University of Innsbruck / Institute of Ion Physics
and Applied Physics / WG: Thin Film Technology

Thin Film Technology

Schwerpunkt Ionen- und Plasmaphysik / Angewandte Physik - Meeting 2006

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Reactive low voltage ion plating: process & plasma analyses

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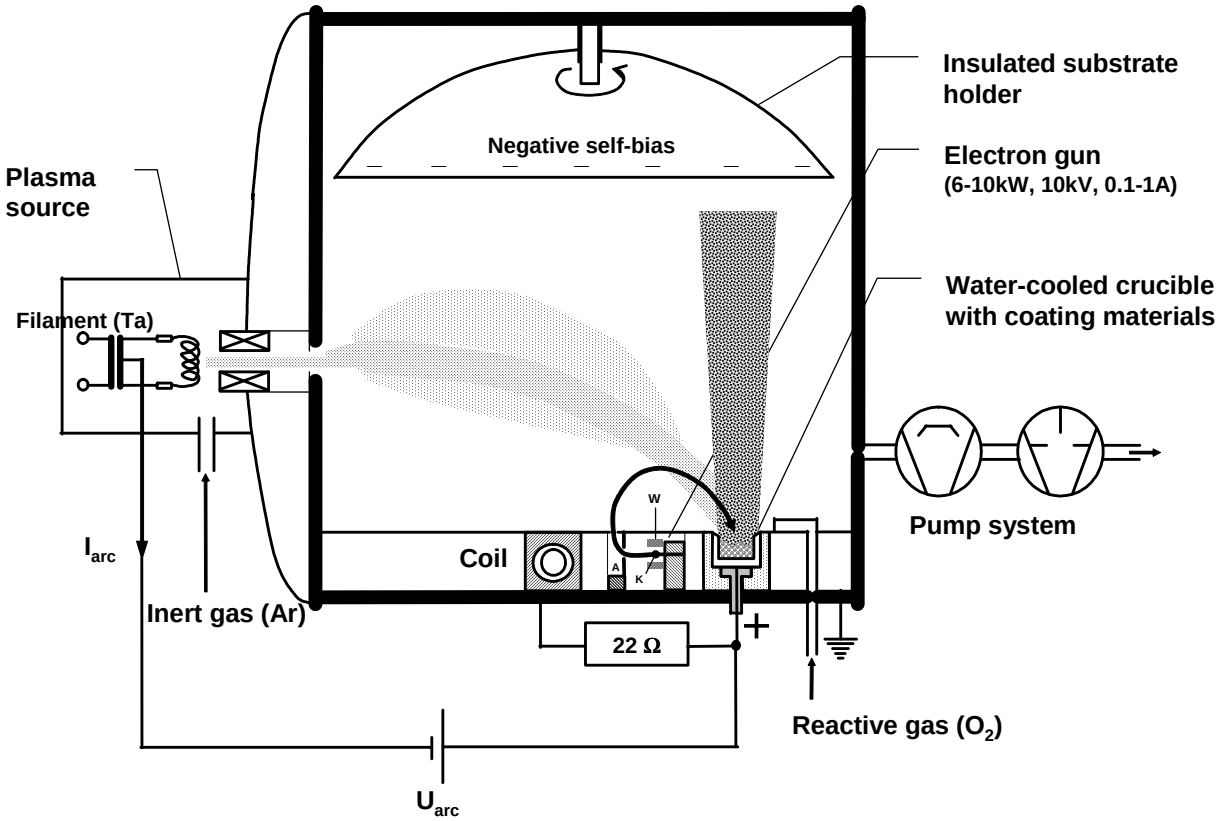
Content

- Description of the coating technique ***Reactive Low Voltage Ion Plating***
- Measurement equipment for plasma characterisation
- Presentation of the results for Ta_2O_5-processes

Coating device

Coating plant Balzers BAP 800 (now Evatec):



- Evaporation of the coating material by 270°-type e-gun
- Plasma circuit: Ta-filament = cathode crucible = anode
- Insulated substrate holder (negative self-bias)
- Rate and thickness control by quartz crystal monitoring

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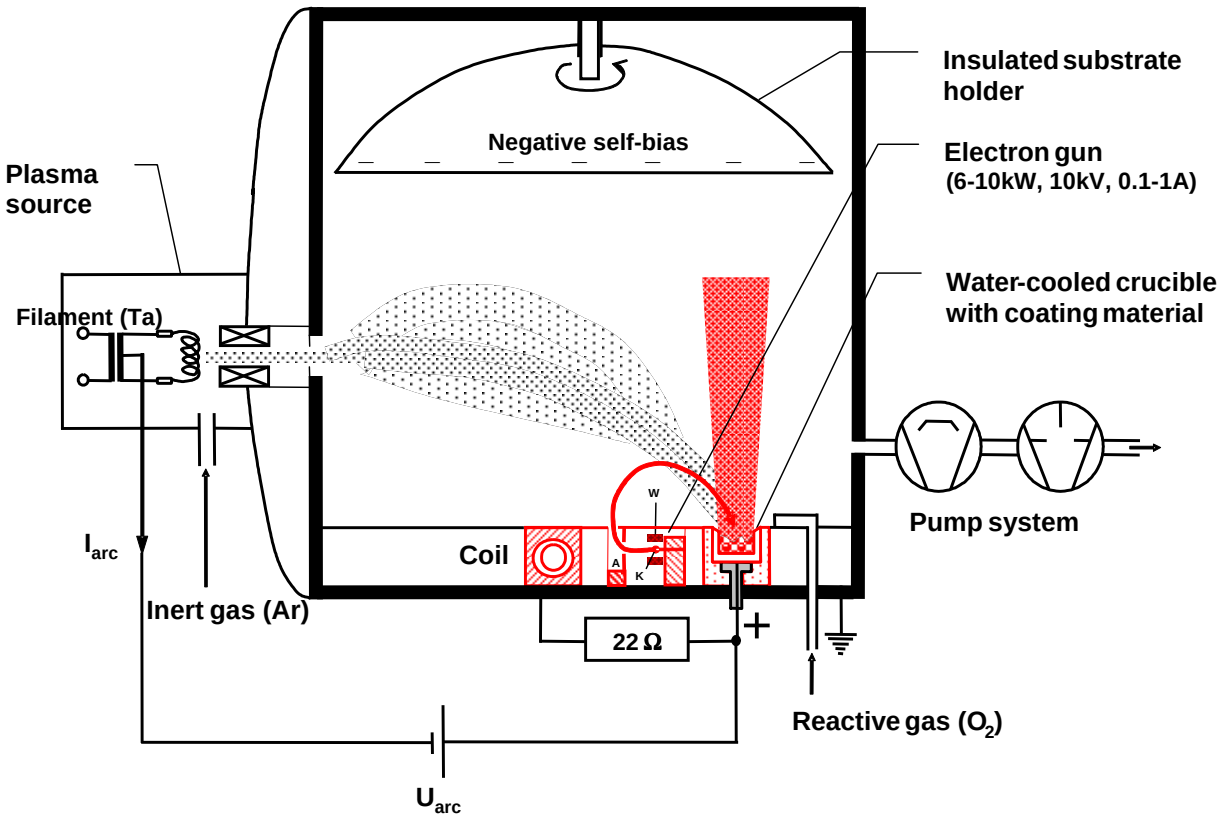

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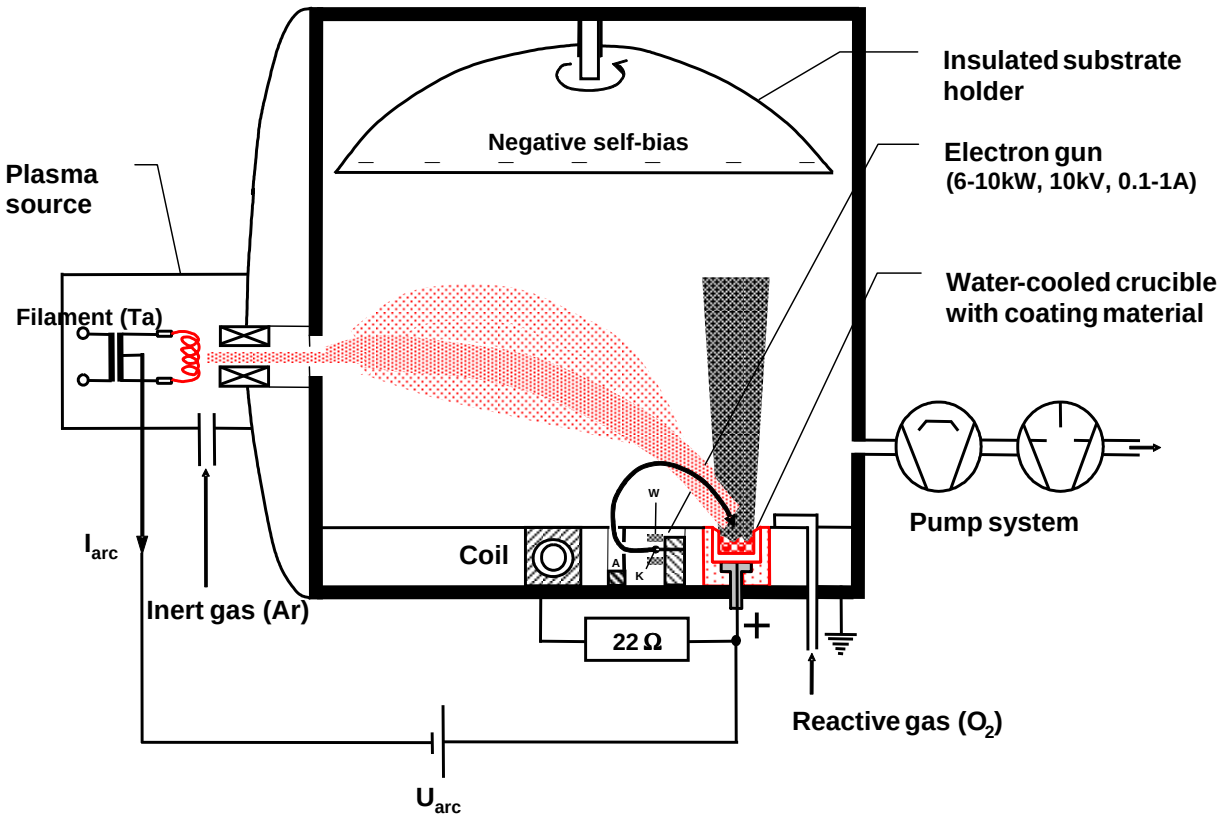

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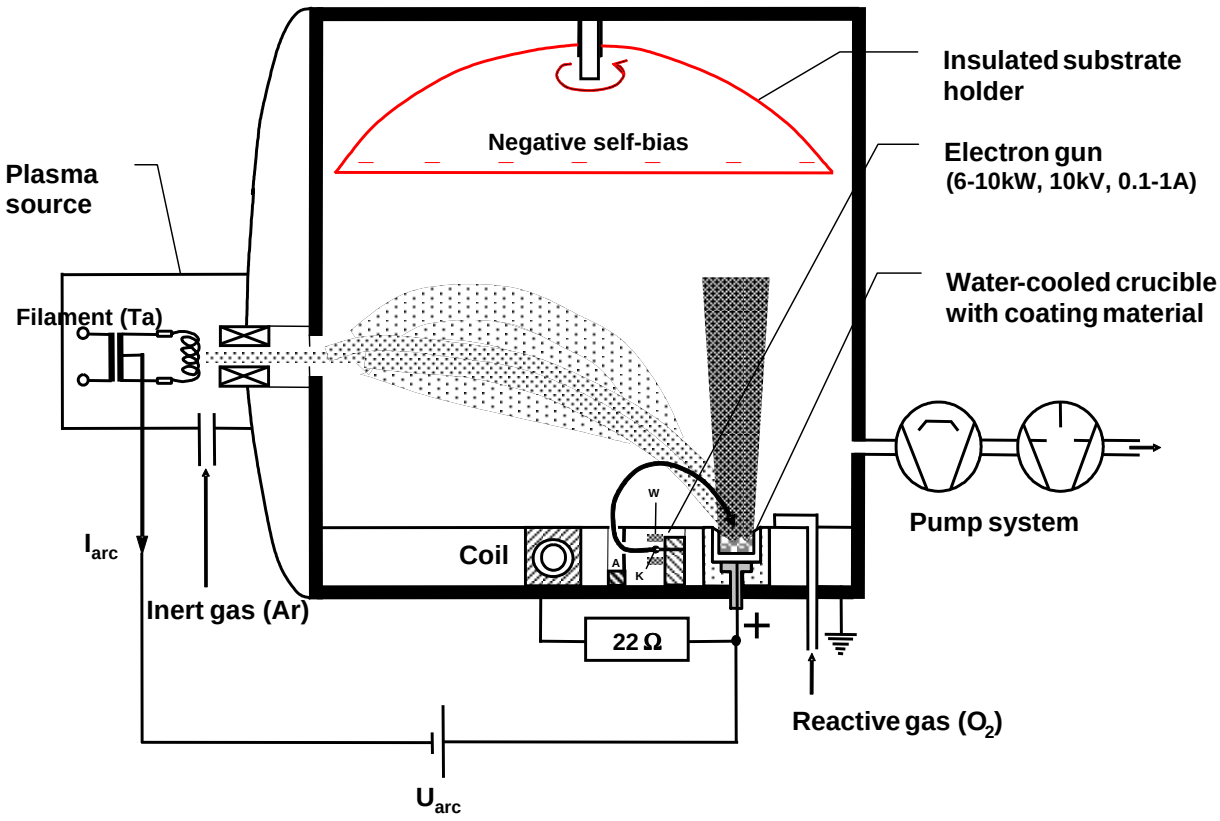

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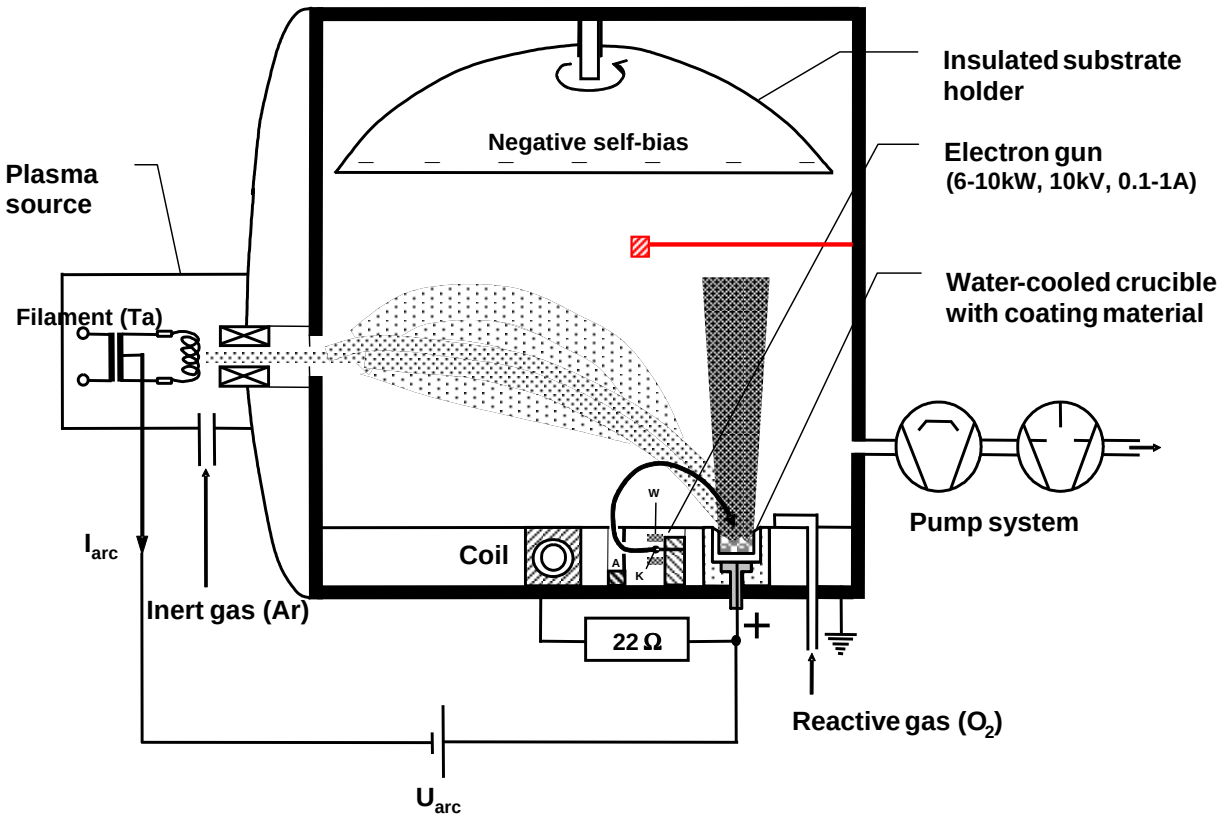

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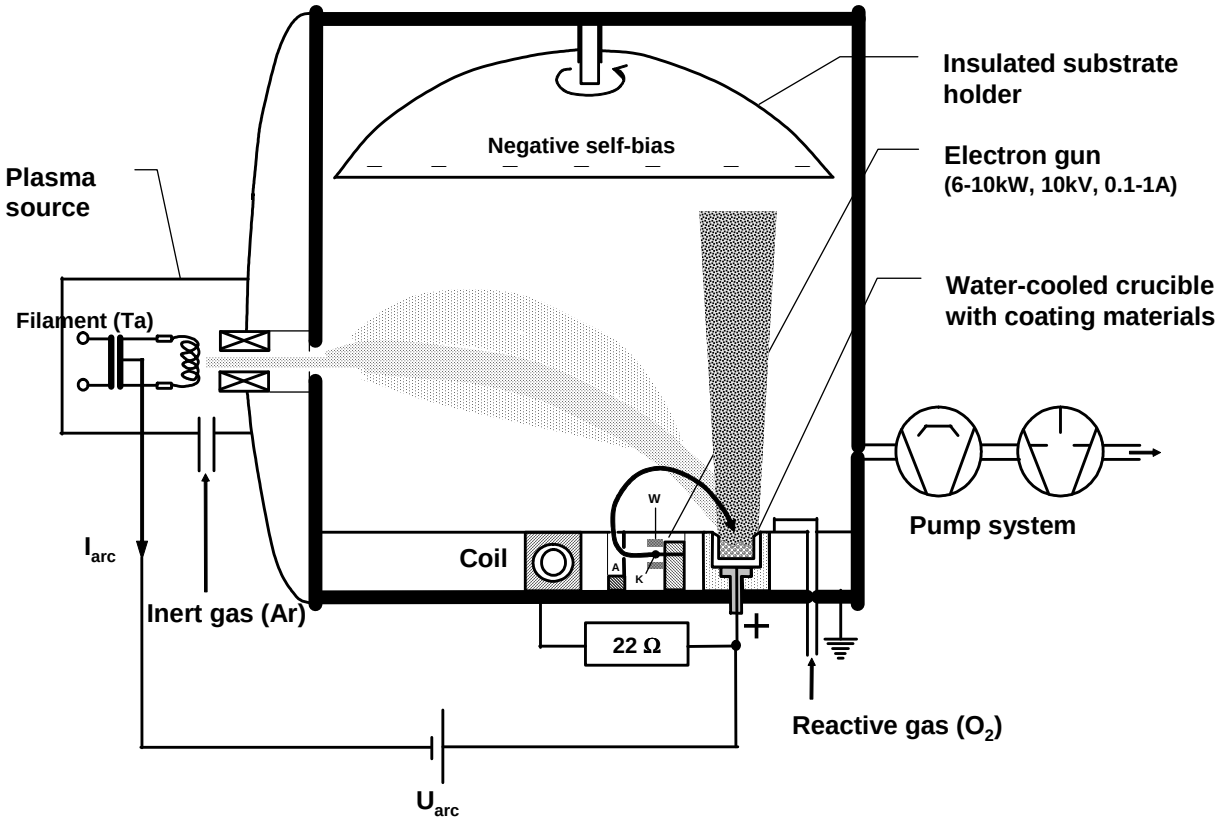
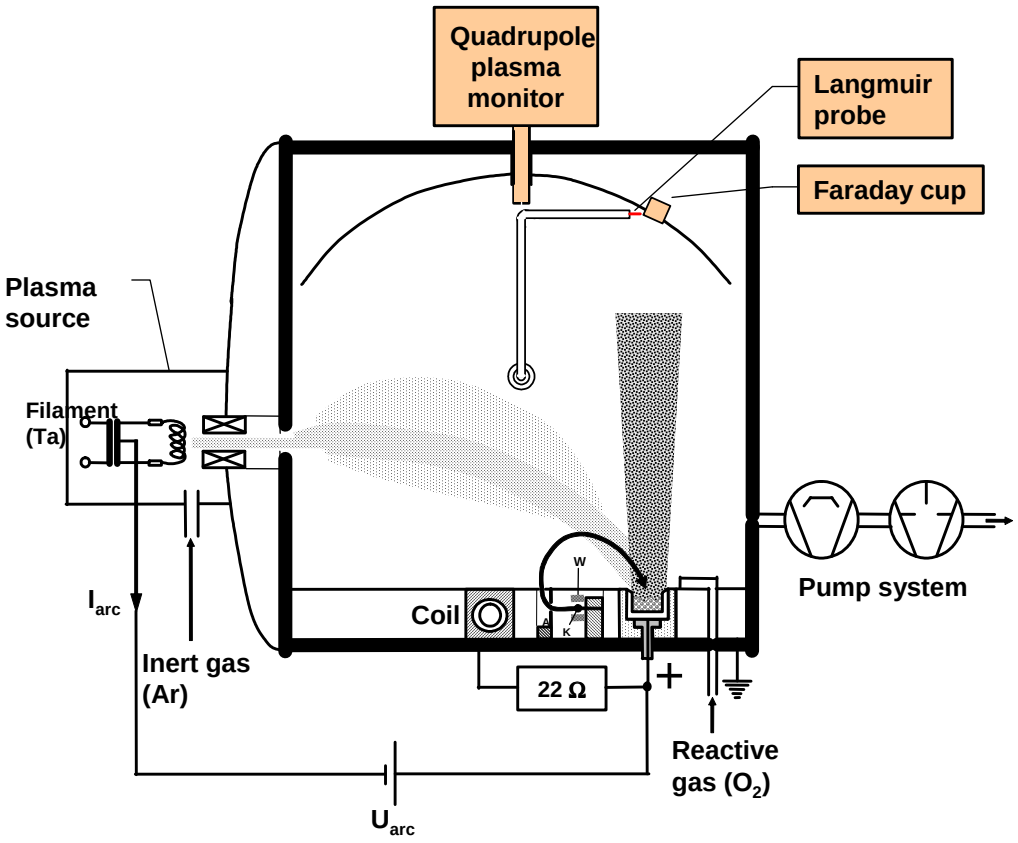


Main parameters of the coating process:

- Arc current of the discharge
- Total gas pressure
- Gas composition
- Deposition rate

Coating device



Typical process parameters:

- Deposition rate: 0.2 – 1.0nm/s
- Total pressure: 0.4 – 3.0×10^{-3} mbar
- Arc current: 15 – 100A
- Arc voltage: 40 – 80V
- Anode potential: 20 – 50V

High kinetic energy of the plasma ions required for densification of the growing film:

➢ Repulsive potential of the anode (20 – 50V)

➢ Self-bias voltage of the insulated substrate holder (-5 – -20V)

Thin film properties

Positive & negative aspects of RLVIP-technique:

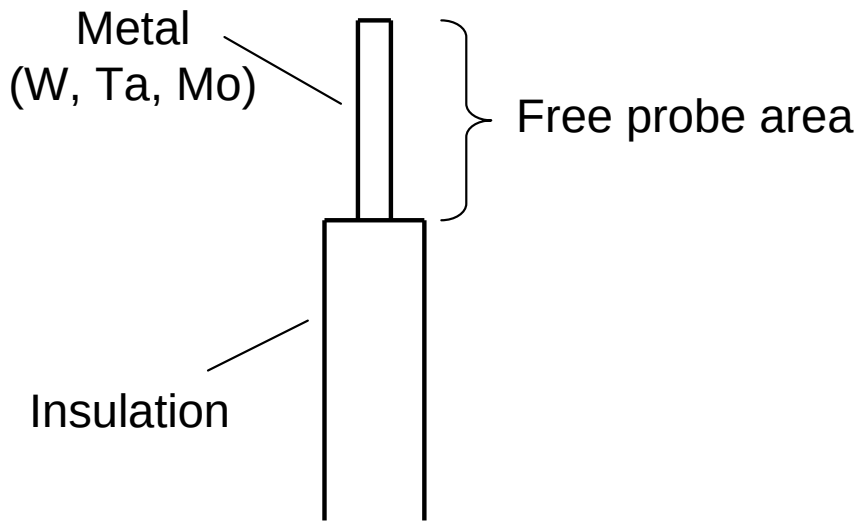
+ High film density
+ Good adhesion of the coating on the substrate
+ High refractive index
+ Very good stability against environmental influences

– Relatively high film stress (compressive stress)
– Residual optical absorption

Instruments for plasma analyses

Langmuir probe system: "Smart Probe" (Scientific Systems)

Schematic:

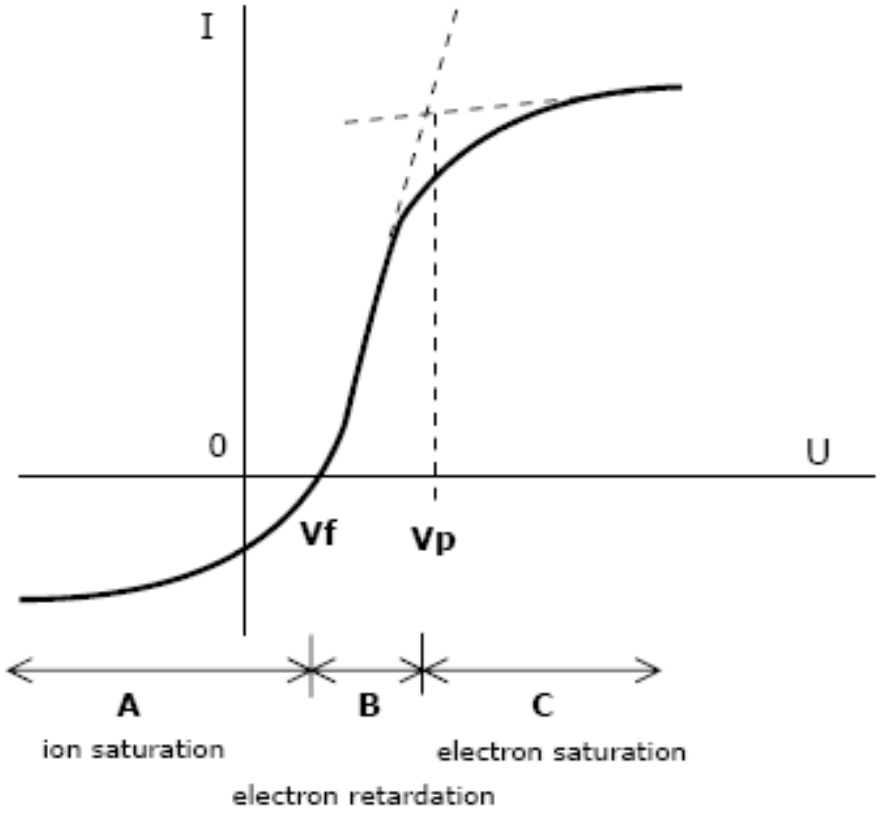


➢ Electrically conducting small heatable electrode which is immersed into the plasma

Instruments for plasma analyses

Langmuir probe system: "Smart Probe" (Scientific Systems)

Current-voltage characteristic:



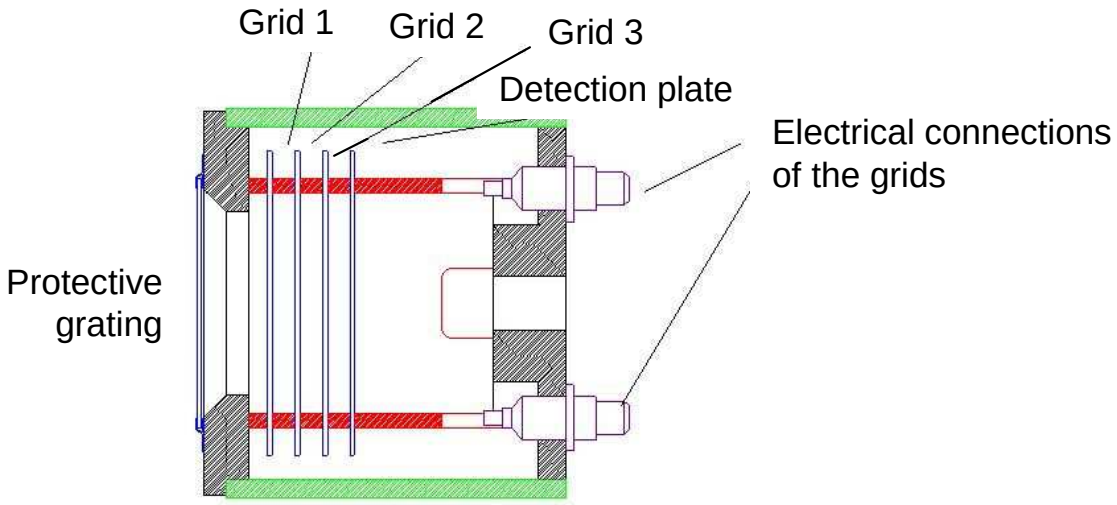
The current-voltage-characteristic of the probe was measured to obtain the following quantities:

- Floating potential
- Plasma potential
- Electron temperature
- Electron density
- Ion density
- Ion current density

Instruments for plasma analyses

Faraday cup system: MIEDA (Multichannel Ion Energy Distribution Analyser)

Schematic:



Measurement of the ion current in dependence of the retarding potential:

→ Ion energy distribution

→ Ion current density

Advantages of this method:

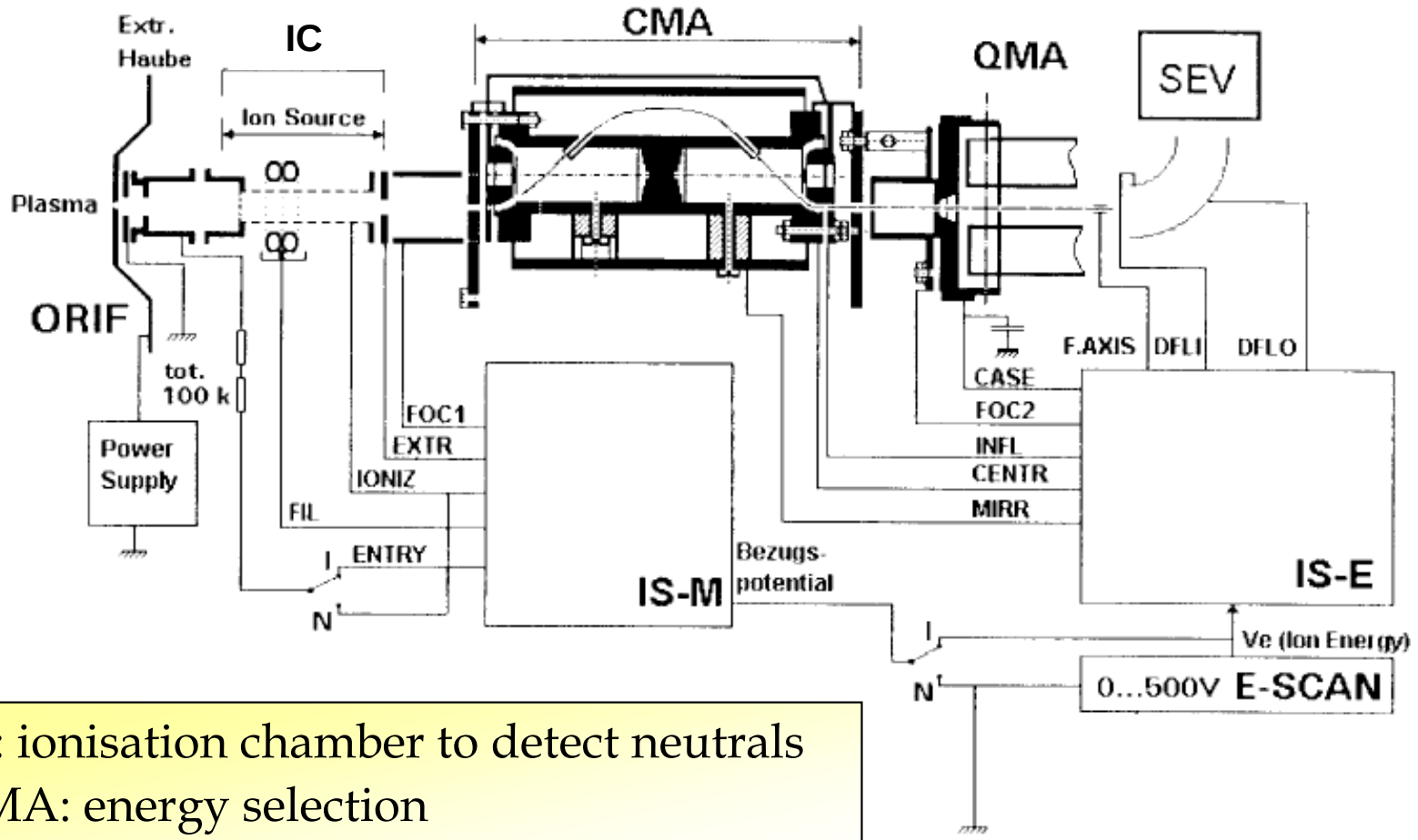
→ Variable measurement position

→ possibility to determine spatial distribution of the ion current (8 channels for measurements)

Instruments for plasma analyses

Plasma monitoring system: "PPM 421" (Inficon)

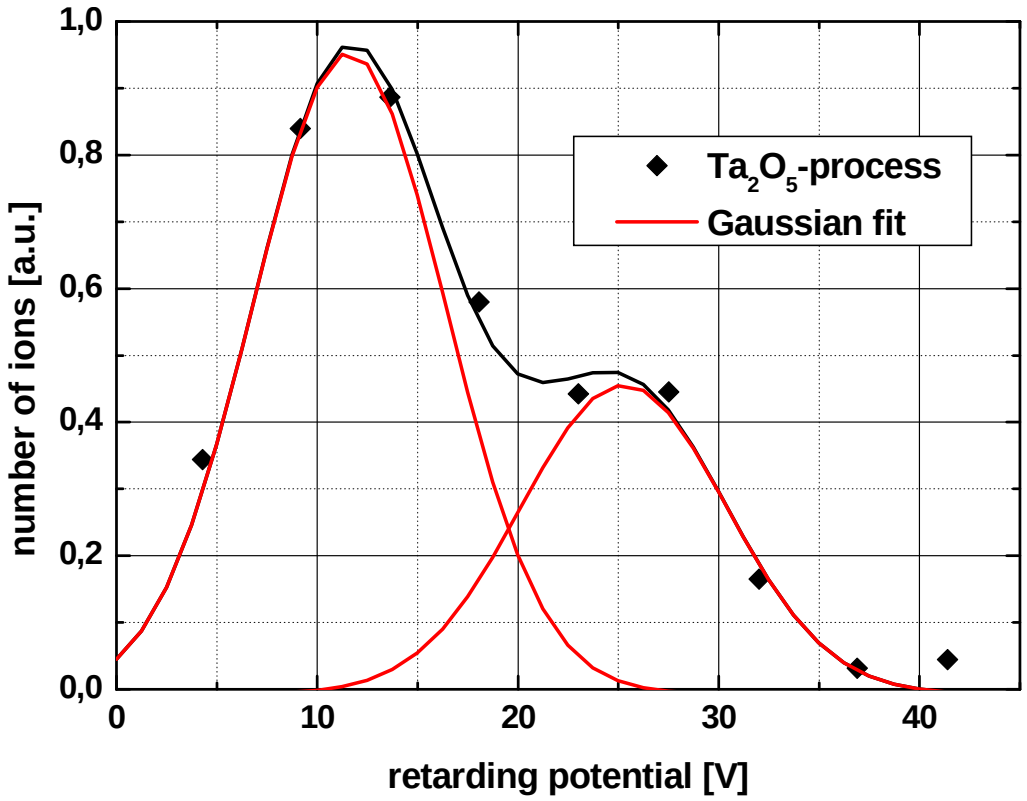
Schematic:

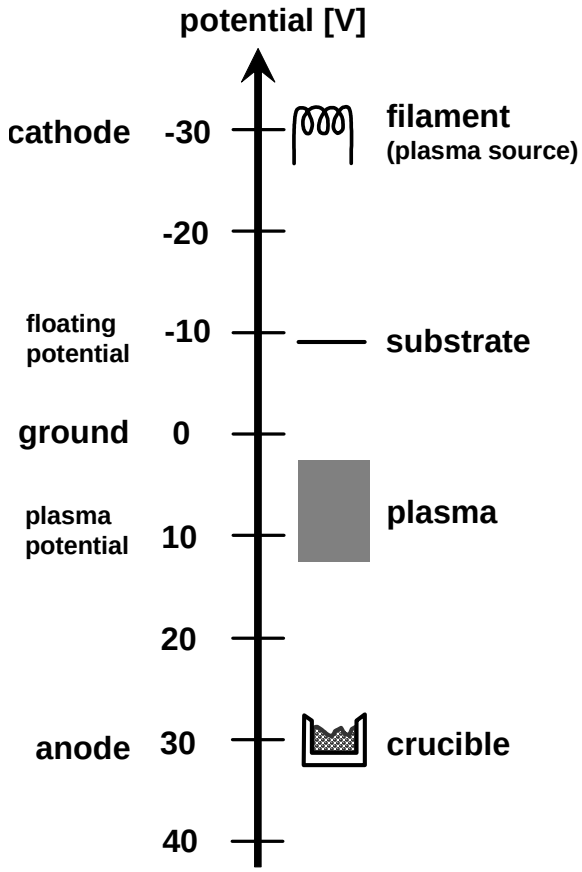


IC: ionisation chamber to detect neutrals
CMA: energy selection
QMA: m/z-selection

Results: ion energy distribution

Example for the ion energy distribution (measured by Faraday cup):





- Two ion peaks observed:
  - low energy peak from ions accelerated by self-bias voltage
  - high energy peak due to additional repulsion from the anode

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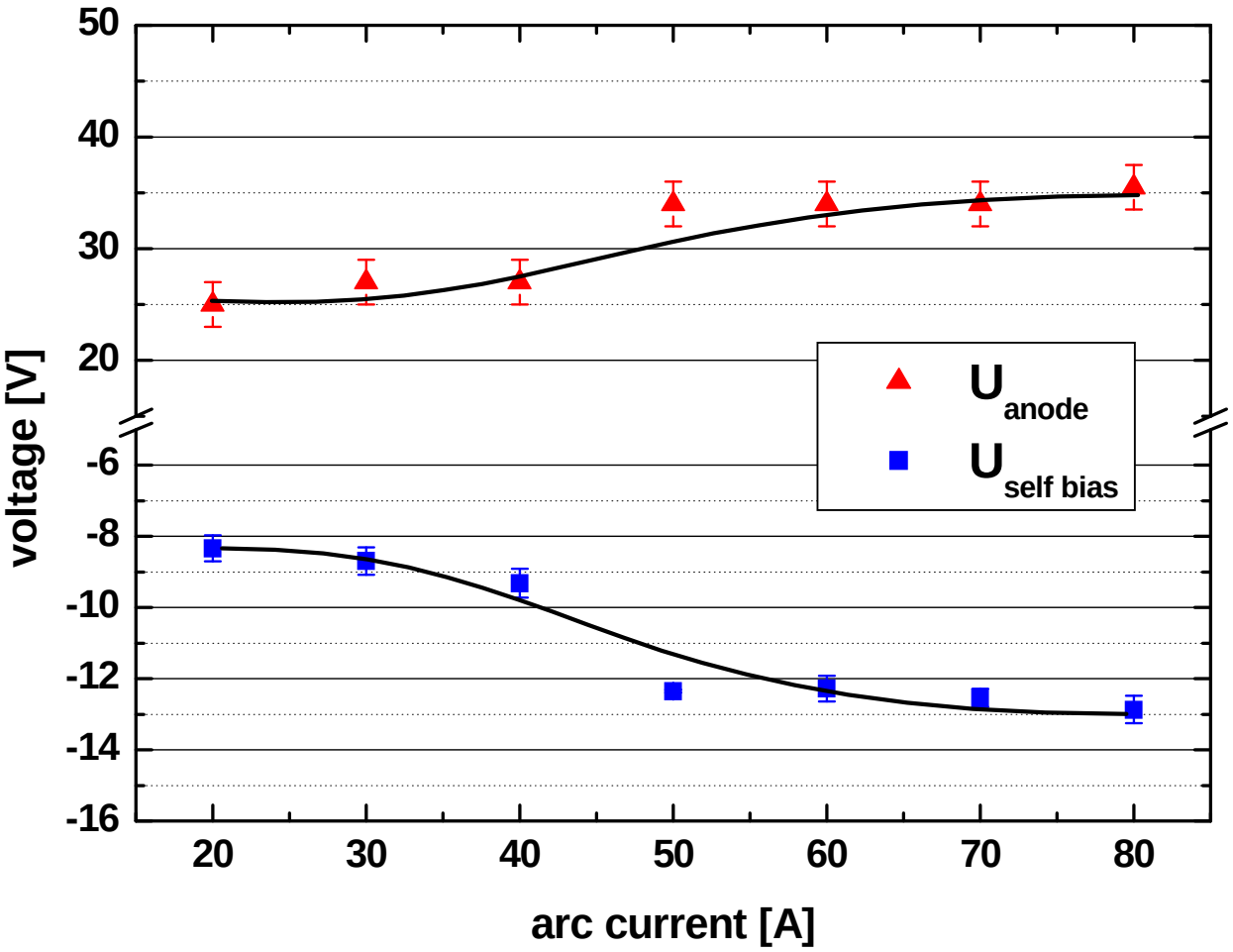
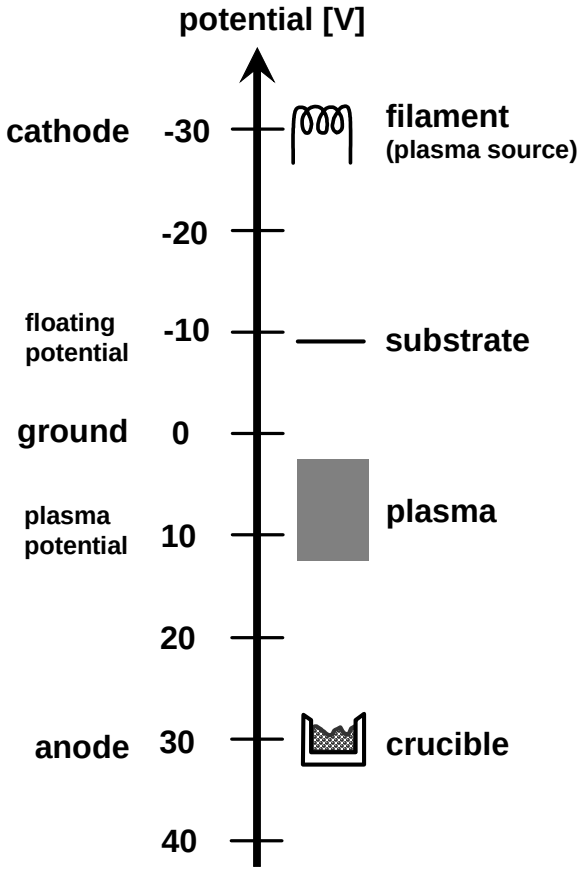
Results: potentials and voltages in dependence of arc current

Process settings: p_{O2}=11x10^{-4}mbar, p_{Ar}=4x10^{-4}mbar, deposition rate: 0.3nm/s;

Coating material: Ta_2O_5





Results: ion current density in dependence of arc current

Thin Film Technology

Process settings: p_{O2}=11x10^{-4}mbar, p_{Ar}=4x10^{-4}mbar, deposition rate: 0.3nm/s;

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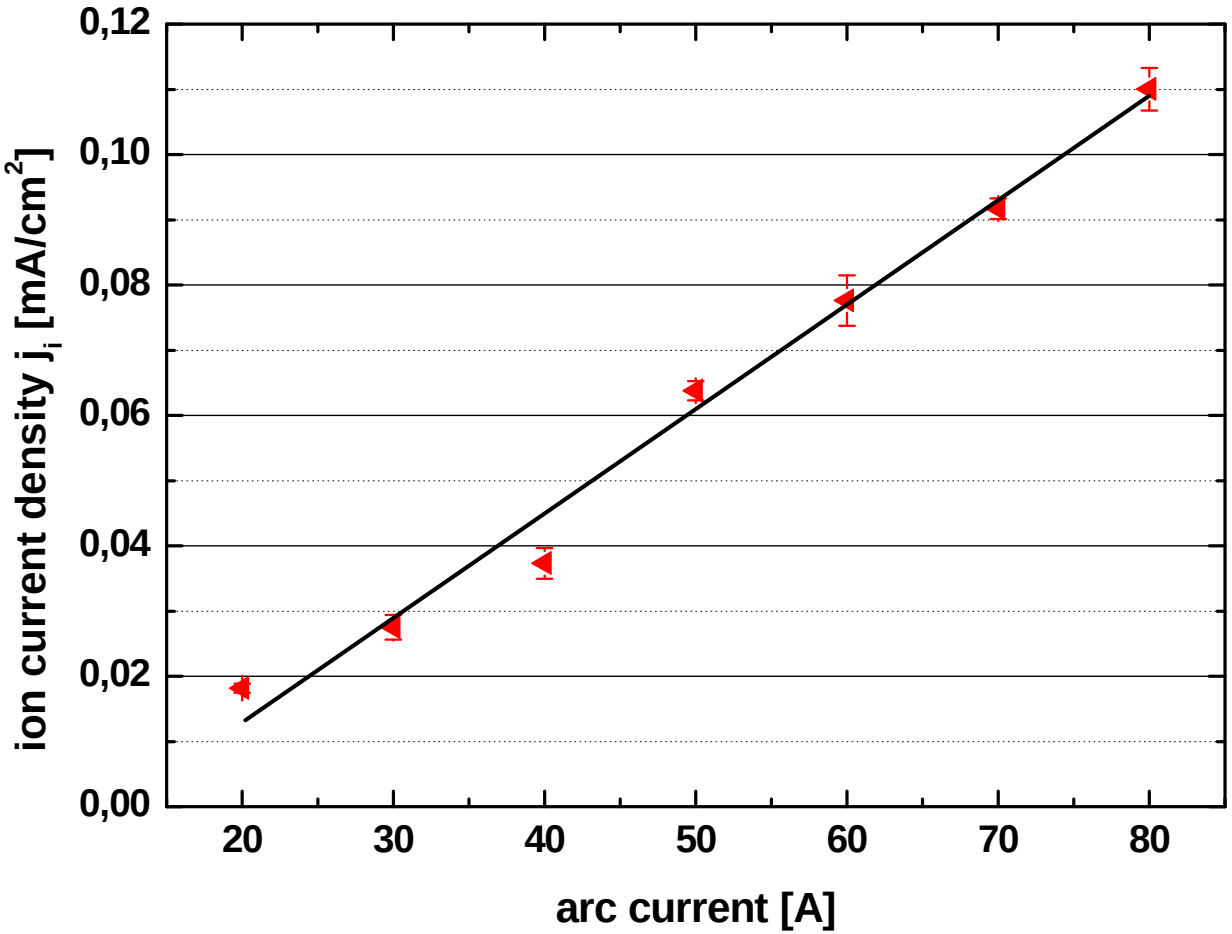

- Strong increase of the ion current density by approximately factor 5
- ~ linear correlation

Results: ion energy input in dependence of arc current

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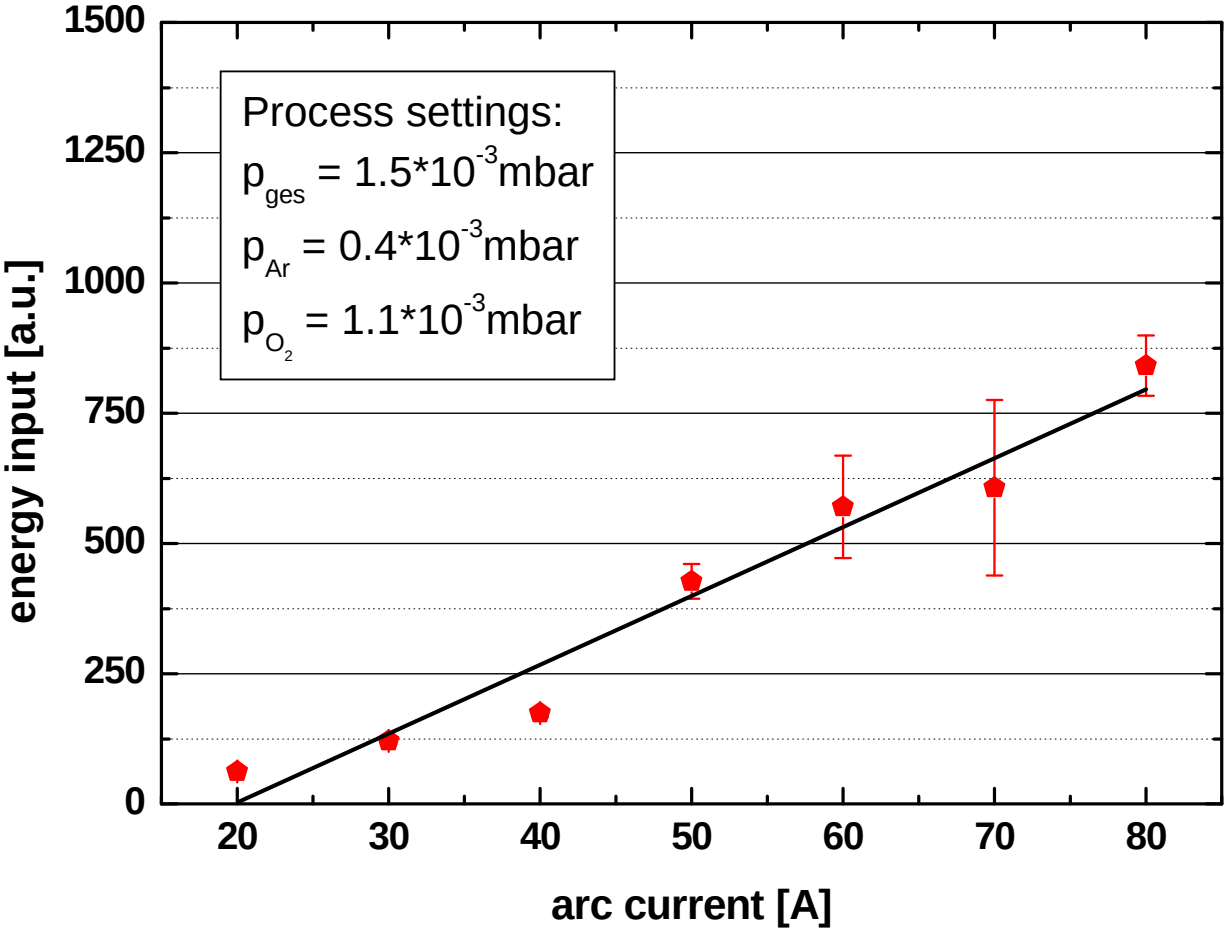
Process settings: p_{O2}=11x10^{-4}mbar, p_{Ar}=4x10^{-4}mbar, deposition rate: 0.3nm/s;

Coating material: Ta_2O_5



- Nearly linear increase of the energy input with rising arc current:

→ enhanced densification by ion bombardment

→ higher refractive index

→ higher optical absorption

→ higher film stress

Results: Correlations between ion energy input and thin film properties

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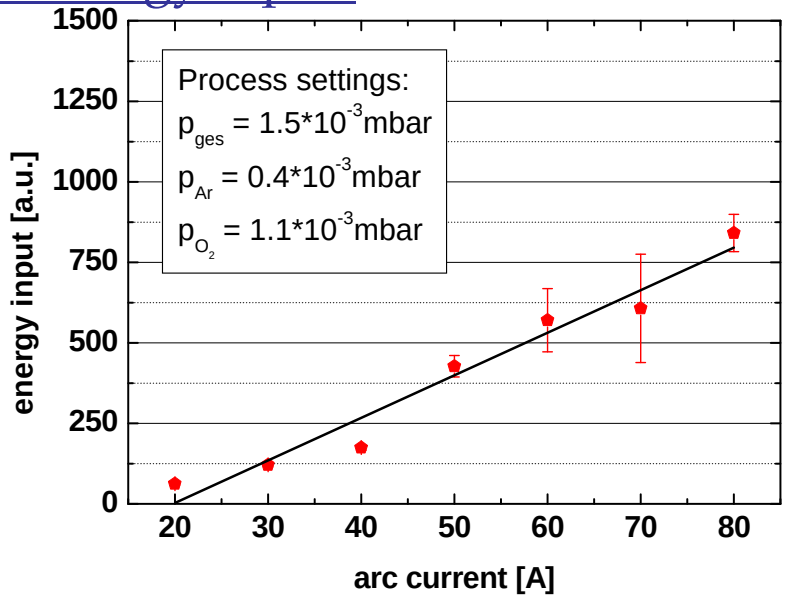
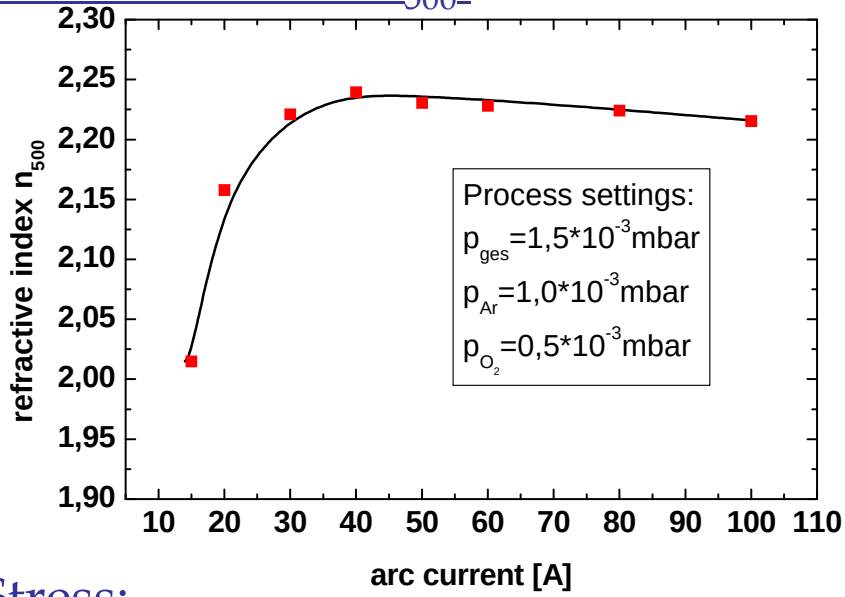
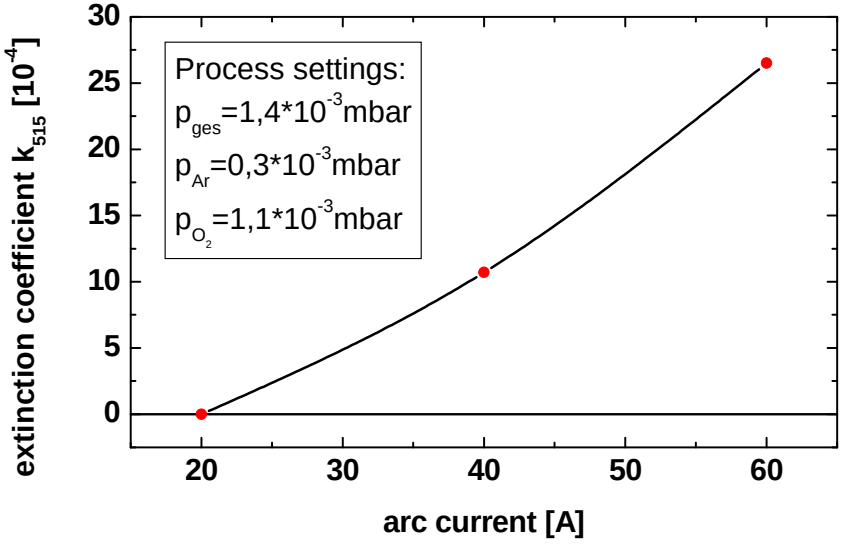
Ion energy input:



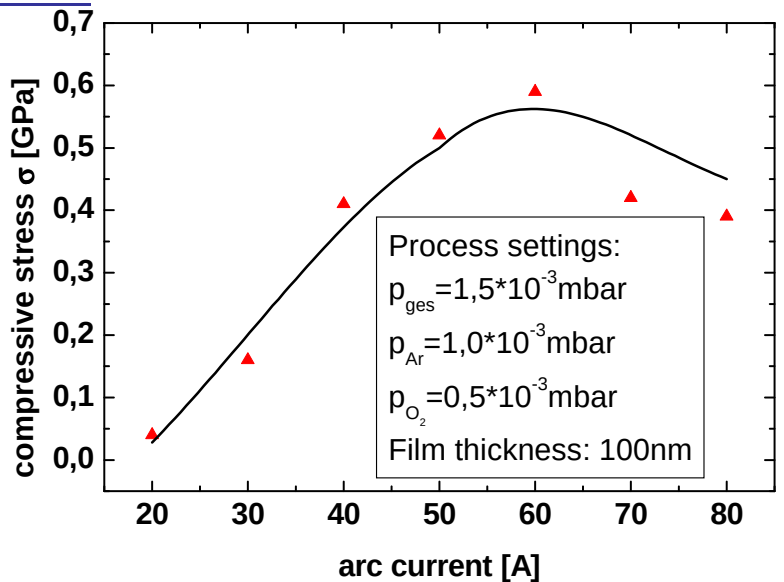
[1]Refractive index n_{500}:



[2]Extinction coefficient k_{515}:



[3]Stress:



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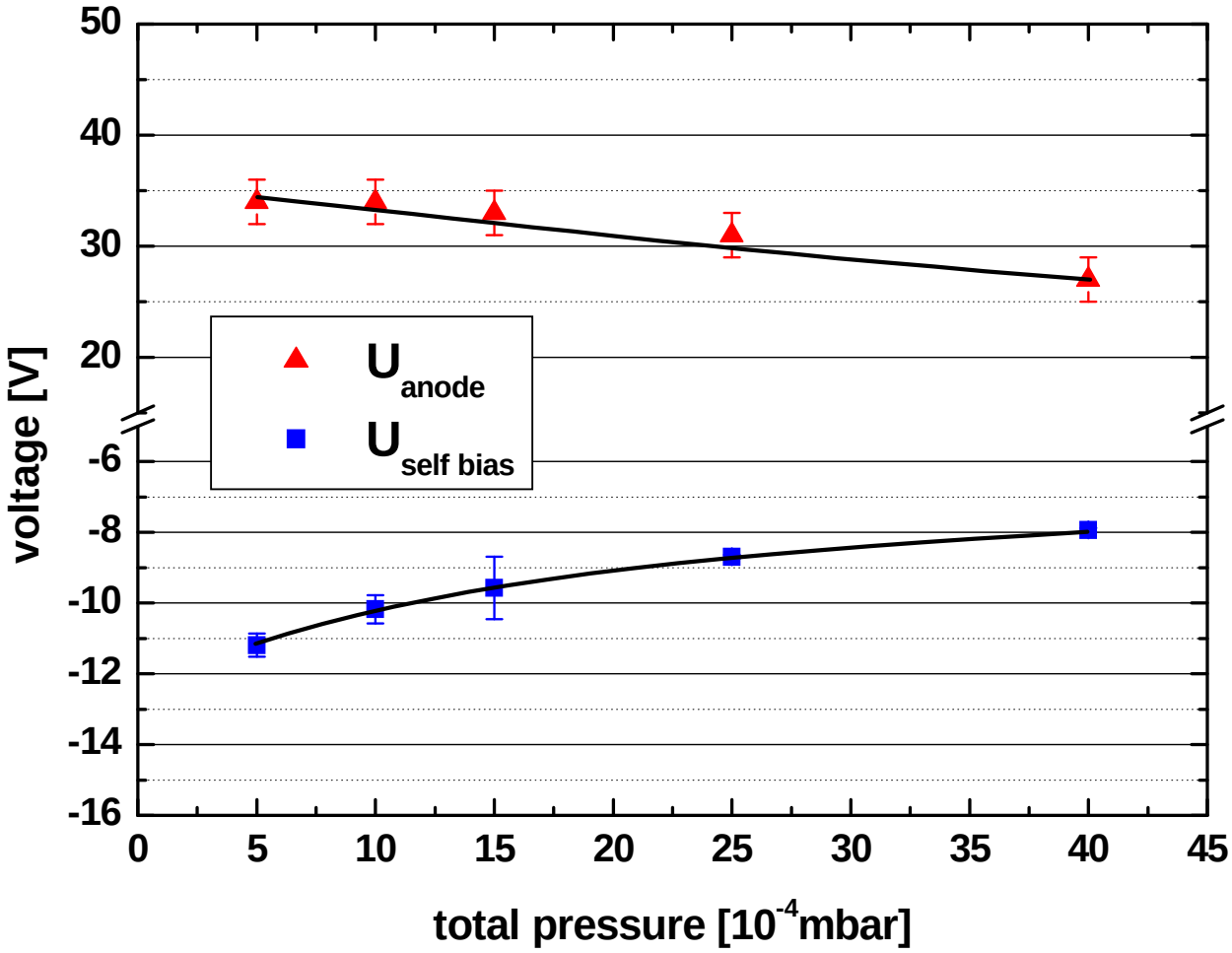
Results: potentials and voltages in dependence of gas pressure

Process settings: I_{arc}=40A , p_{Ar}=4x10^{-4}mbar, deposition rate: 0.3nm/s;

Coating material: Ta_2O_5



- Distinct decrease of the absolute values of anode potential and self-bias voltage with rising pressure
- Lower kinetic energy of the positive ions
- Additional energy loss due to shorter mean free path at high pressures

Results: ion current density in dependence of gas pressure

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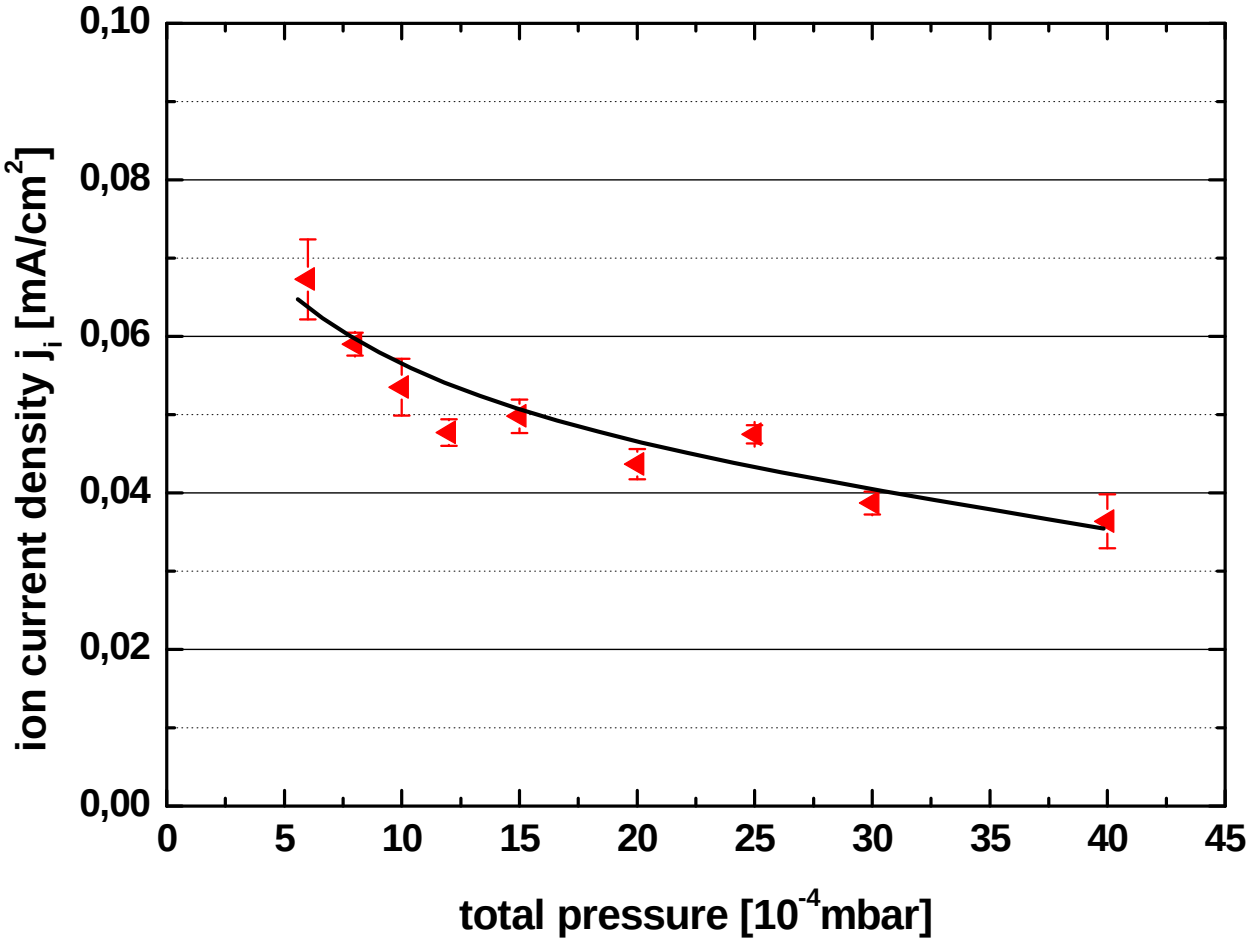
Process settings: I_{arc}=40A , p_{Ar}=4x10^{-4}mbar, deposition rate: 0.3nm/s;

Coating material: Ta_2O_5

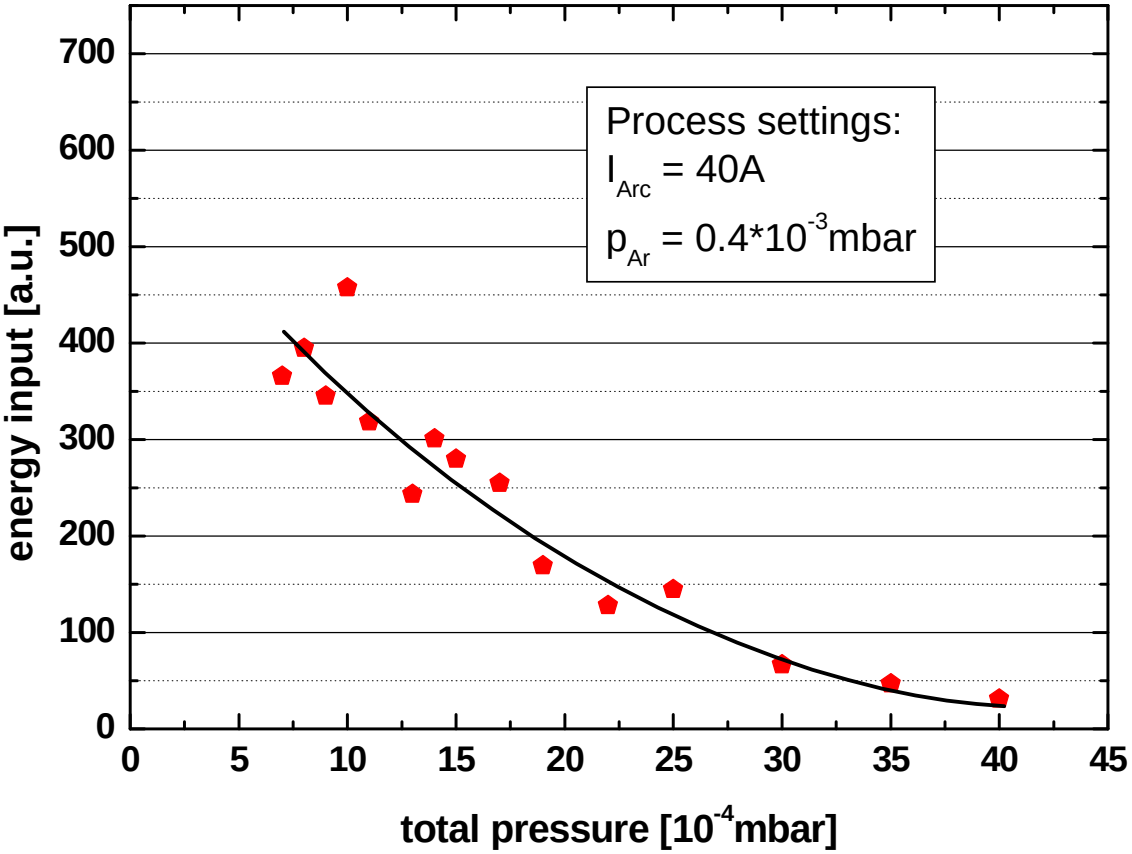


- Decrease of ion current density by roughly factor 2
- Higher number of impacts at high pressures (lower mean free path)

Results: energy input in dependence of gas pressure

Process settings: I_{arc}=40A , p_{Ar}=4x10^{-4}mbar, deposition rate: 0.3nm/s;

Coating material: Ta_2O_5



- Strong decrease of the energy input with rising gas pressure
  → less densification
  → lower refractive index
  → lower optical absorption (high stoichiometry)
  → decreasing stress values

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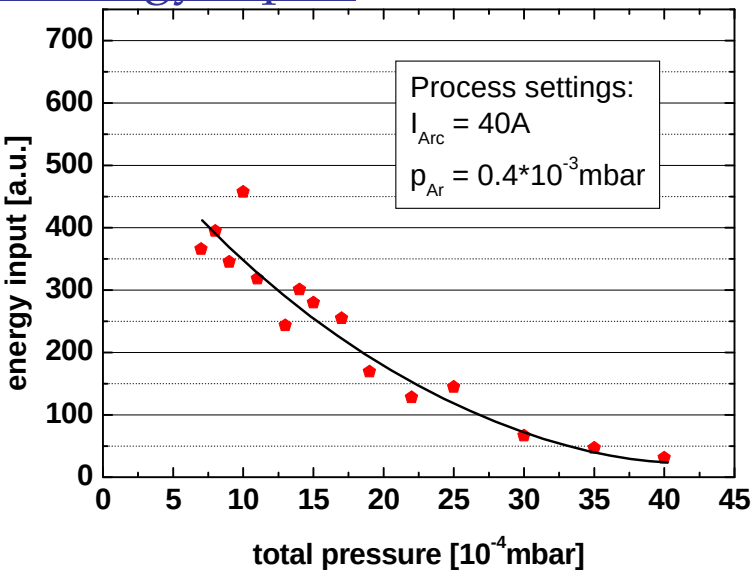
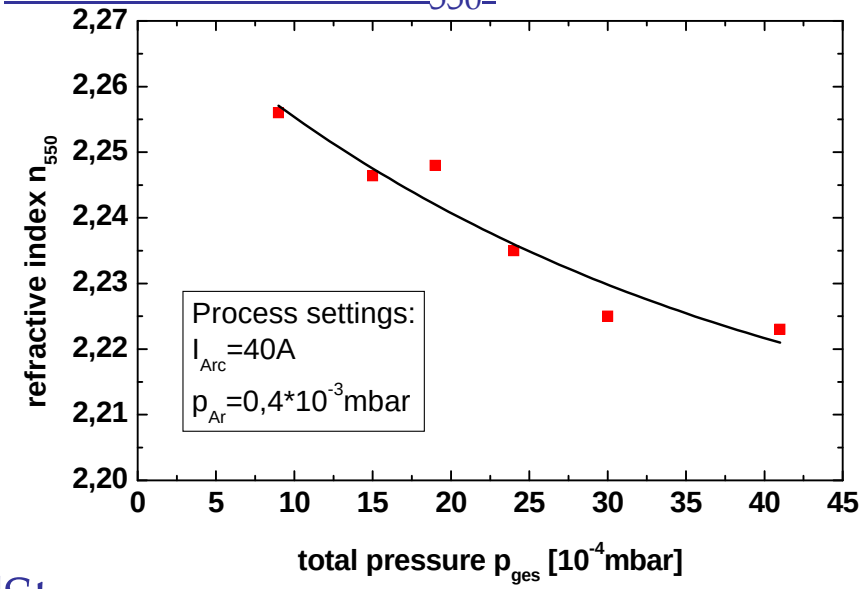
Results: Correlations between ion energy input and thin film properties

Ion energy input:



[4]Refractive index n_{550}:



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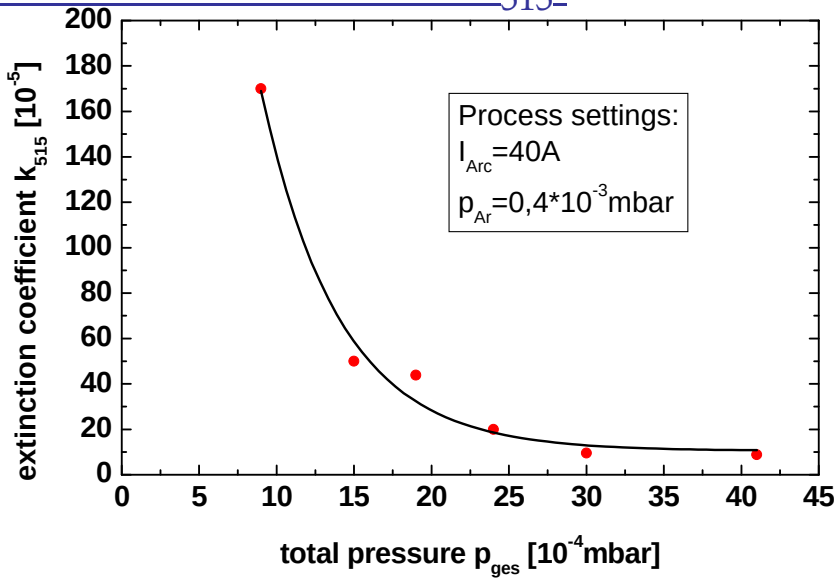
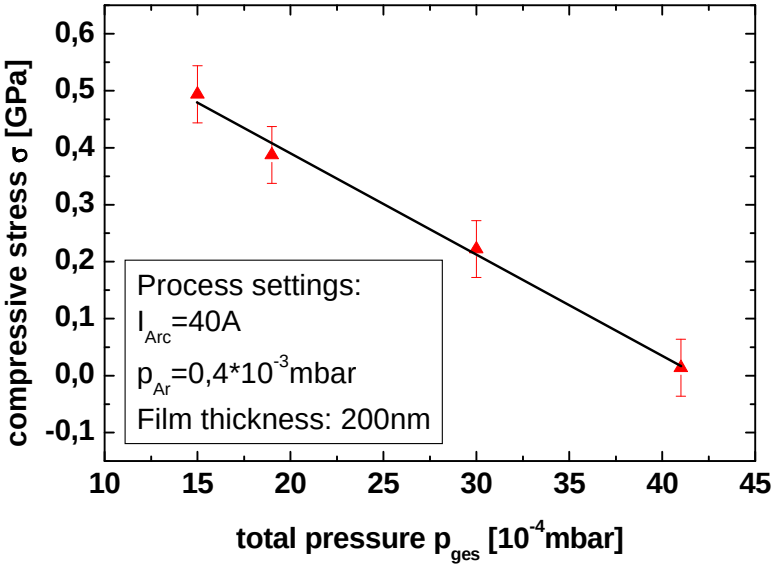


[4]Stress:



References:

1 Strauss G.N., Pulker H.K.: Untersuchung des Plasmas für das reaktive Niedervolt-Ionenplattieren, Vakuum in Forschung und Praxis Vol.12 1/2000, S.25

2 Lechner W.: Optische Charakterisierung von dünnen dielektrischen Schichten abgeschieden mit PVD-Verfahren, Dissertation, Universität Innsbruck (1999)

3 Strauss G.N., Danh N.Q., Pulker H.K.: Mechanical Stress in thin SiO2 and Ta2O5 films produced by reactive-low-voltage-ion-plating (RLVIP), Journal of Non-Crystalline Solids 218 (1997), S.256

4 Schlichtherle S., Huber D., Pulker H.K.: Influence of Relevant Gas Pressure on the Properties of Ionplated Ta2O5 Films, Vakuum in Forschung und Praxis Vol.15 2/2003, S.83

Thank you for your attention!