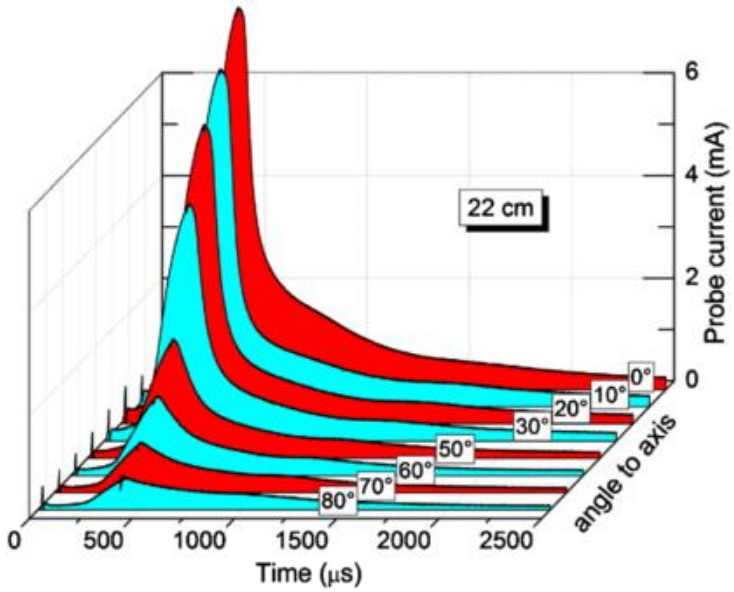
- Substrate only interacts with ions entering the sheath, the plasma remains mostly unaffected
- Results give “snapshot” of the ion density at the sheath edge with the exposure time defined by the PBII on-time

Proof of Concept – DOES IT WORK?

-3000 V applied on grid setup
vs.
-300 V applied directly



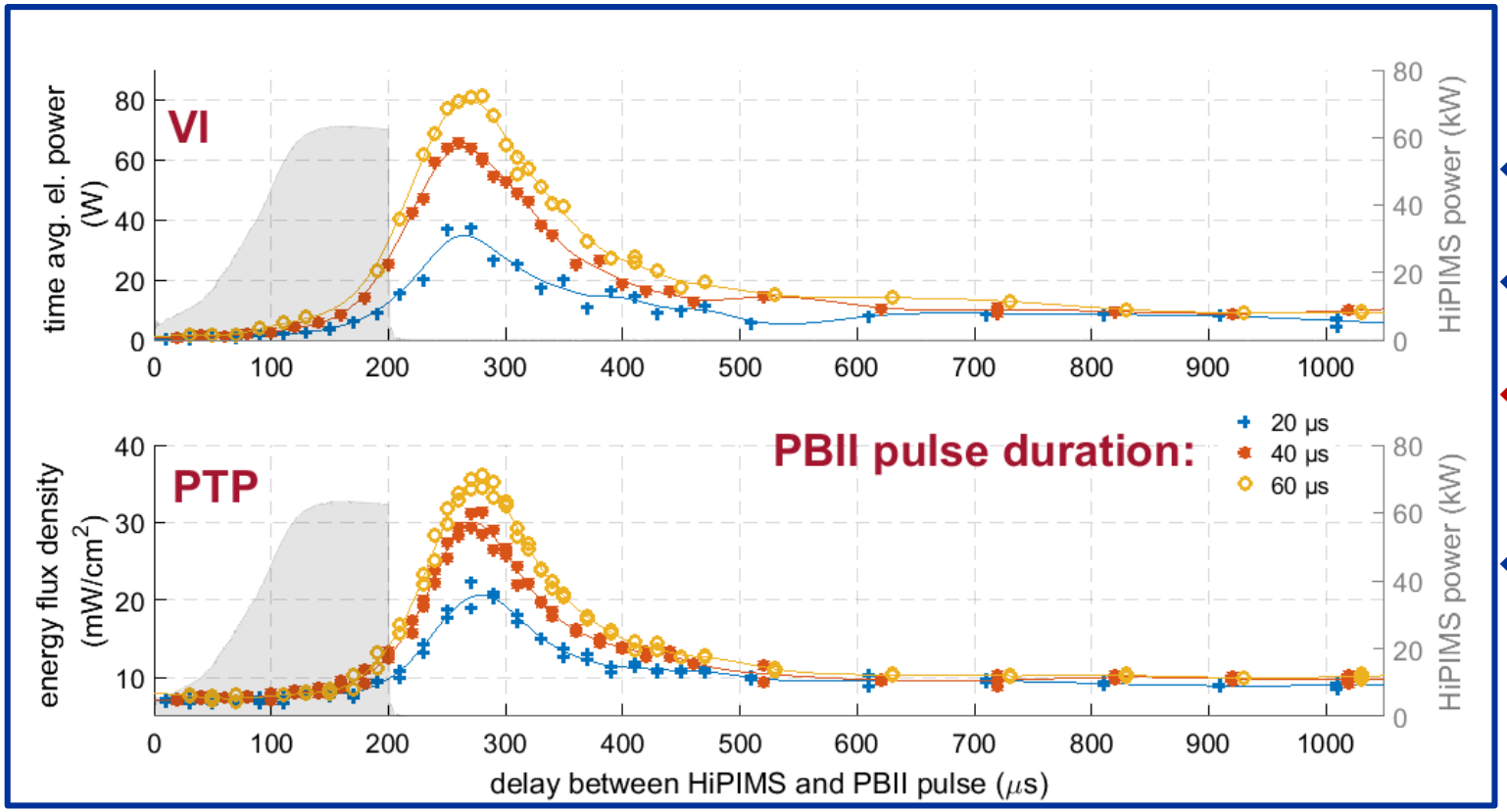
1.5 Pa, 18 cm, 580 V, 200 µs, 100 Hz, PBII 20µs



1.75 Pa, 22 cm, 400 µs, 1000V Vacuum-Arc Triggered HiPIMS
Horwat, D. & Anders, A. (2010), Journal of Applied Physics, 108(12).

- excellent agreement of the waveforms.
- No influence of PBII voltage on position of detected maximum

Variation of PBII Parameters – PBII pulse duration

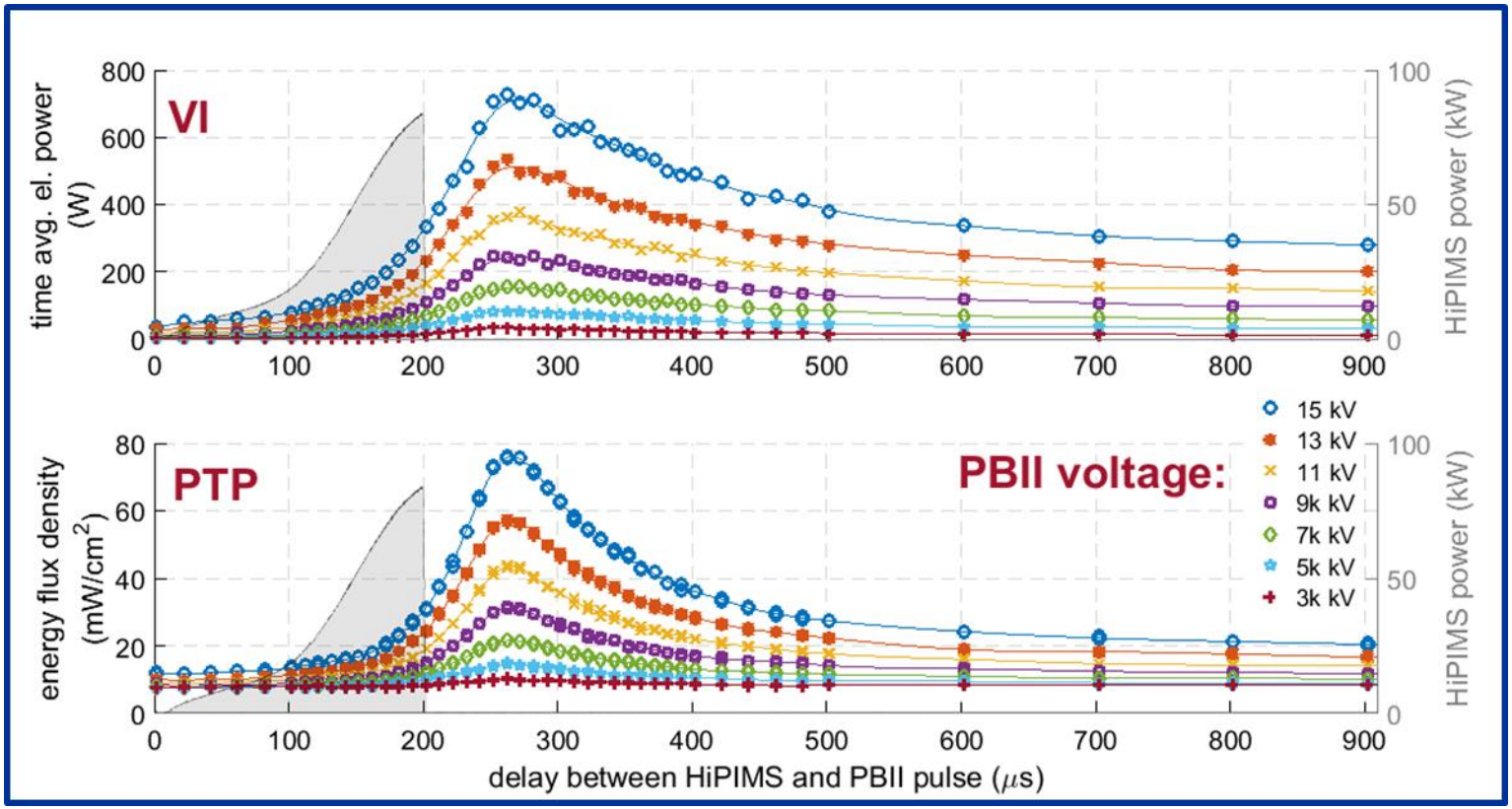


1.5 Pa, 200 µs, 100 Hz, 600 V, PBII voltage -3 kV

- Constant HiPIMS
- Variation of delay
- 3 different PBII pulse durations
- Parallel VI and PTP measurement

- Direct correlation between VI and PTP results
- Longer pulse duration increases number of ions arriving from the plasma during on-time of the PBII pulse → longer "exposure time"
- Energy flux and electrical power increase due to increased amount of oscillating ions and corresponding increased creation of SEE

Variation of PBII Parameters – PBII voltage



1 Pa, 200 µs, 100 Hz, 580 V, PBII On-Time 5 µs

- Constant HiPIMS
- Variation of delay
- 7 different PBII voltages
- Parallel VI and PTP measurement

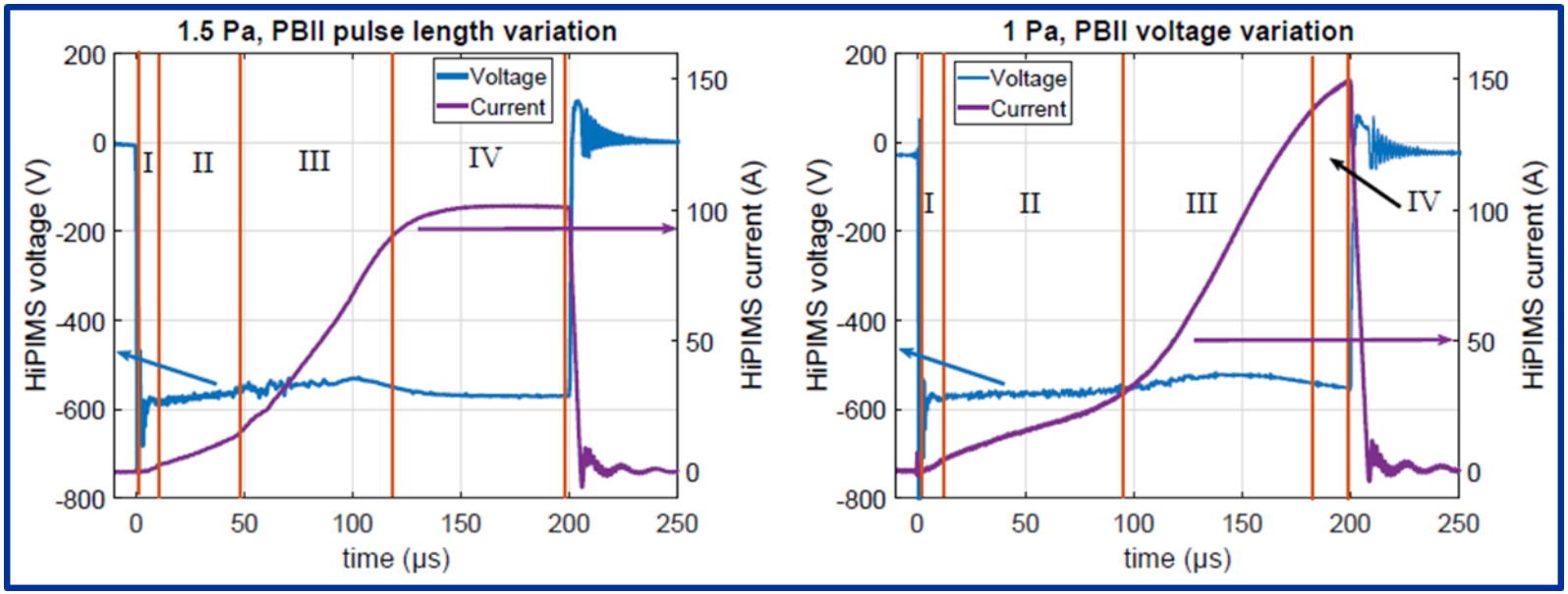
- Direct correlation between VI and PTP results
- Higher PBII voltage → higher ion energy → increased $\lambda_{SE} \sim \sqrt{U_{PBII}}$
- Strong increase of electrical power on grid and energy flux measured by PTP $>\propto \left(U_{PBII}^{\frac{3}{2}}\right)$

B. Szapiro and J. J. Rocca., Journal of Applied Physics, 65(9):3713-3716, 1989.

Conclusions

- Setup with high voltage pulsed grid and passive thermal probe can be used for qualitative measurement of power and energy influx onto a highly biased substrate during HiPIMS deposition.
- Energy flux measured on the PTP below the grid is composed of portions from energetic ions and secondary electrons created on the grid.
- For all delay variations a peak-like shape of the curves for electrical power and energy flux density were observed. This peak can be attributed to an ion density wave which travels from the HiPIMS target towards the substrate, creating a peak as it arrives at the grid.
- Increased PBII pulse lengths means longer "exposure time" and, thus, more ions trapped in the grid potential and correspondingly larger energy flux
- Increasing PBII voltage results in increased electrical power and energy flux caused by a combination of increased ion and electron energy, higher secondary electron yield and larger sheath expansion.

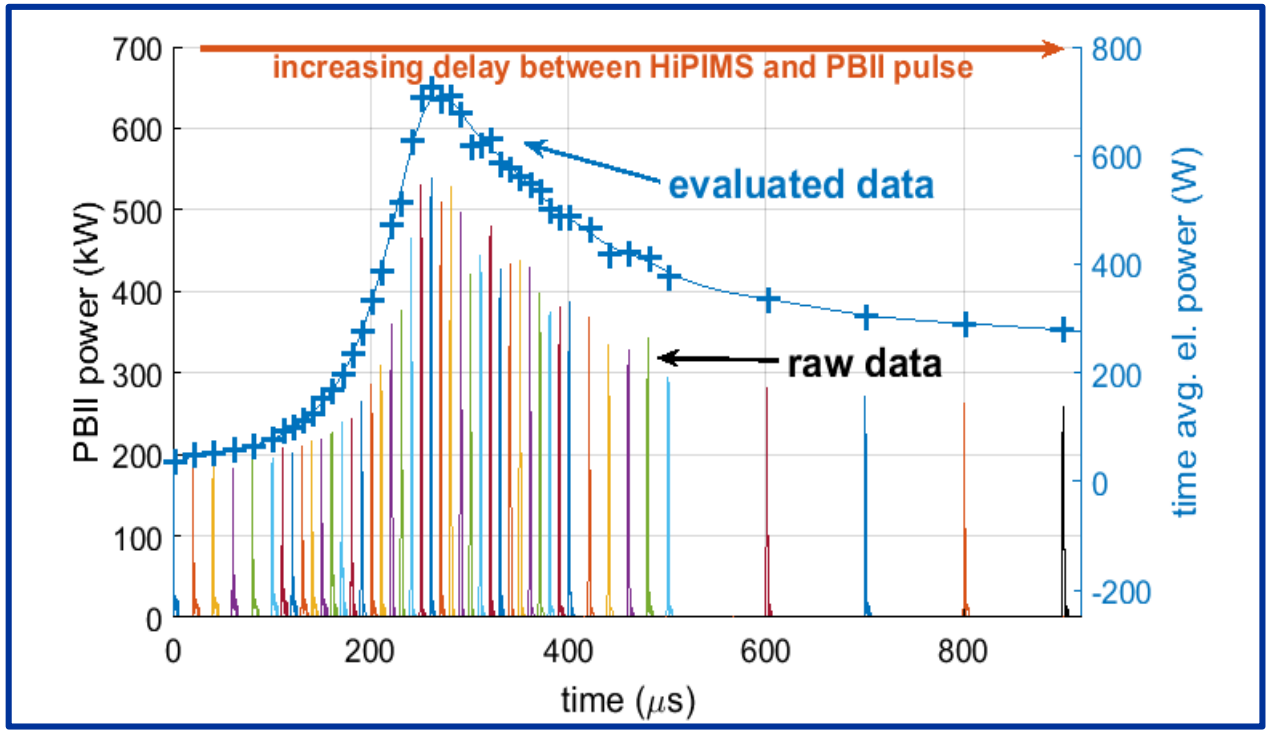
Thank you for your attention!


1.5 Pa, PBII pulse length variation
Voltage
Current
I
II
III
IV
HiPIMS voltage (V)
HiPIMS current (A)
time (µs)
1 Pa, PBII voltage variation
Voltage
Current
I
II
III
IV
HiPIMS voltage (V)
HiPIMS current (A)
time (µs)

Theory and Method – VI-Probe measurements

- Oscilloscope measurement of voltage and current on PBII substrate grid
- Calculation of time averaged power gives a comparable value to energy flux measured by the PTP

$$P_{PBII,avg} = \overline{P}_{PBII,rec} \cdot \frac{t_{rec}}{T_{HiPIMS}}$$



Delay 0 - 900 µs, 5 µs PBII pulse duration, 15 kV PBII voltage, 1 Pa, 580 V HiPIMS voltage, 200 µs pulse at 100 Hz