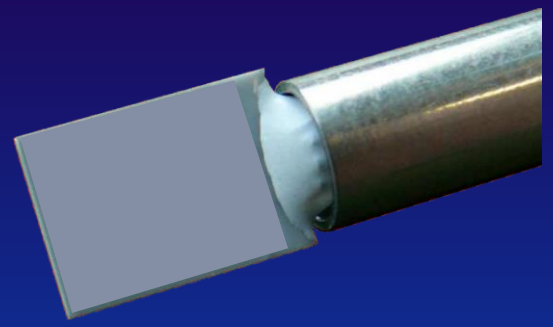
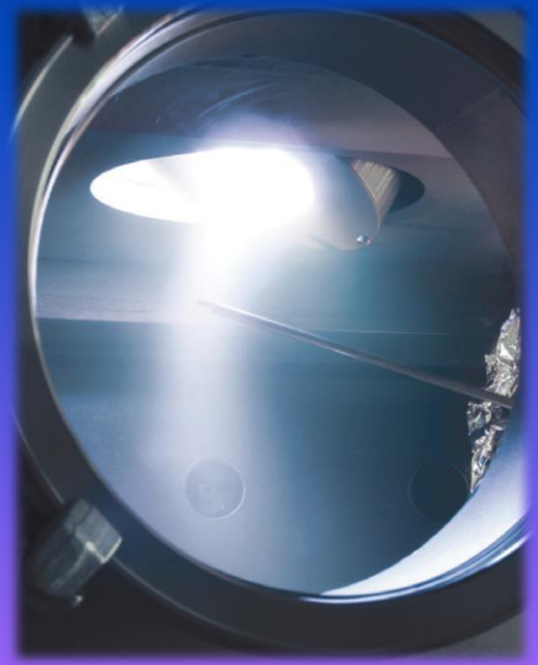
A Probe for direction-dependent measurement of the energy influx – diagnostic and monitoring of plasma processes



XXVIII. Erfahrungsaustausch Oberflächentechnologie mit Plasma- und Ionenstrahlprozessen

Mühlleithen, März 2023



R. Wiese [1]
H. Kersten [2]
G. Wiese [3]
R. Bartsch [4]

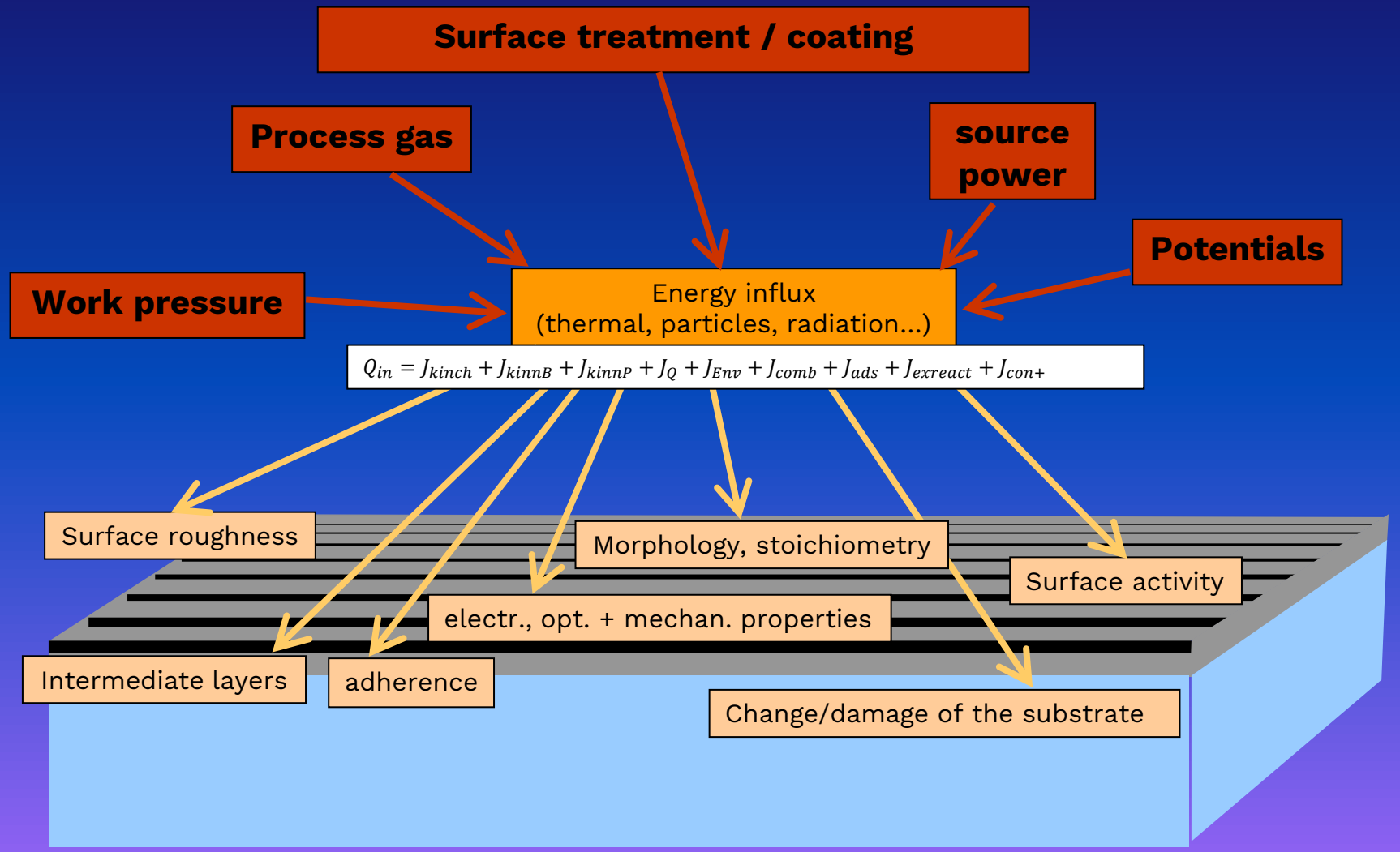
[1] *Ampower Science and Engineering GmbH*
[2] *Christian-Abrecht-Universität Kiel*
[3] *Sonotec GmbH, Halle*
[4] *neoplas GmbH, Greifswald*

History

- 2008 Patent
- 2008 Functional model
- market survey
- 2010 – 2011 Project E-Impact
  - Probe with bias voltage
  - Double probe (directional measurement)
- Measurements in different plasmas (Kiel, Liverpool, Leipzig)
  - Experience gained, another look at the probe
  - Comparison with other probes
- Offer from corporation Hiden
- Attempt to cooperate with Zirox
- Job at neoplas
- Feb 2022 Setting up a business

Motivation

process parameter → energy influx → layer properties



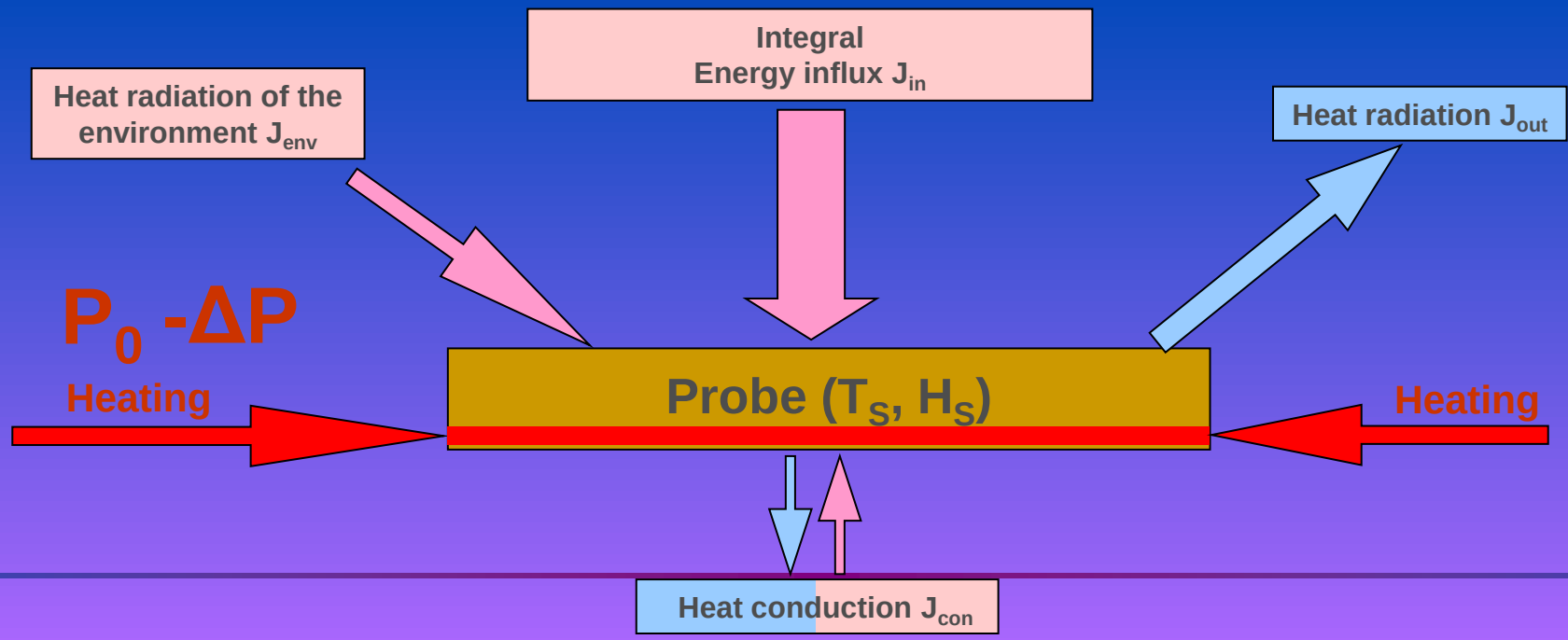
Measurement principle of the Active Thermal Probe

$$\dot{H}_S(cool) = J_{env} - J_{out} \pm J_{con}(T_S - T_c)_{cool} + P_0 = 0$$

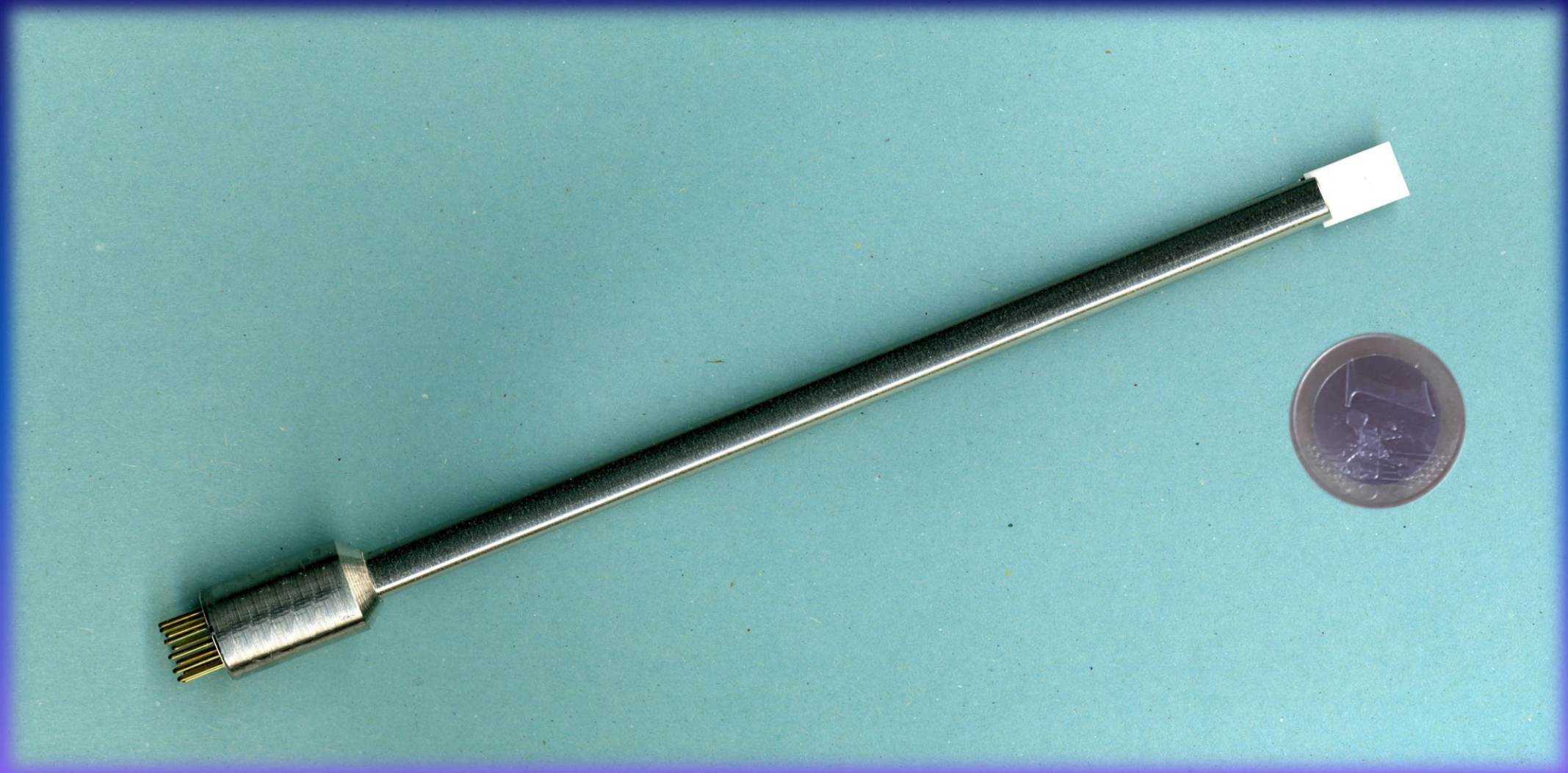
$$\dot{H}_S(heat) = J_{in} + J_{env} - J_{out} \pm J_{con}(T_S - T_c)_{heat} + P_0 - \Delta P = 0$$

$T_S = const$ ⇝ $\dot{H}_S = m \cdot c \cdot \frac{dT_S}{dt} = 0$

$$J_{in} = \Delta P$$



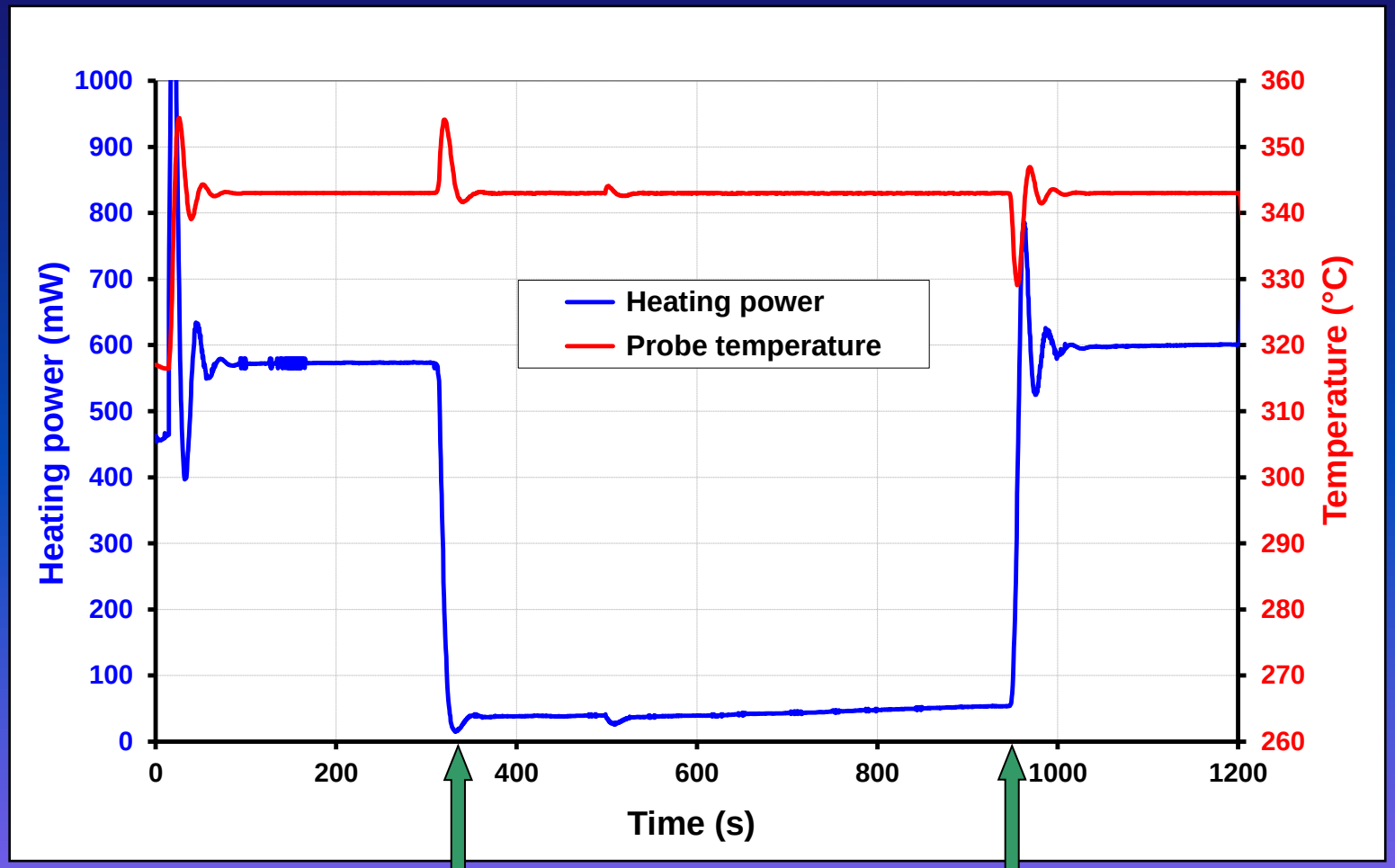
Measurement principle – parameters achieved



Measurement principle – parameters achieved

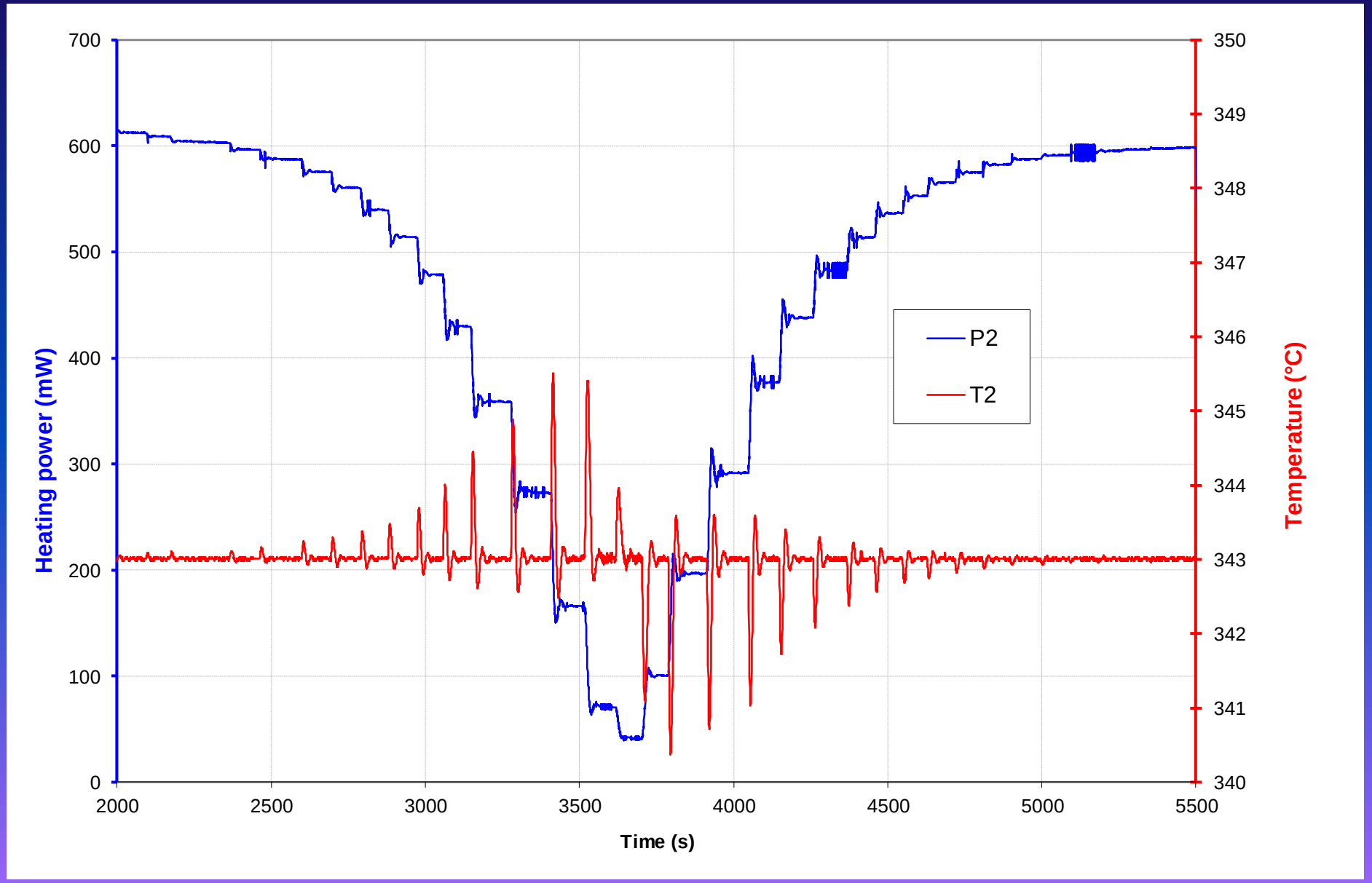
- Measurement area: 7 x 7 mm
- Sensor thickness: 0.35 mm
- Probe temperature: 0 … 400 °C (600 °C)
- temperature constancy: 0.03 °C
- Max. power fluctuation: 0.1 mW/cm²
- Time resolution: 0.2 - 20 s
- Measuring range: 0.001 … 2 W/cm²
  in “passive mode” until 100 W/cm²
- Accuracy/measurement error : 1 mW/cm²

Measurement principle of the Active Thermal Probe

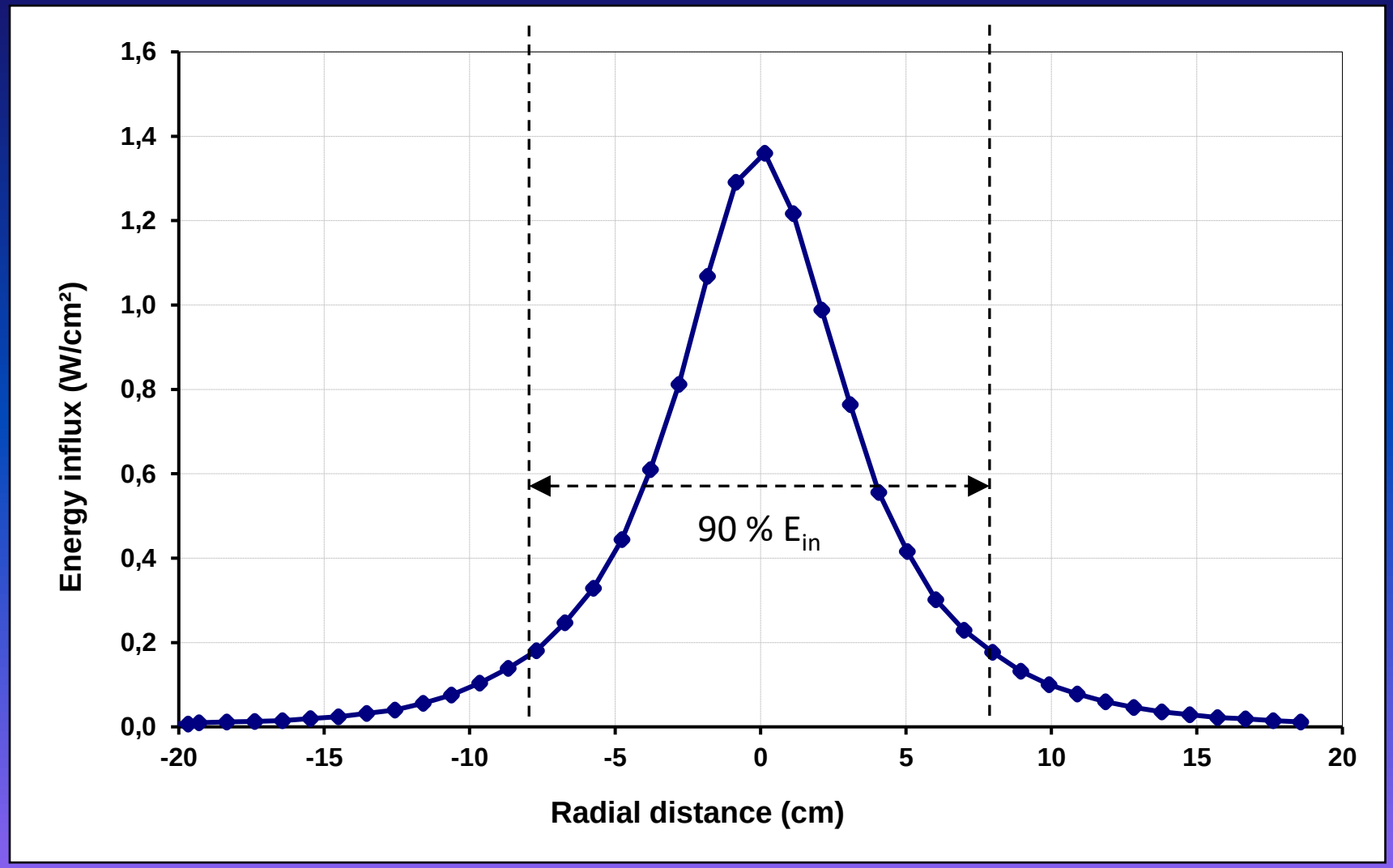


R. Wiese, H. Kersten, G. Wiese, R. Bartsch,
EPJ Techniques and Instrumentation,
Volume 2, Issue 1, 2015

Measurement principle of the Active Thermal Probe



Sample measurements - ion source profile



p = 4 · 10⁻² Pa
Working gas: Ar
Beam voltage: 500 V
Source distanz: 22,5 cm
Source diameter: 16 cm

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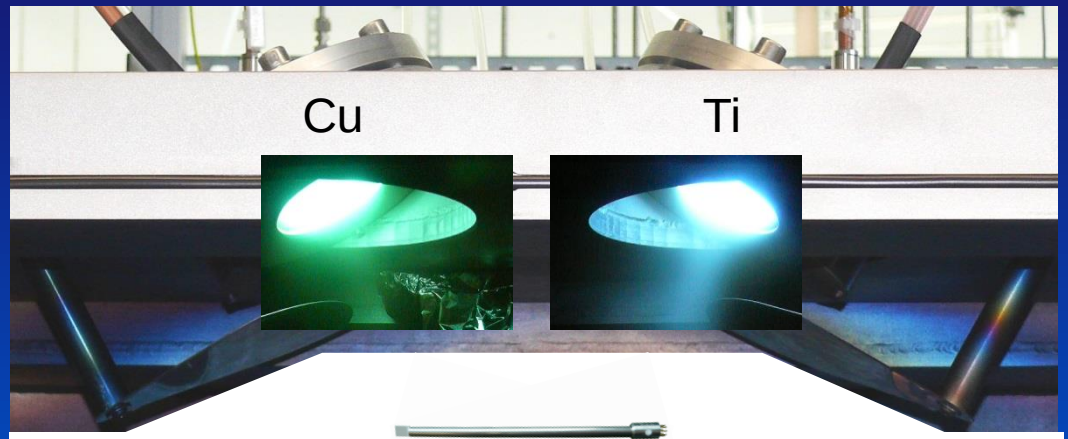
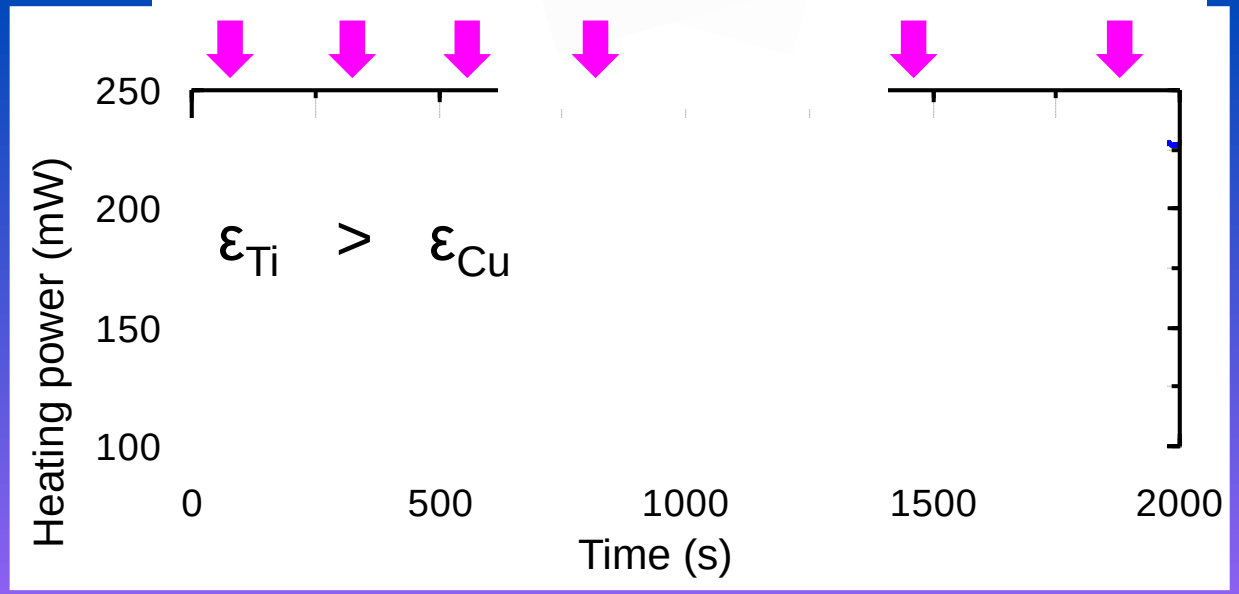
Volume 2, Issue 1, 2015

Sample measurement: Energy influx during coating

$Q = \varepsilon \cdot \sigma \cdot A \cdot T_S^4$

$T_S = 320\ °C$





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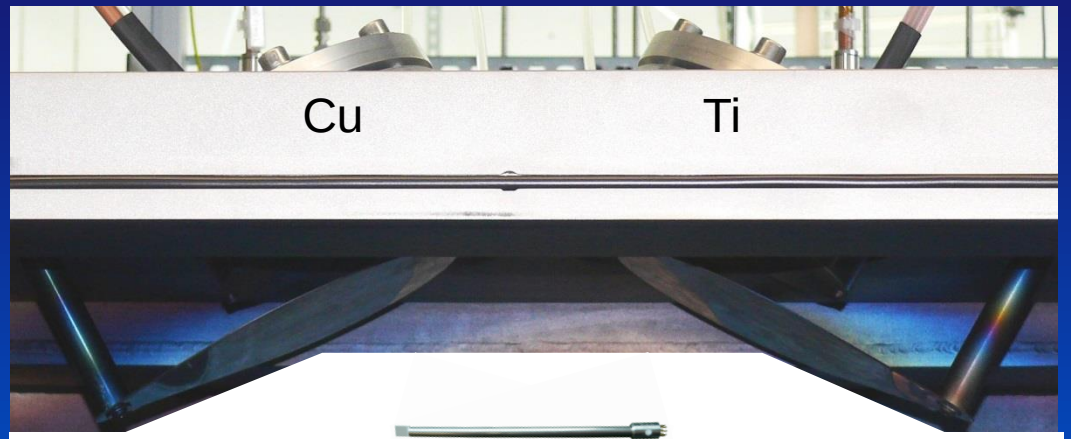

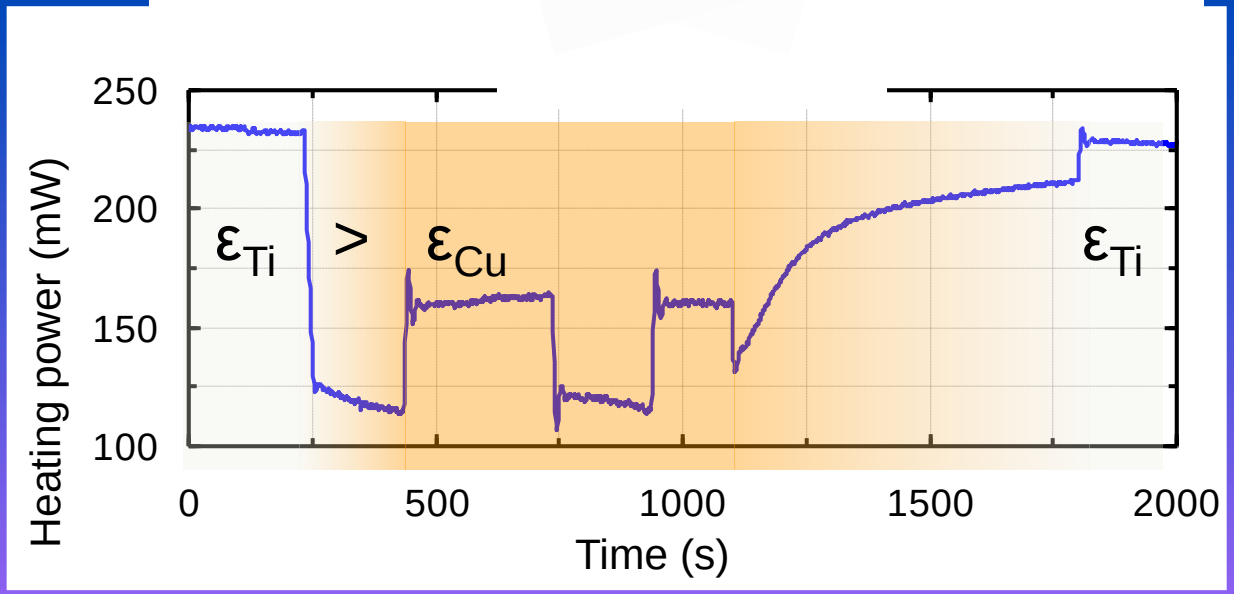

Measurement of the energy influx during coating is possible!

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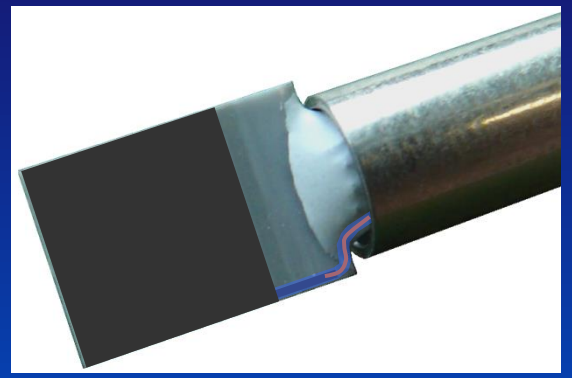
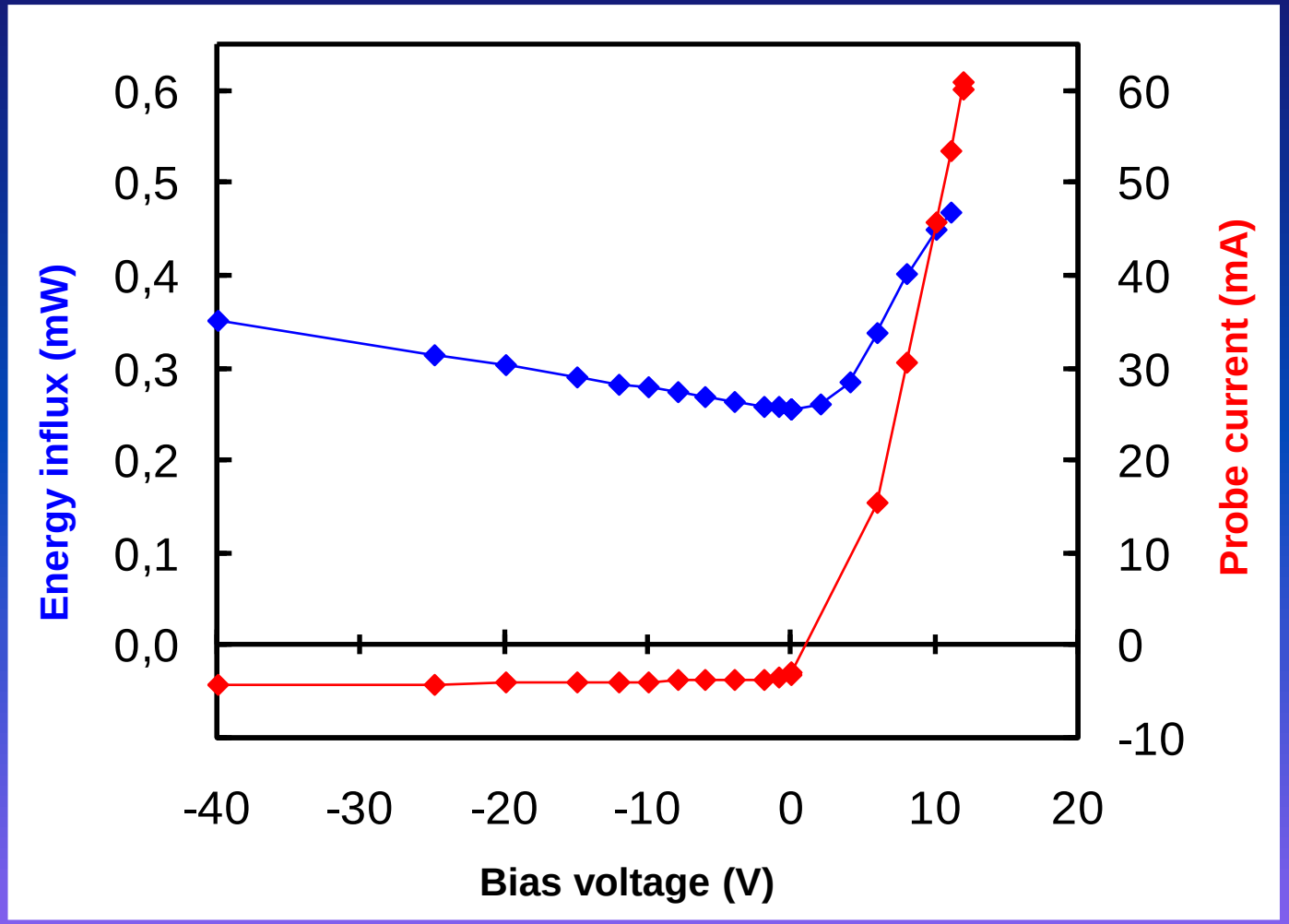
EPJ Techniques and Instrumentation,
Volume 2, Issue 1, 2015

What else is new??

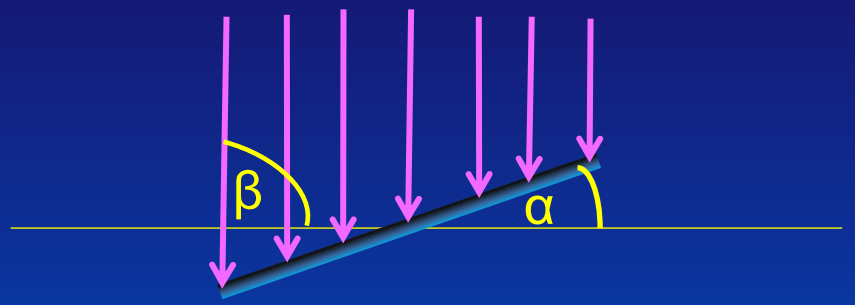
Design: Probe with bias voltage



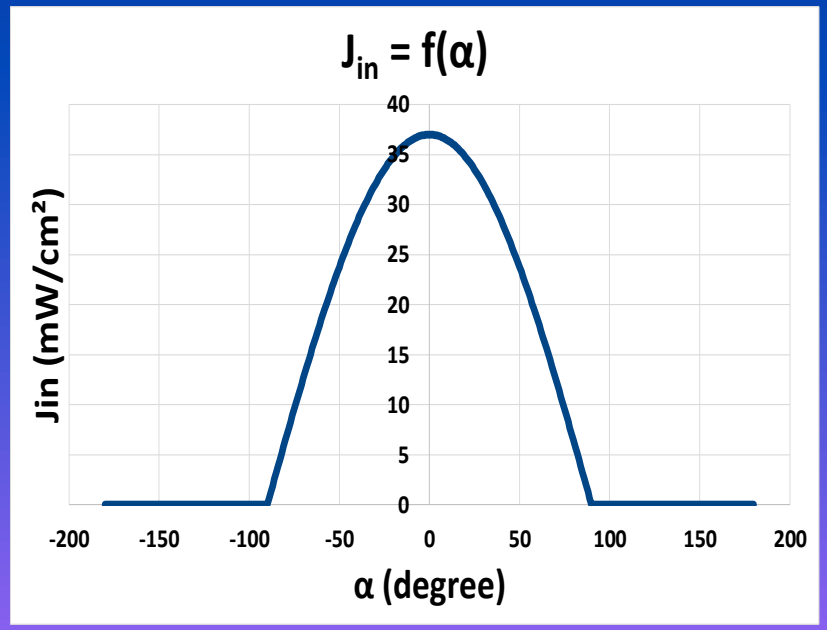
RF-discharge
p = 10 Pa
Working gas: Argon
P = 150 W



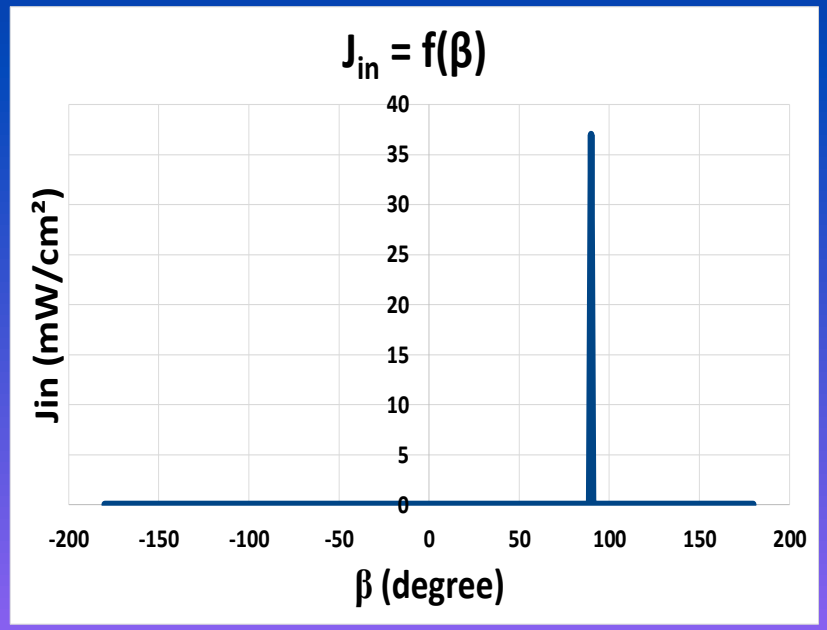
Design: Double probe for directional measurements



R. Wiese, H. Kersten, G. Wiese, R. Bartsch,
EPJ Techniques and Instrumentation,
Volume 2, Issue 1, 2015

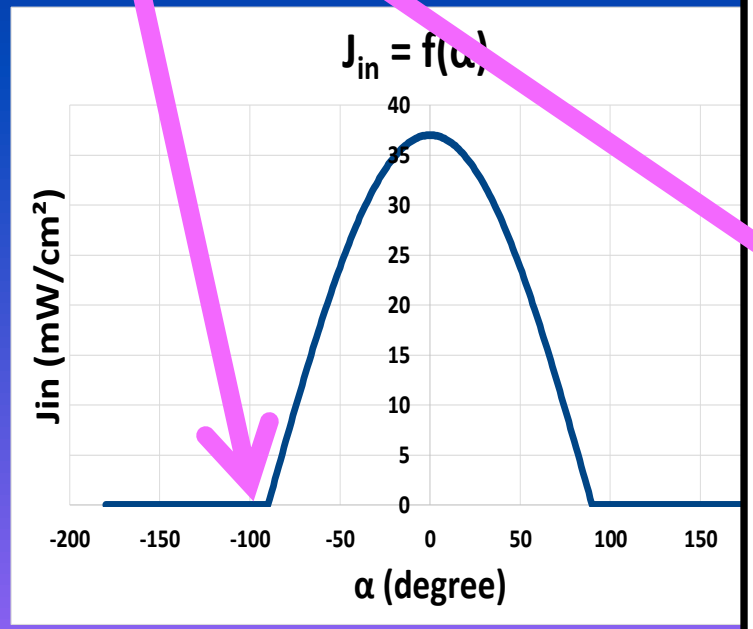


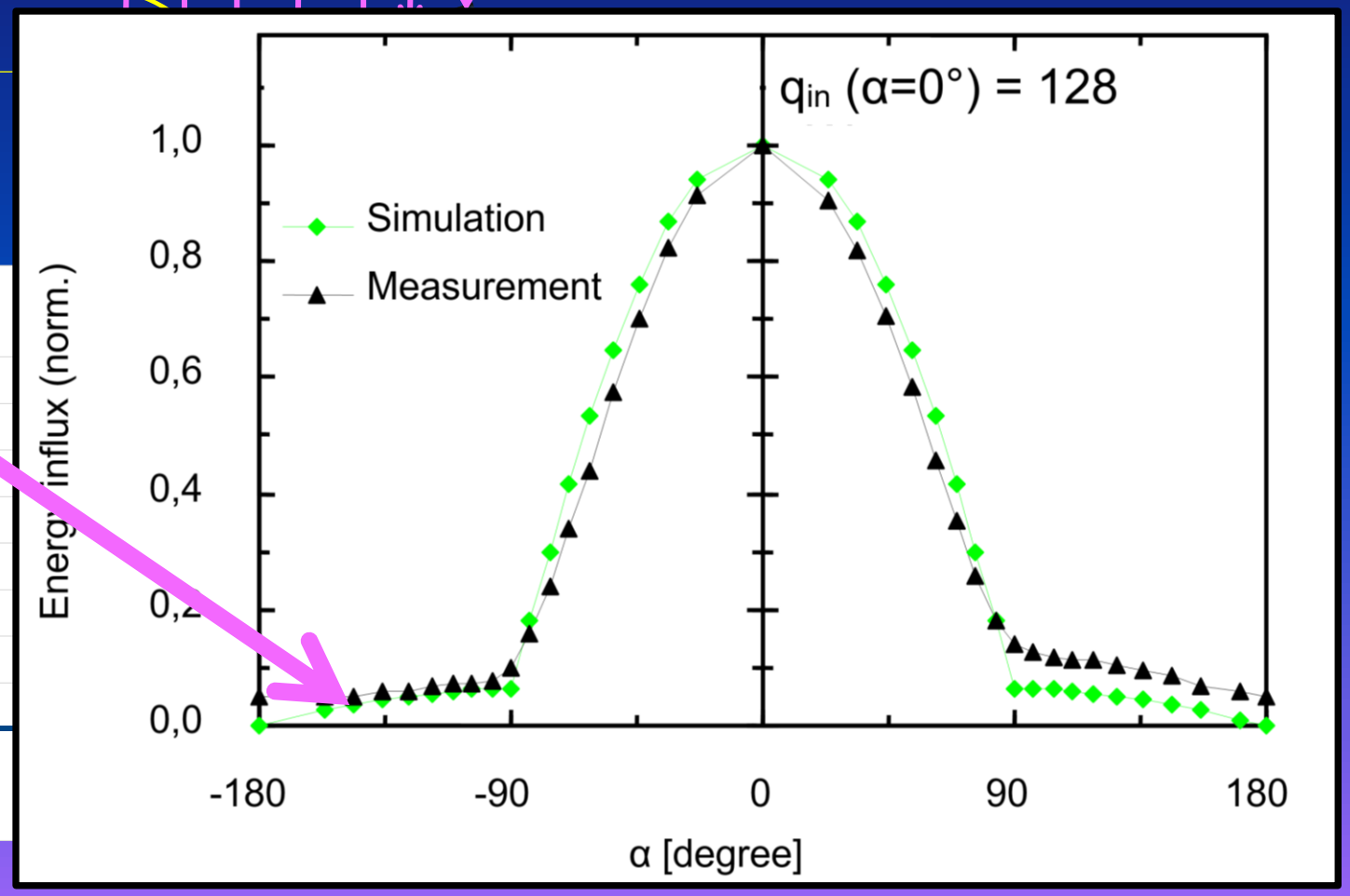
Laplace



Design: Double probe for directional measurements

Energy influx is (almost) zero on the back. Without shielding !





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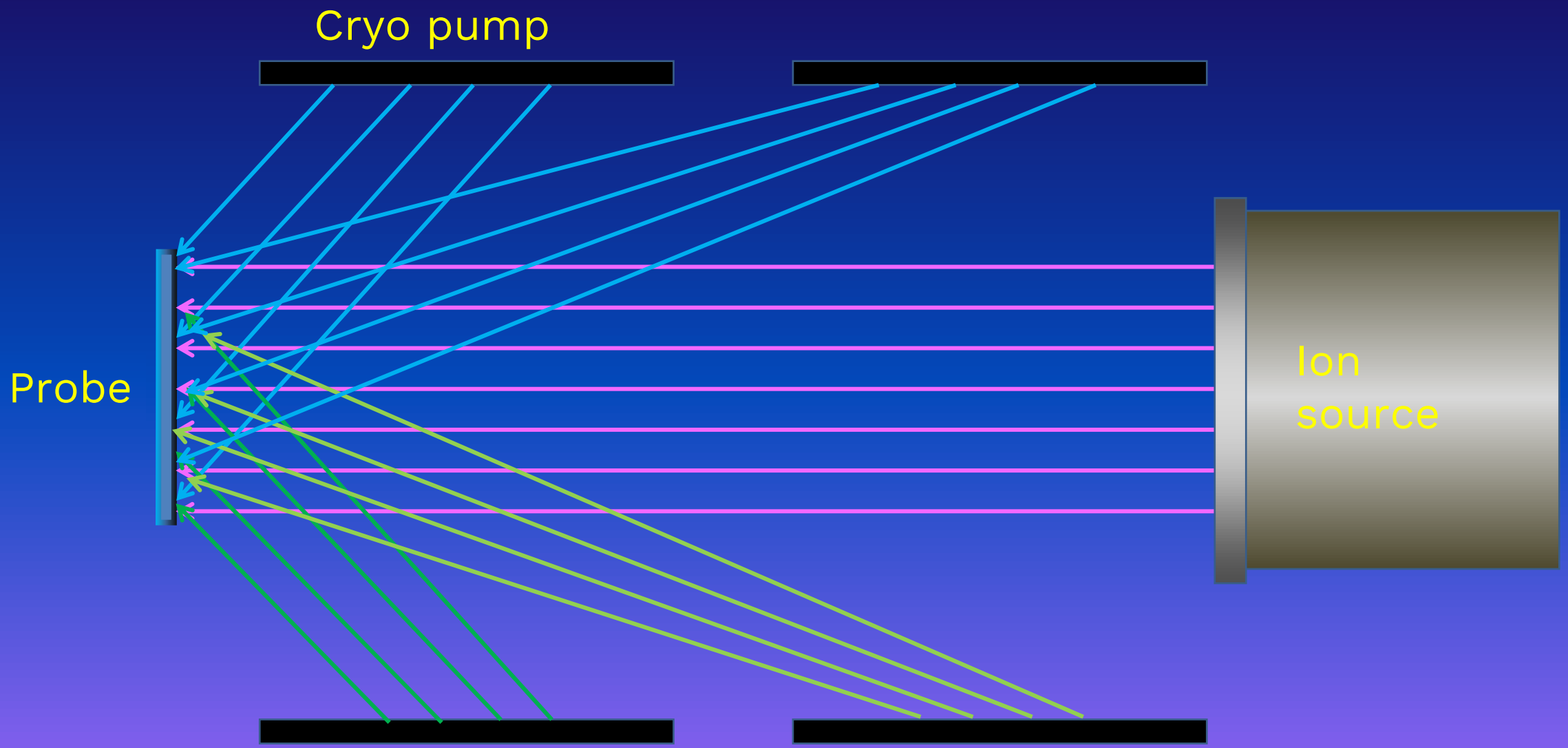
EPJ Techniques and Instrumentation,
Volume 2, Issue 1, 2015

Application: Double probe



Comparison with other measurement methods for the integral energy influx J_{in}

- Determination of *dT/dx* :
  spatial gradient

*# Tandian, N.P., Pfender, E., PCPP **17**(1997), 353.*
*# Steffen,H., Kersten, H., Wulff,H., JVST A**12**(1994), 2780.*
*# Kersten,H., Snijkers, R, Schulze, J., Kroesen, G.M.W, Deutsch, H., deHoog, F.J., APL **64**(1994), 1496.*
*# Gardon, R., RSI **24**(1953), 366*

- Measurement *dTs /dt* :
  Time derivative (passive), PTP

*# Thornton, J.A., JVST **11**(1974),666.*
*# Wendt, R., Ellmer, K., Wiesemann, K., JAP **82**(1997), 2115.*
*# Ekpe, S.D., Dew, S.K., JVST A**22**(2004), 1420.*
*# Thomann, A.L.,Semmar, N., Dussart, R., Mathias, J., Lang,V., RSI **77**(2006), 033501.*
*# Čada, M., Bradley, J., Clarke, G., Kelly, P.J., JAP **102**(2007), 063301*
*# Kersten, H., Kroesen, G.M.W., Contrib.PlasmaPhys. **30**(1990), 725.*

- Measurement *Tp*
  Particle fluorescence

*# Swinkels,G., Kersten,H.,Kroesen,G., Deutsch,H. JAP **88**(2000), 1747.*
*# Maurer, H., Basner, R., Kersten, H., RSI **79**(2008), 093508.*

Comparison with other measurement methods for the integral energy influx J_{in}

Energy influx J_{in} → Intensity of the thermal effect → Measurement intensity I_{th}

$$I_{th} = ?(J_{in})$$

→ **no calibration is necessary**

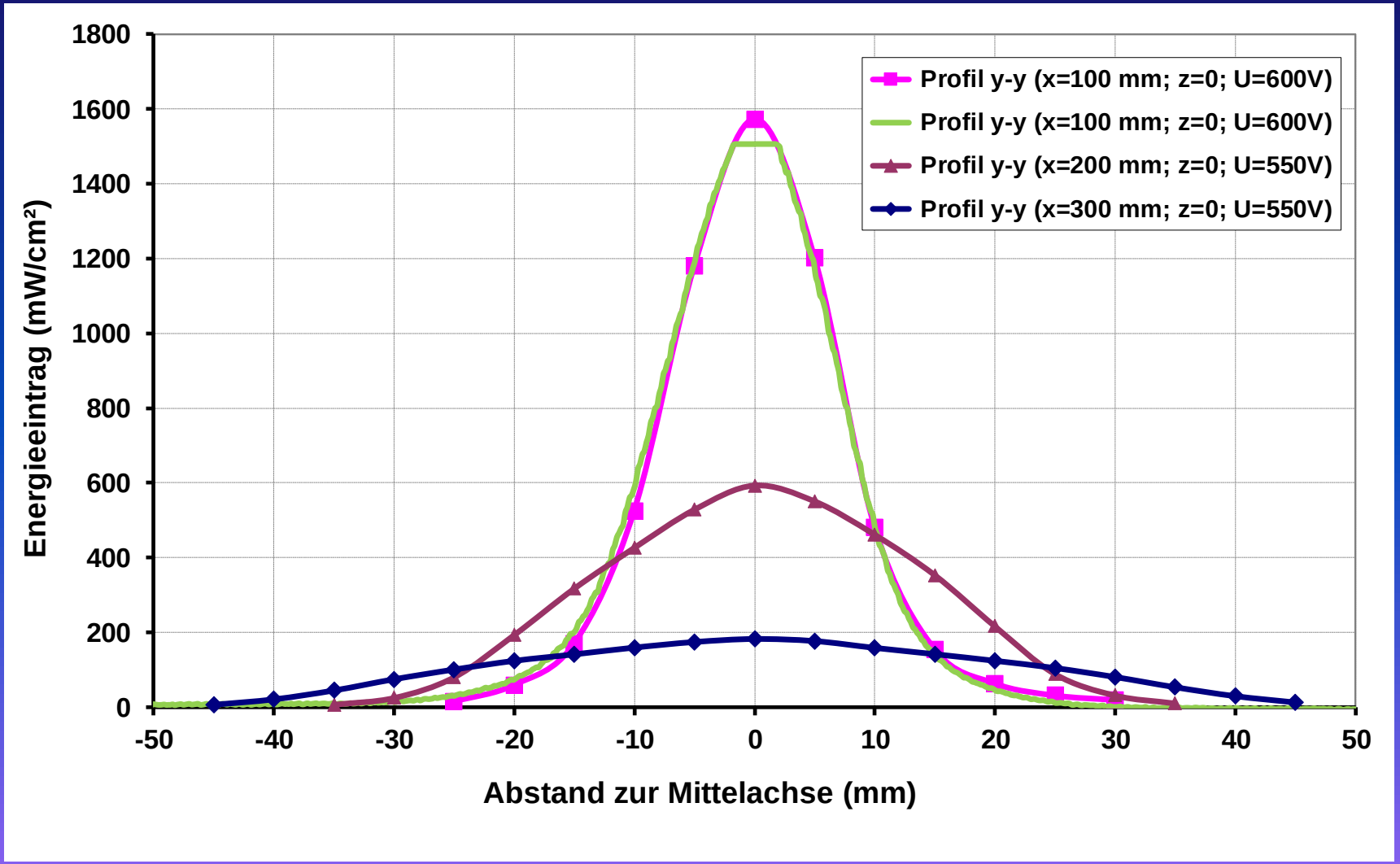
→ **continuous measurement**

→ **Result of the simulation:**
3% deviation between simulation and measured value

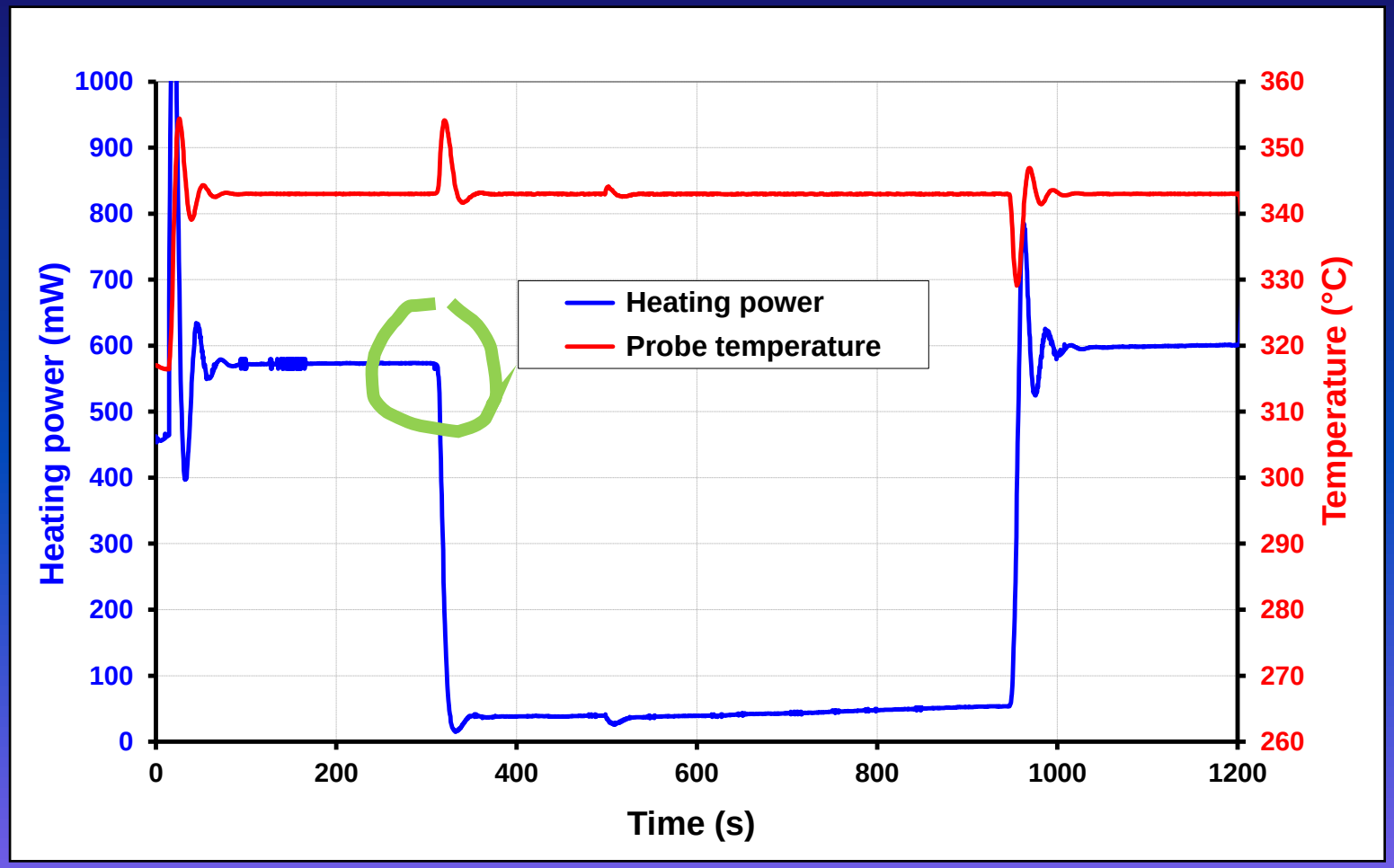
- Measurement Q_{in} :
  Compensation (active), ATP

*# Wiese, R., Kersten, H., Galvanotechnik **99**(2008), 1502.*
*# Wiese, R., Kersten, H., Wiese, G., Bartsch, R., EPJTI **2**(2015), 2.*

Continuos Measurement



Suitable for process control ?

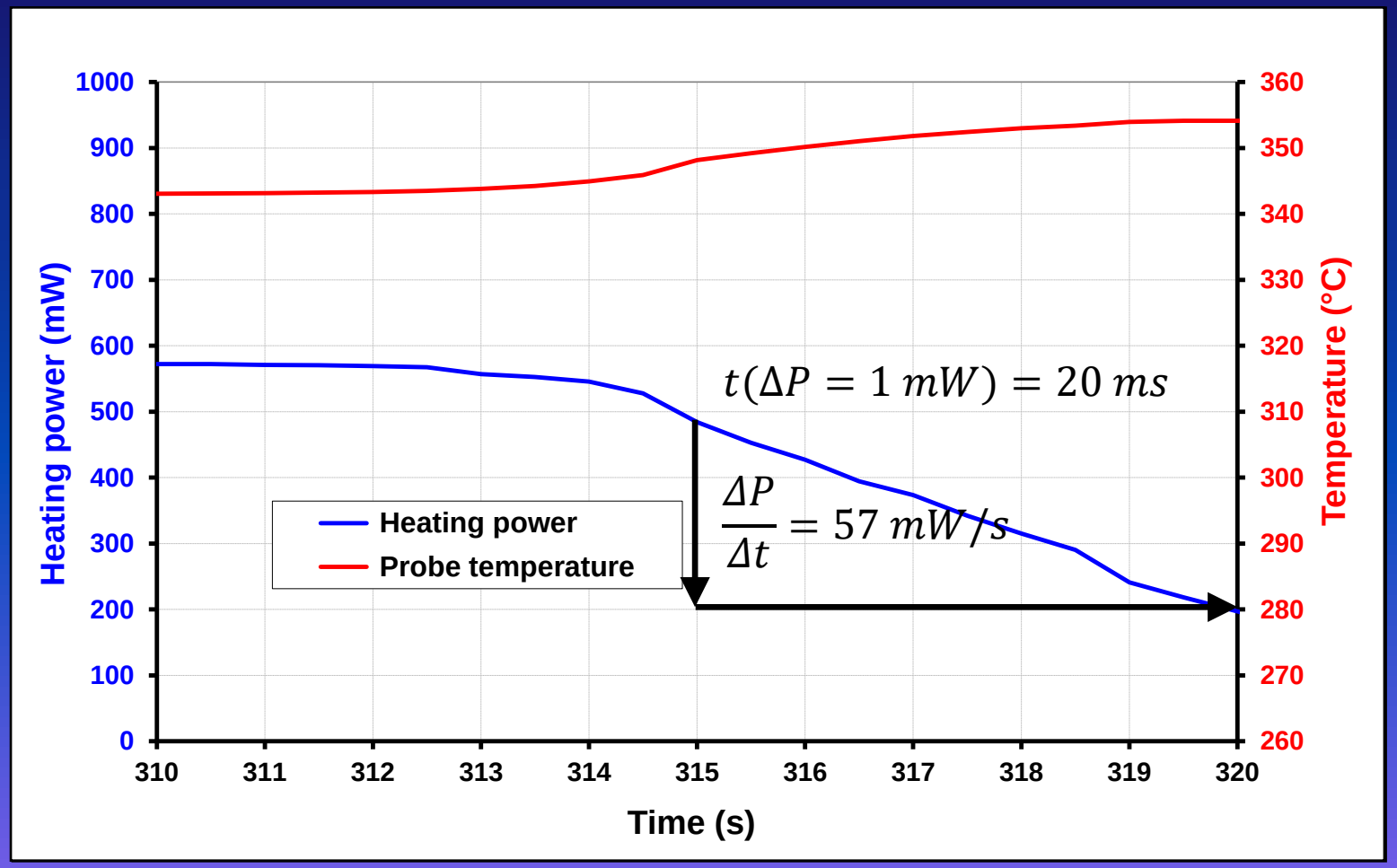


Are the values constant?

Yes

Is the reaction speed sufficient ?

Process control – reaction speed sufficient ?



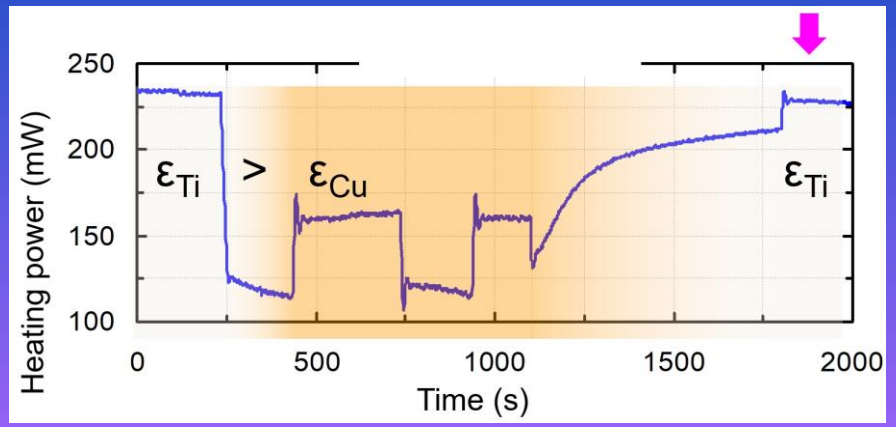
after 20 – 100 ms
→ **alarm signal**

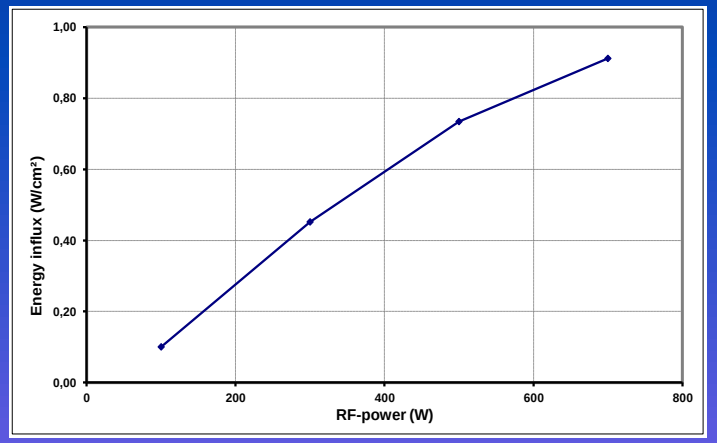
after 10 – 15 s
→ measured value
of the energy influx

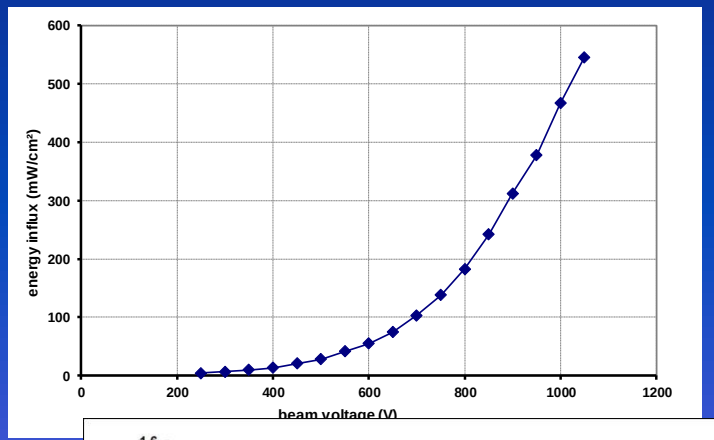
→ Active Thermal Probe is suitable for process control

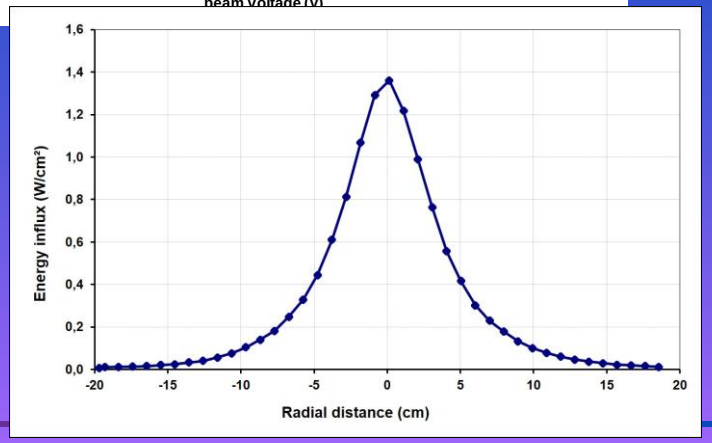
Summary

- Energy influx define the surface properties
- Conventional measurement methods $J_{in} = f(I_{th})$
- Measuring principle of the Active Thermal Probe $J_{in} = \Delta P$
- Sample measurements
  - Ion source
  - RF-plasma
  - Magnetron



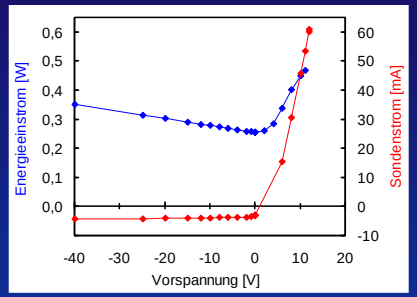




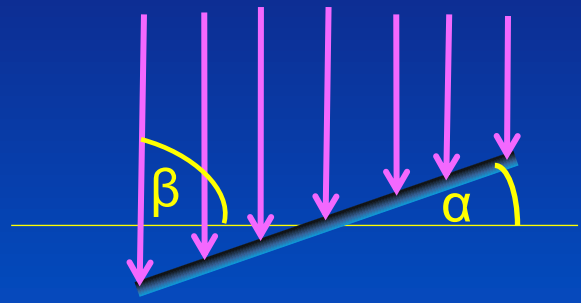


The top results:

- Probe with bias voltage



- Double probe for directional Measurement
  Without any shilding !



- No calibration necessary

$$I_{in} = f(I_{th})$$

- Measurement during coating is possible

- **Probe suitable for:**
  academic questions,
  process diagnostics and
  process control

Outlook

- Neue komfortable Software
- Interner AD/DA-Wandler – kein Steuerteil notwendig
- Option eines im Plasma floatenden Schutzrohres
- Mechanische Optimierung der Sonde
- Miniaturisierung der Sensorfläche
- Fertigung der Doppelsonde

Acknowledgment

INP Greifswald

CAU

GO Messtechnik

ZIROX Sensoren und Elektronik GmbH

neoplas

UST UMWELT SENSOR TECHNIK

VISUTRONIK automatisierungstechnik computerservice

INTERPANE GLASS FOR LIFE

IOM

CiS Forschungsinstitut für Mikrosensorik und Photovoltaik GmbH

LZH LASER ZENTRUM HANNOVER e.V.

SENTECH

IST Fraunhofer IST

ZSW

neoplas control solutions for your operations in gases and plasmas

fachhochschule stralsund

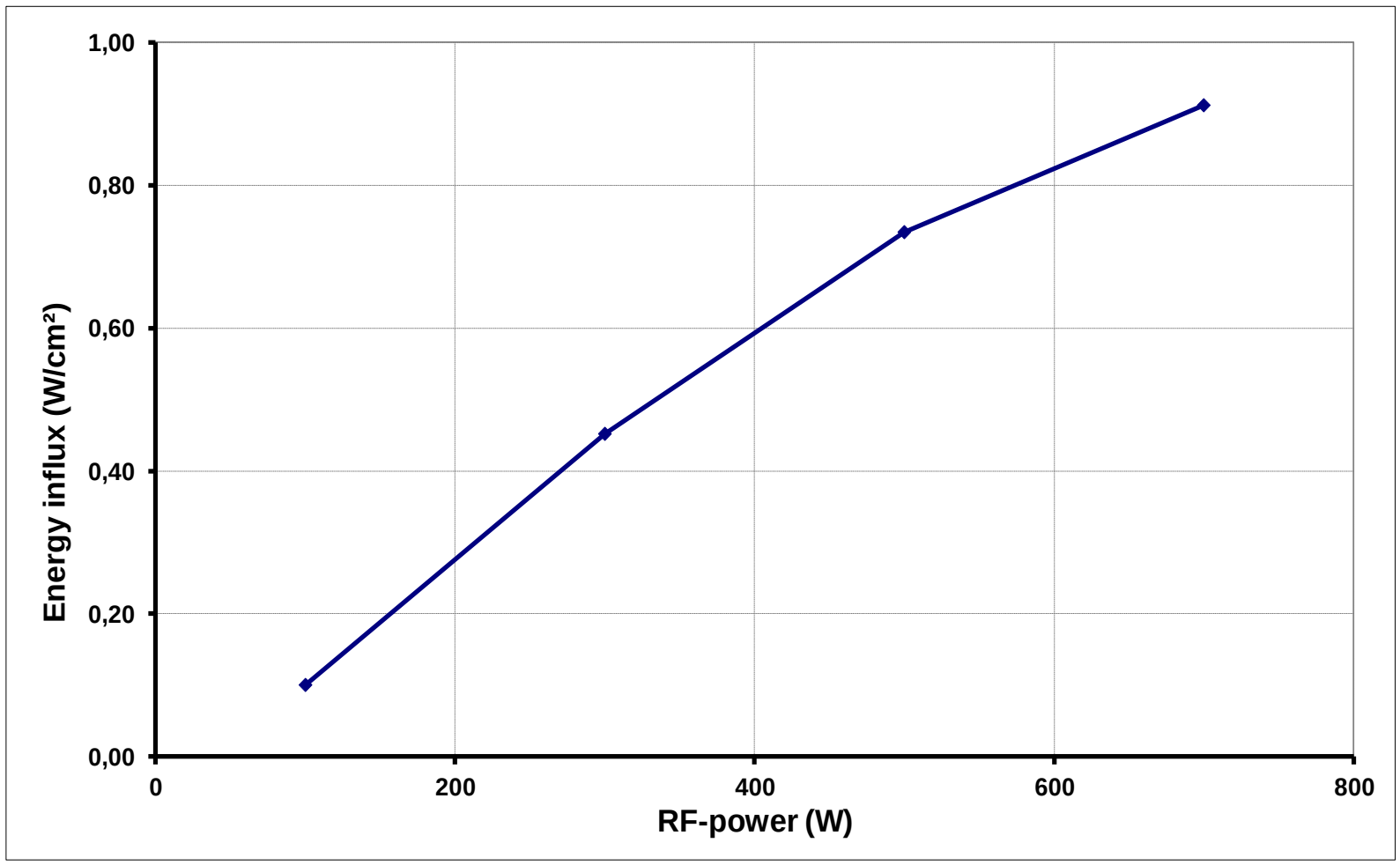
Bundesministerium für Wirtschaft und Technologie

EFDS

Ampower Science and Engineering

Thank you for your attention !

Sample measurement: Energy influx in RF-plasma



p = 0,5 Pa
Working gas: Argon
inductive coupling

R. Wiese, H. Kersten, G. Wiese, R. Bartsch, EPJ Techniques and Instrumentation, Volume 2, Issue 1, 2015