Willkommen
Welcome
Bienvenue

Empa
Materials Science and Technology

Tunable ion flux density and its impact on AlN thin films deposited in a confocal DC Magnetron Sputtering System

XXIV. Erfahrungsaustausch Oberflächentechnologie mit Plasma- und Ionenstrahlprozessen - Mühlleithen / Vogtland, 07. - 09. März 2017

C A U
Christian-Albrechts-Universität zu Kiel

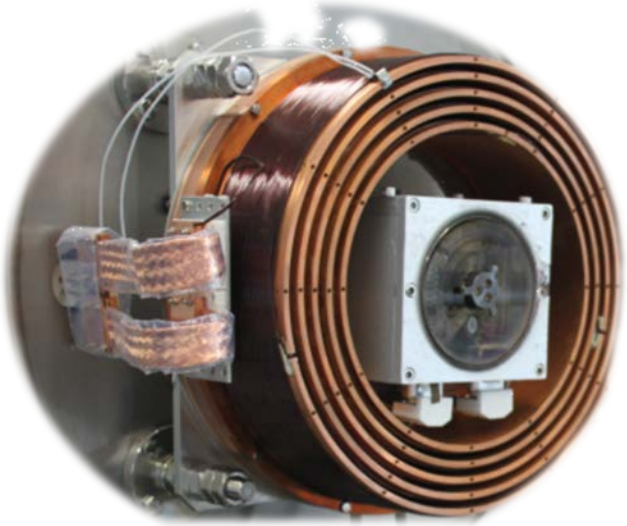
ERNST MORITZ ARNDT
UNIVERSITÄT GREIFSWALD
Wissen
lockt.
Seit 1456

Mathis Trant[1], Maria Fischer[1], Kerstin Thorwarth[1], Sven Gauter[2], Hans Josef Hug[1], Jörg Patscheider[1]

[1]*Empa, Laboratory for Nanoscale Materials Science, Switzerland*
[2]*Institut für Experimentelle und Angewandte Physik, University of Kiel, Kiel, Germany*

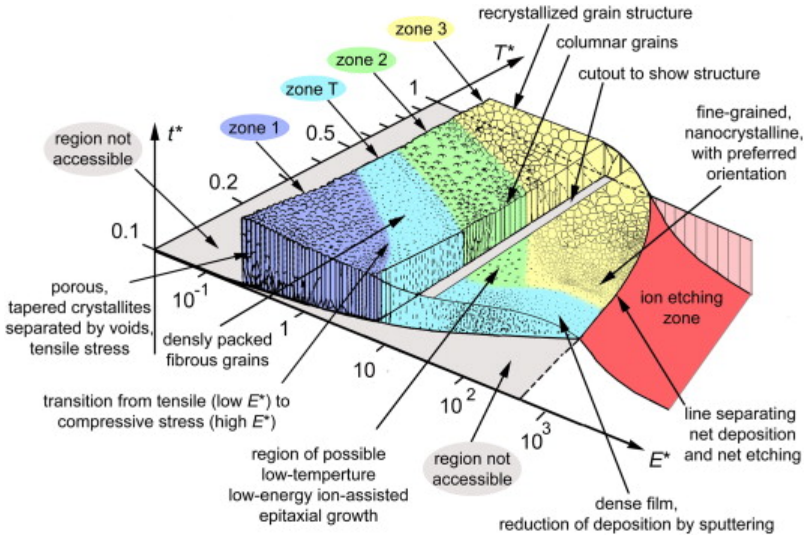
Outline

- Motivation & Introduction
- Results
  - Part A: Plasma Analytics
  - Part B: Thin Film Properties
- Conclusion



Motivation

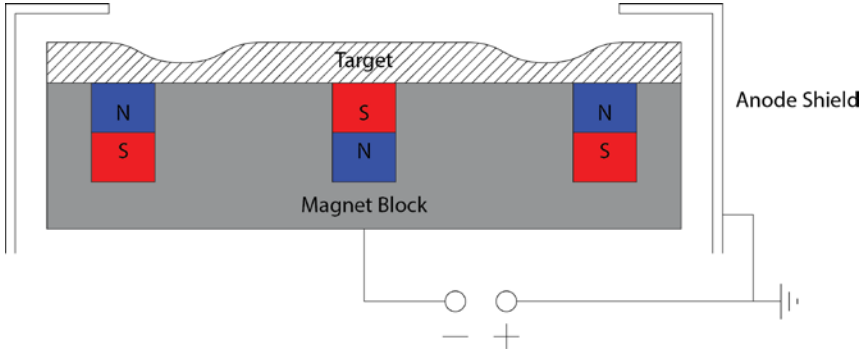
- **Plasma** analytics
- **Plasma** control
- Control of **thin film** growth through **plasma** conditions



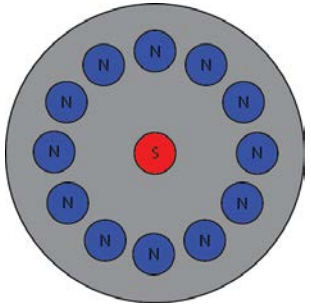
Ref: A. Anders, Thin Solid Films, Volume 518, Issue 15, 31 May 2010, Pages 4087-4090

Magnetic Configuration of Single Magnetron

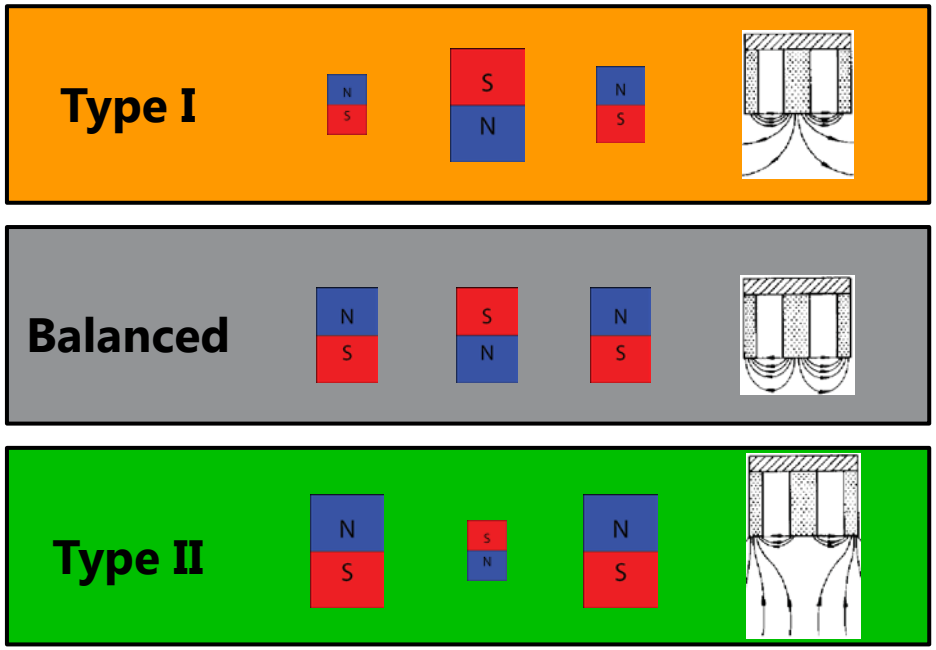
Empa
Materials Science and Technology



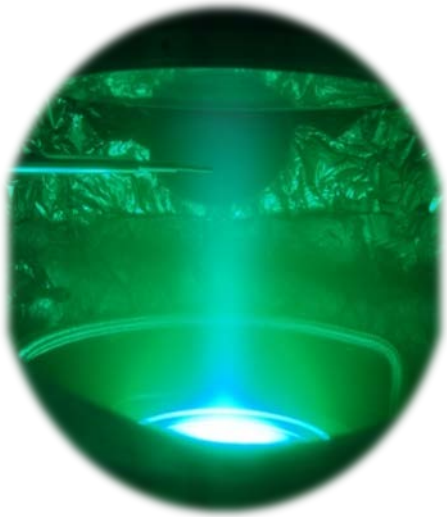
Side View



Top View

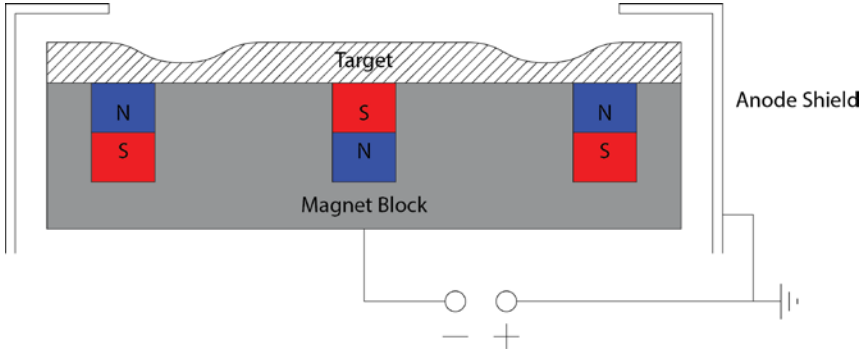


Ref: Window, B., & Savvides, N. (1986). Journal of Vacuum Science & Technology A, 4(2), 196.

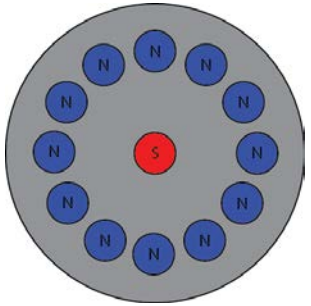


Ref: CAPST, Sungkyunkwan University, Suwon, South Korea

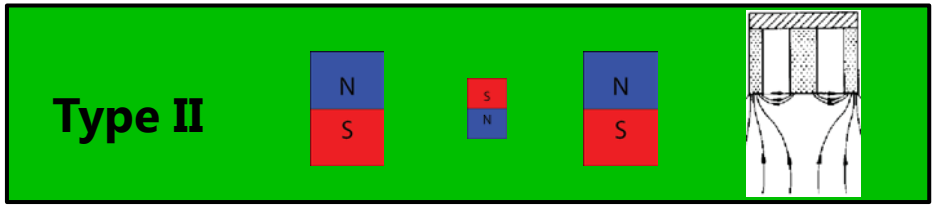
Magnetic Configuration of Single Magnetron



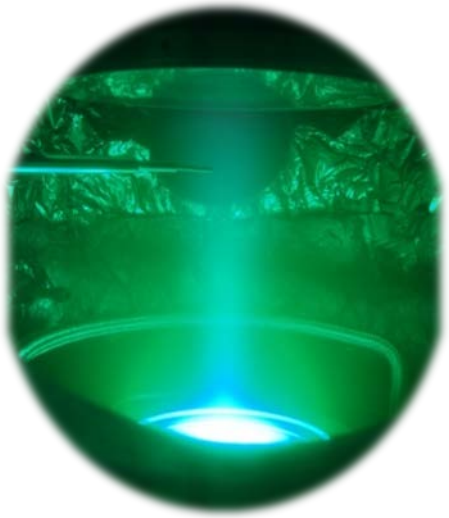
Side View



Top View



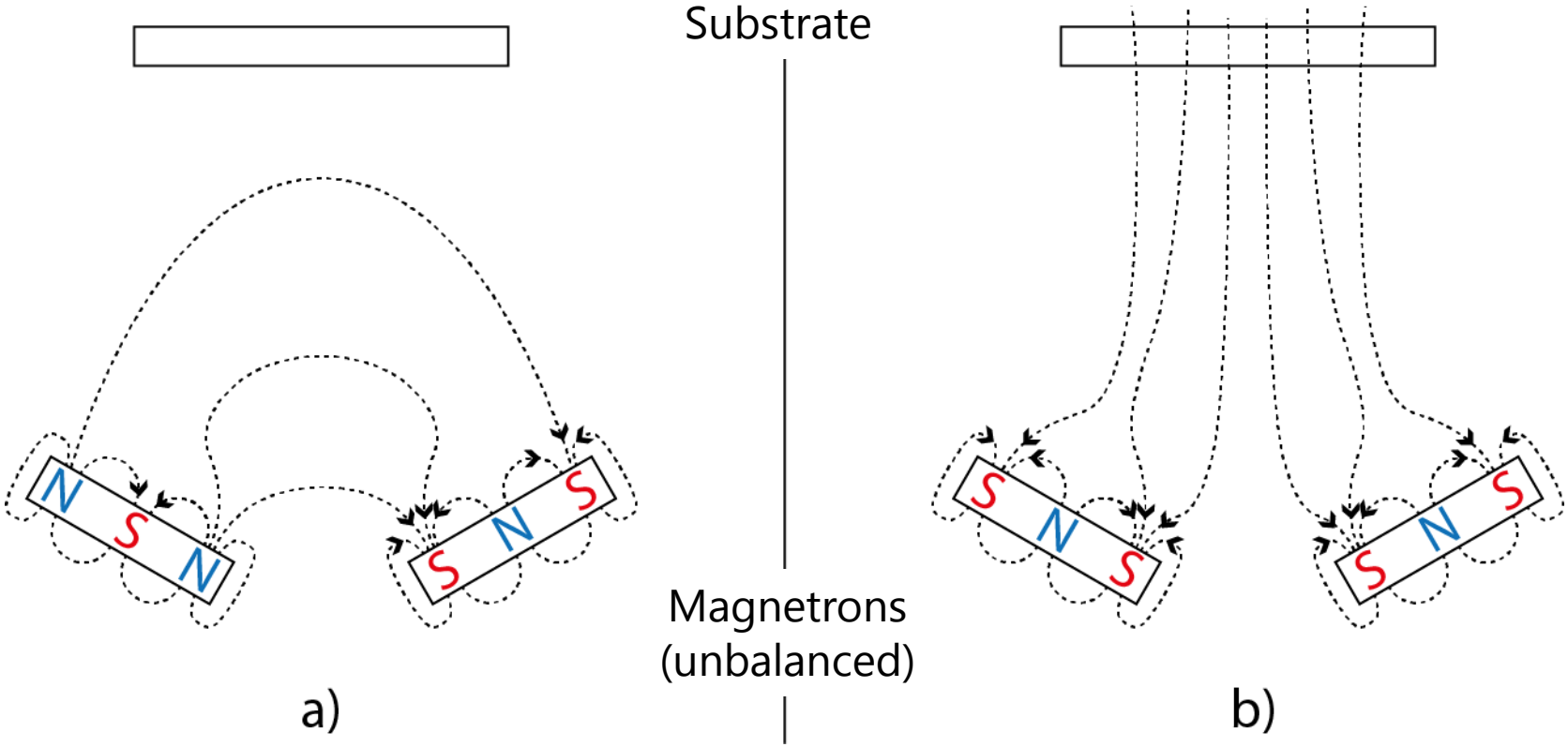
- Plasma extended towards substrate
- Interaction of growing film with plasma



Ref: Window, B., & Savvides, N. (1986). Journal of Vacuum Science & Technology A, 4(2), 196.

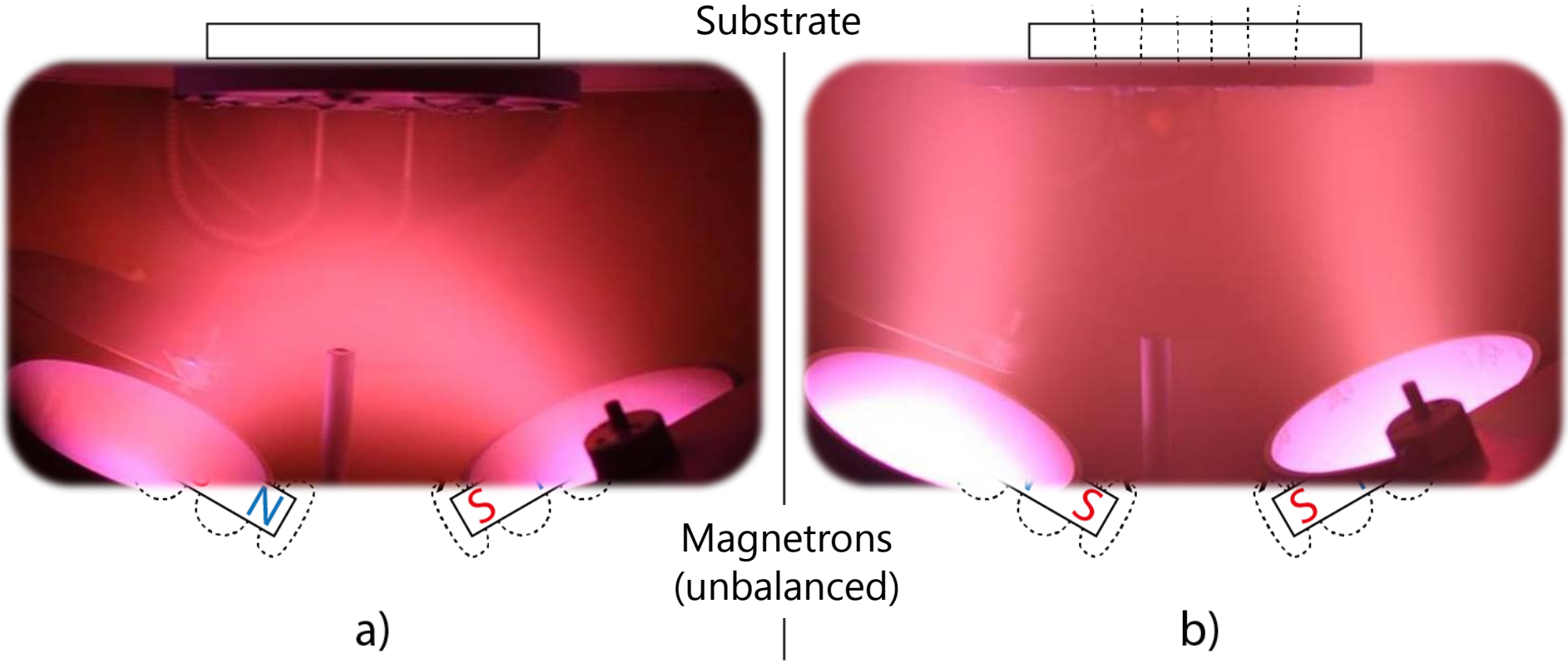
Ref: CAPST, Sungkyunkwan University, Suwon, South Korea

Confocal Dual Magnetron Sputtering



Confocal Dual Magnetron Sputtering

Empa
Materials Science and Technology

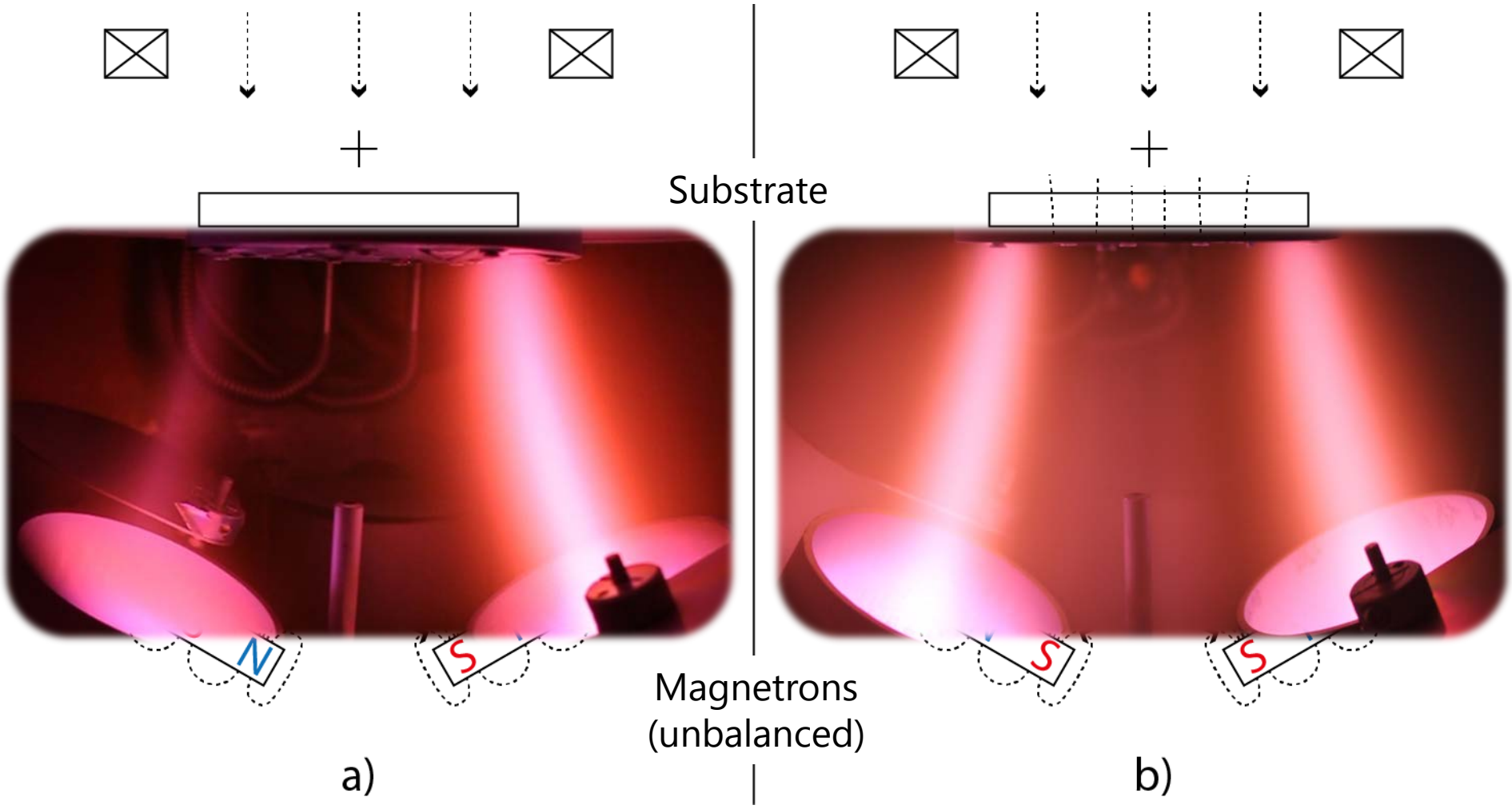


Closed Field

Open Field

Confocal Dual Magnetron Sputtering

Empa
Materials Science and Technology



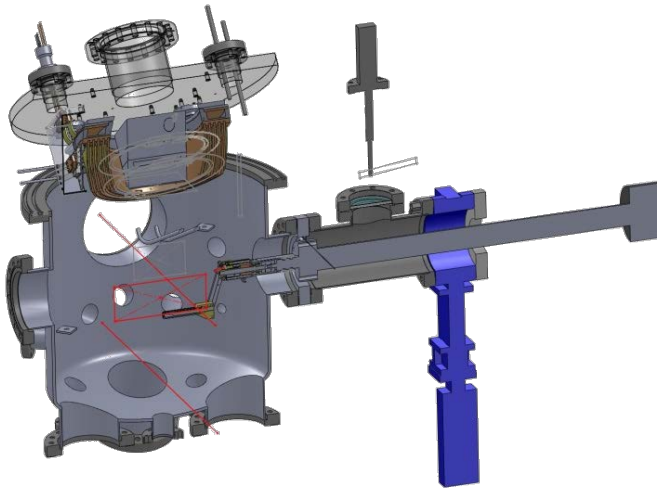
Closed Field

Open Field

Plasma Analytics Setup

In Situ Coil	
N	150
L	58 cm
R	8.8 – 12.2 cm
$\|B^{max}\|$ @ substrate	**≈200 G**

Plasma Analytics Setup

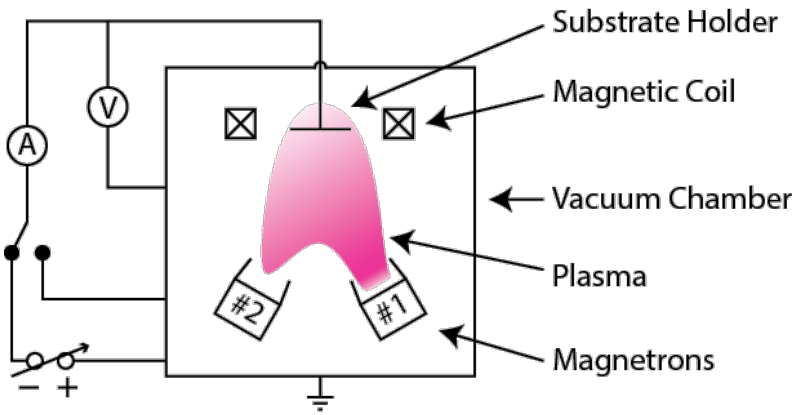


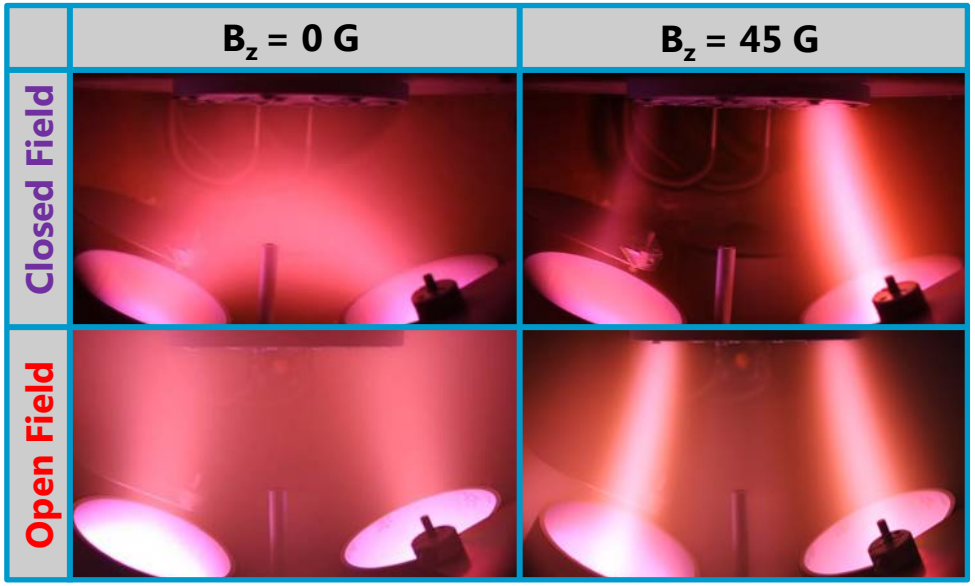
In Situ Coil	
N	150
L	58 cm
R	8.8 – 12.2 cm
$\|B^{max}\|$ @ substrate	**≈200 G**

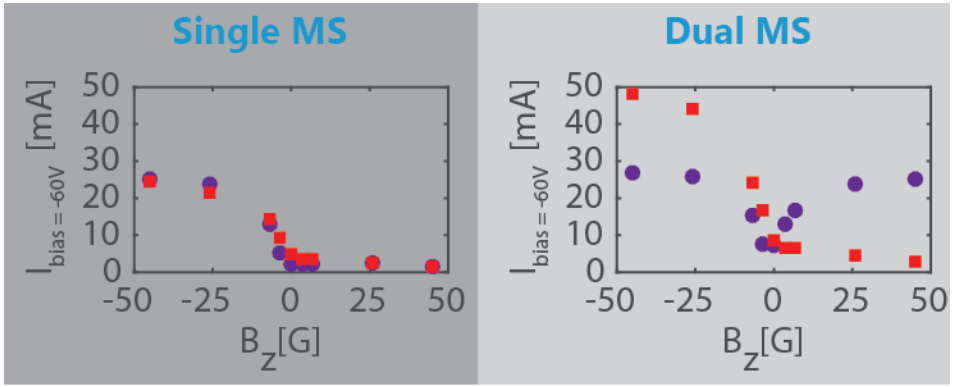
- **Plasma Analytics**
  - 'Substrate Holder'
  - Langmuir Probe
  - Calorimetric Probe
  - 'Thermocouple'

Confocal DCMS	
$\phi = \phi_{Ar}$	15 sccm (p ≈ 5µbar)
$P_{1,2}$(Al)	200 W (10W/cm^2)
$d_{target<->substrate}$	12 cm

Plasma Analytics
I – Substrate Holder







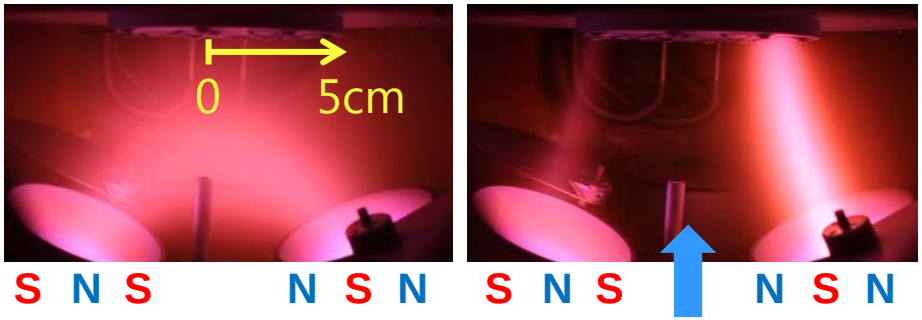
open
closed

- Enhancement of ion flux for both configurations
- Ion flux is the sum of ion flux from individual guns

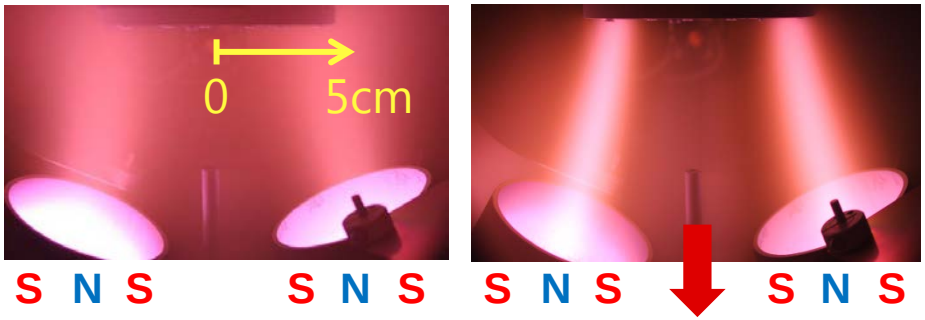
Plasma Analytics
II - Langmuir Probe

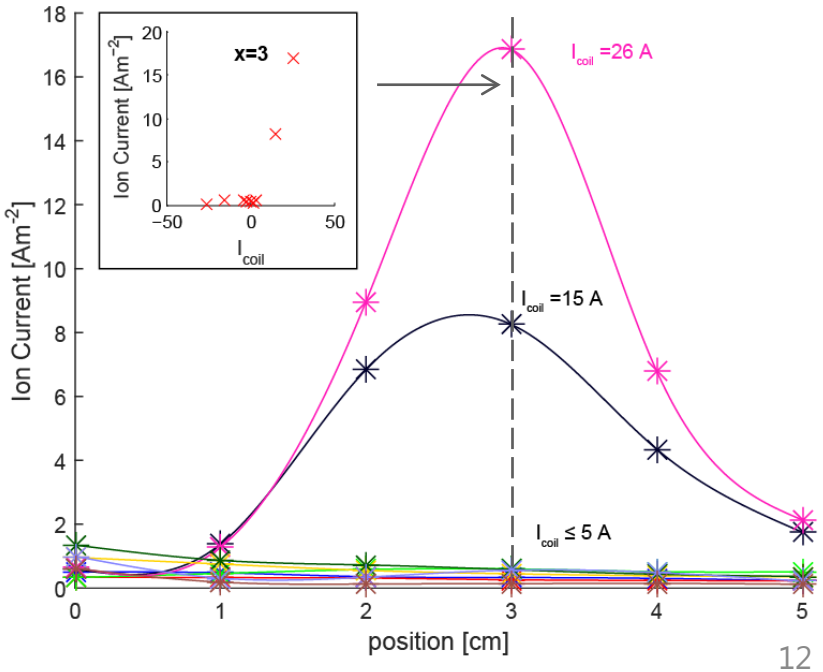
Empa
Materials Science and Technology

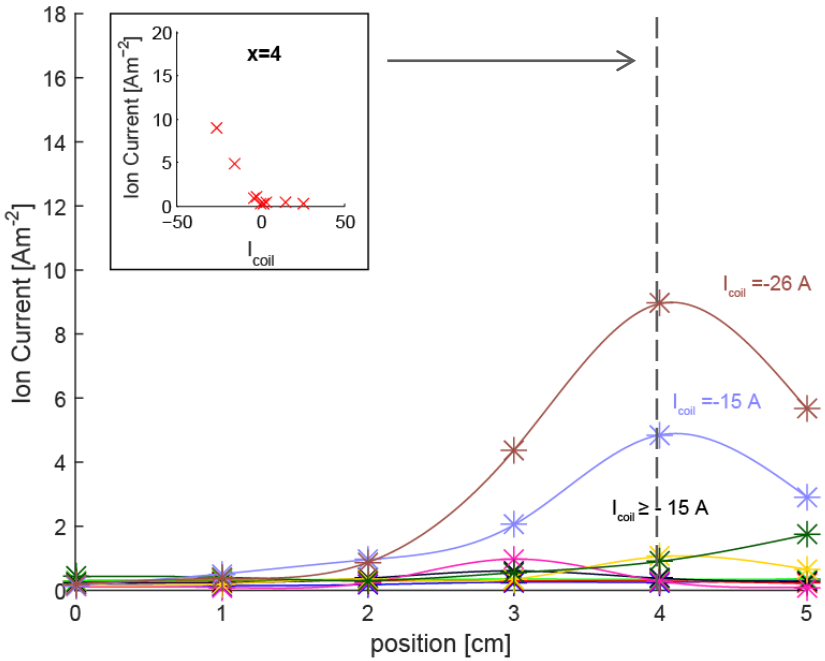
Closed Field



Open Field



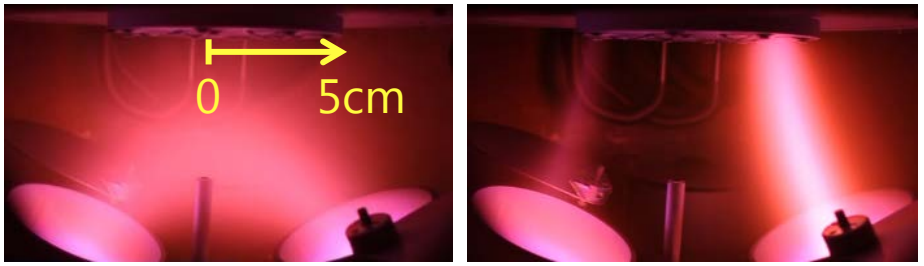




Plasma Analytics
II - Langmuir Probe

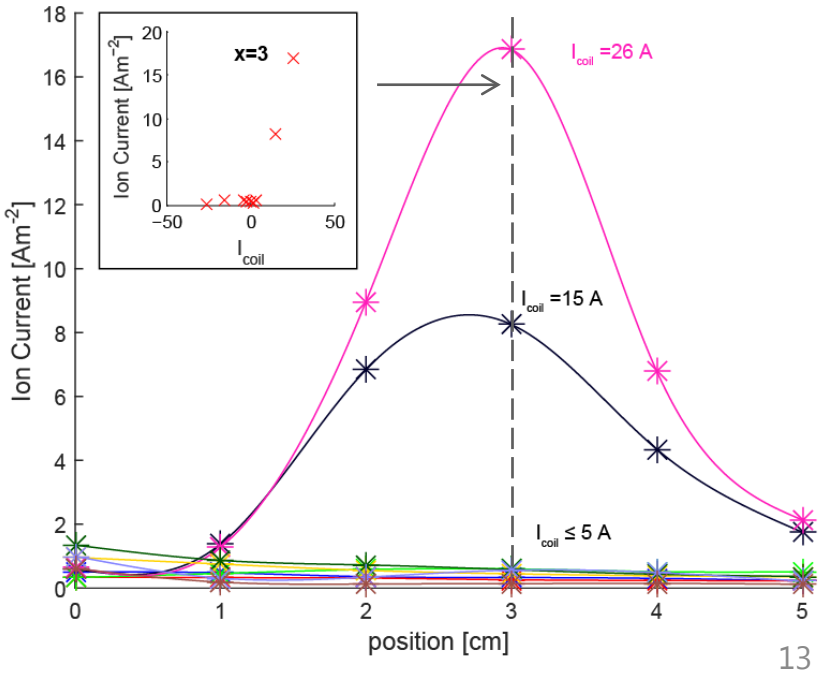
Empa
Materials Science and Technology

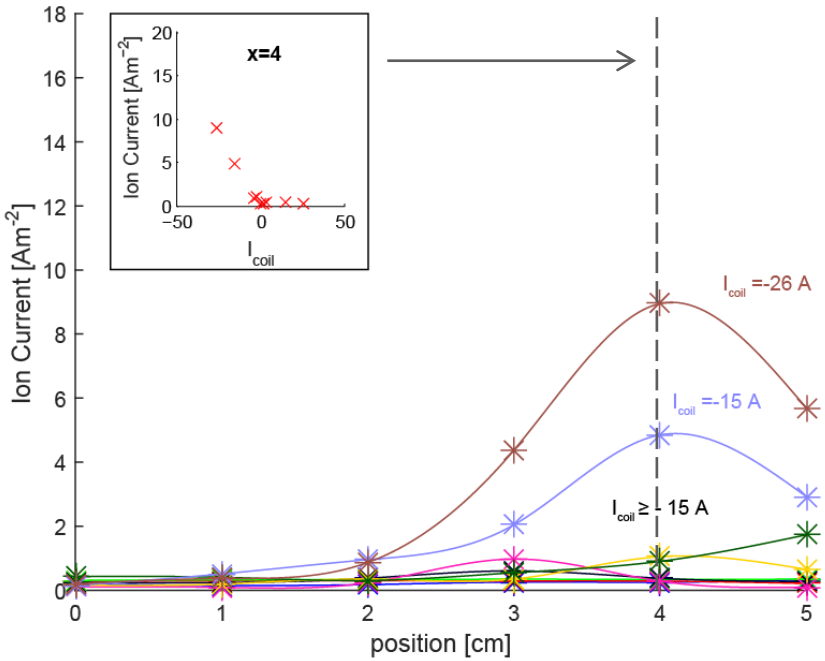
Closed Field



Open Field

Local increase of ion flux density by more than one order of magnitude

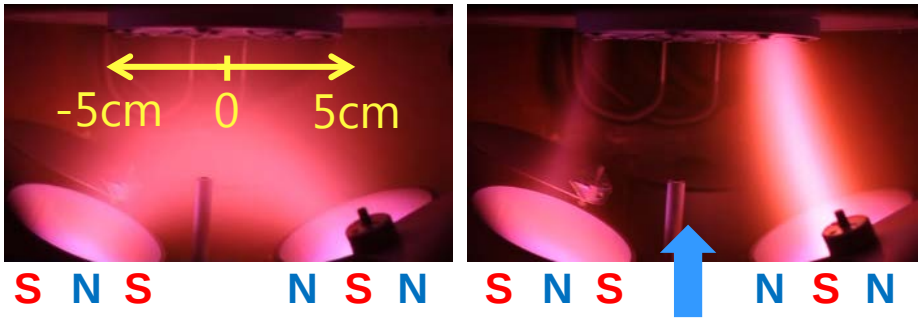




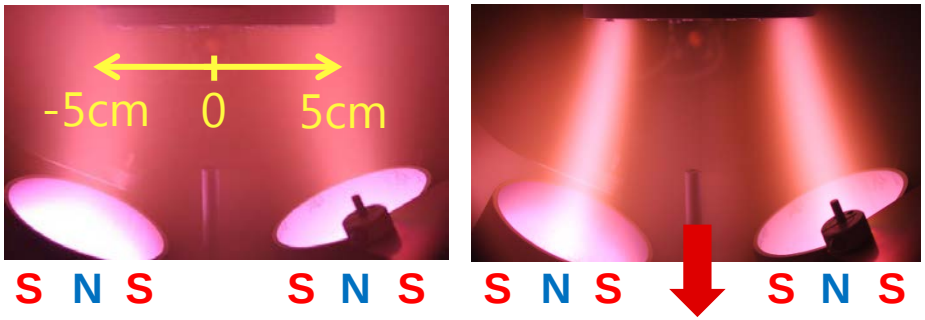
Plasma Analytics
III – Calorimetric Probe

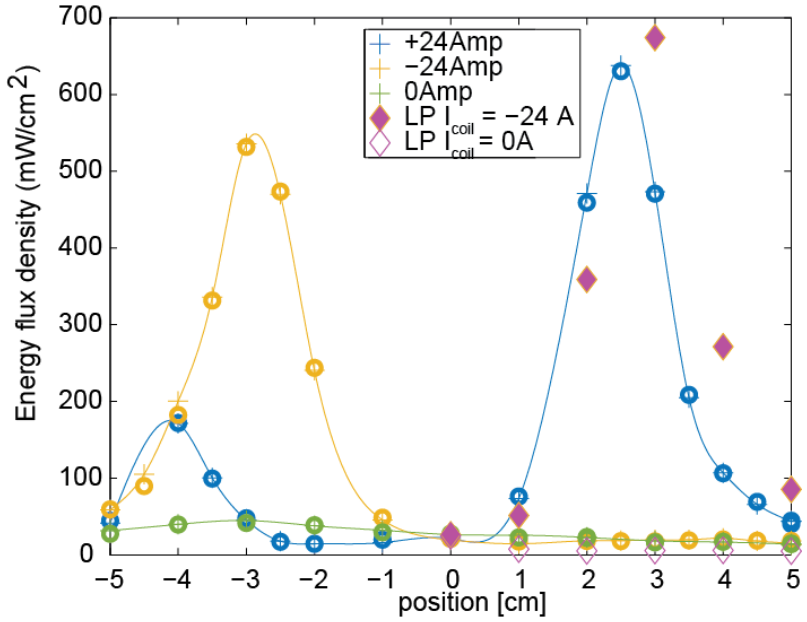
Empa
Materials Science and Technology

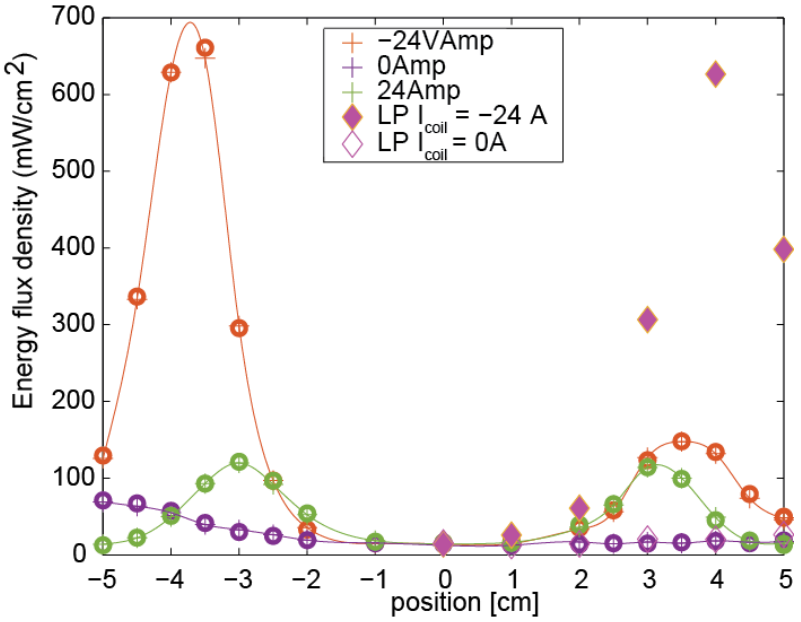
Closed Field



Open Field



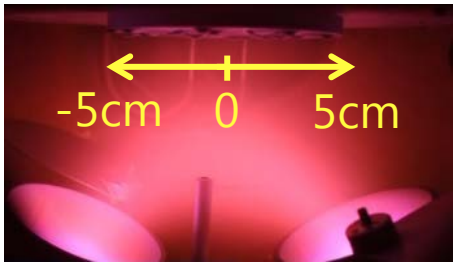


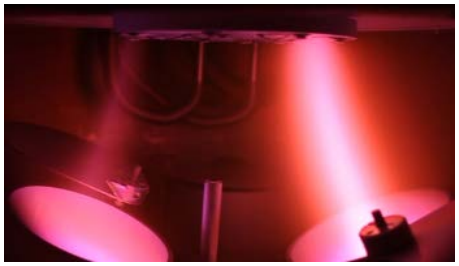


Plasma Analytics
III – Calorimetric Probe

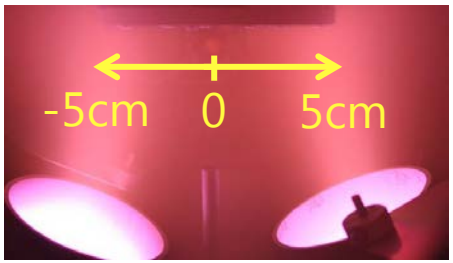
Empa
Materials Science and Technology

Closed Field



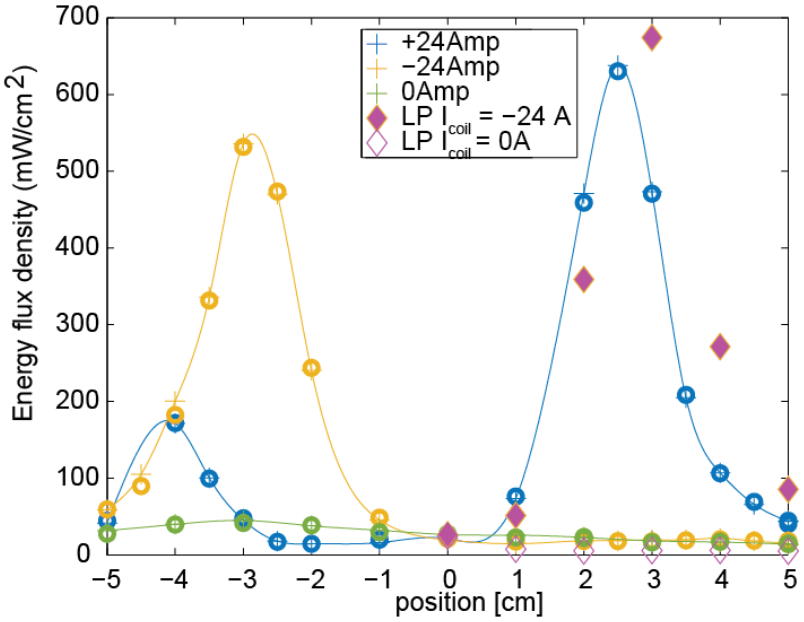


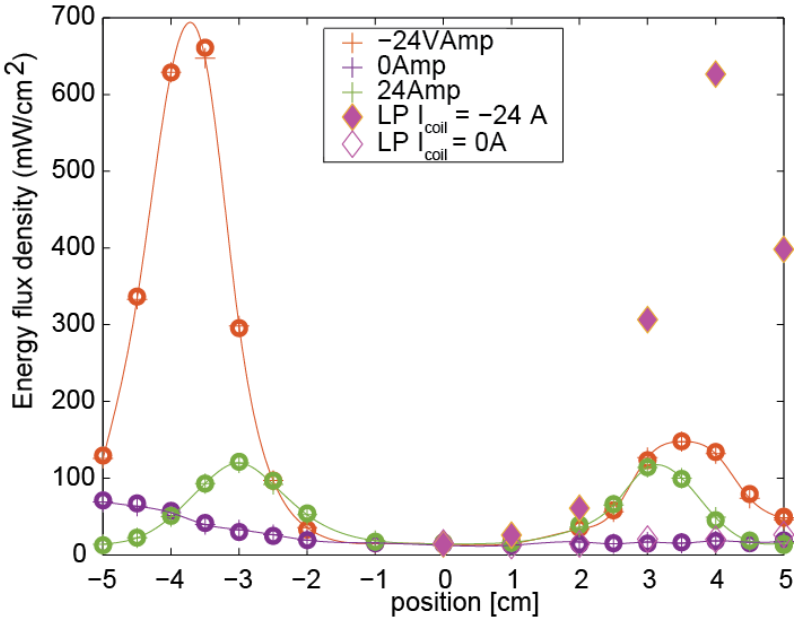
Open Field



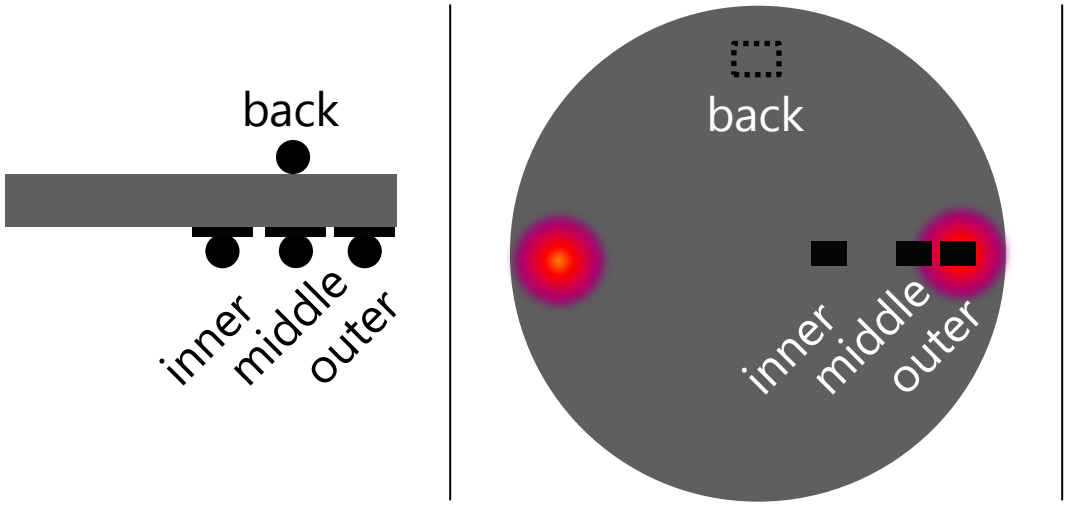
Local increase in energy flux density by more than one order of magnitude.

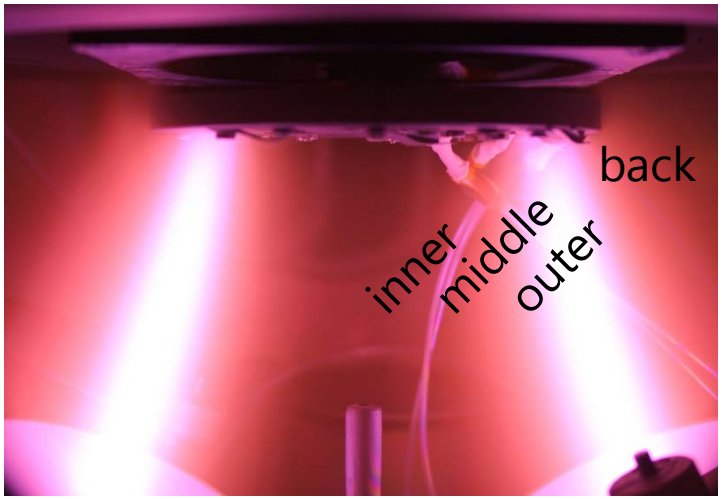
Almost identical spatial profiles to ion current density





Plasma Analytics
IV – Temperature

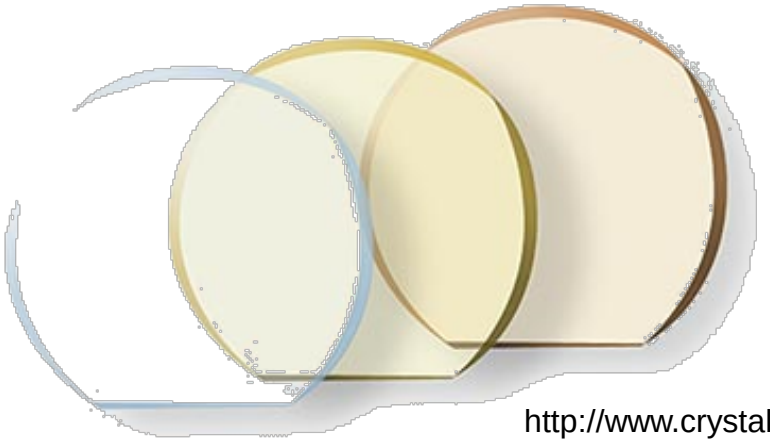




Open Field, I_{coil} = -24A

I_{coil} [A]	Temperature [°C] (open field; $P_{1,2}$(Al) = 200W)			
	T_{outer}	T_{middle}	T_{inner}	T_{back}
0	116	108	100	79
-24	259	171	145	115

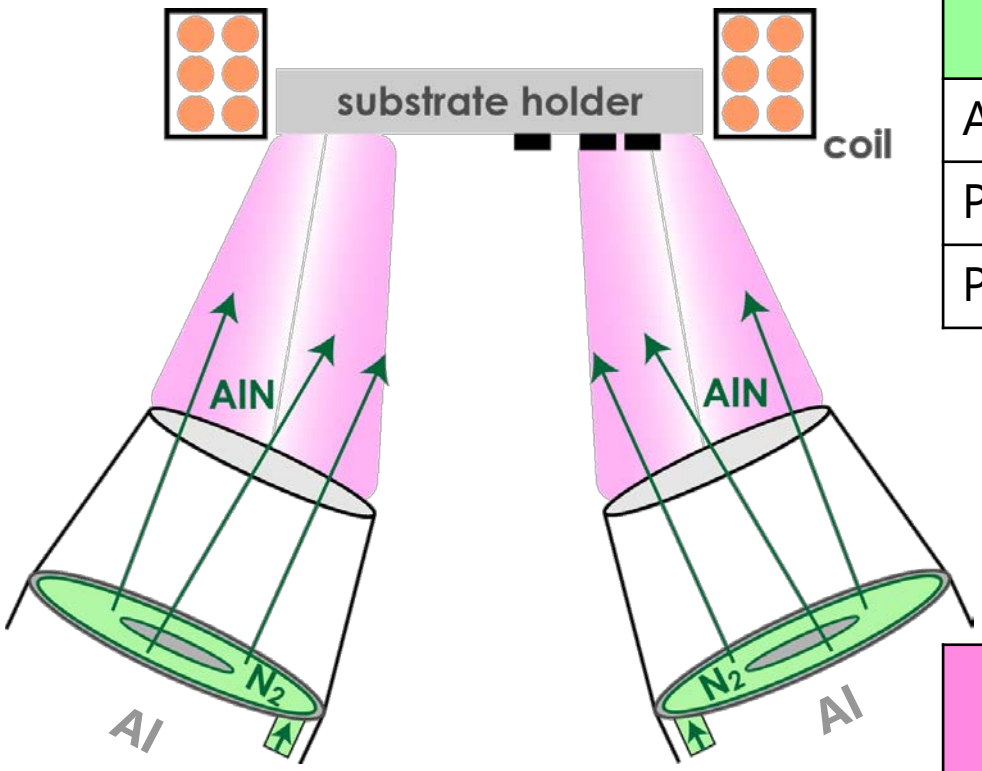
Motivation
Why Aluminum Nitride?



http://www.crystal-n.com

- **Hard** (around 20 GPa)
- **Wide bandgap** semiconductor (6.2 eV)
- **Optically Transparent** (400-800 nm)
- **Piezoelectric** (5.15 pm/V for d_{33})

AlN Thin Film Properties
Setup



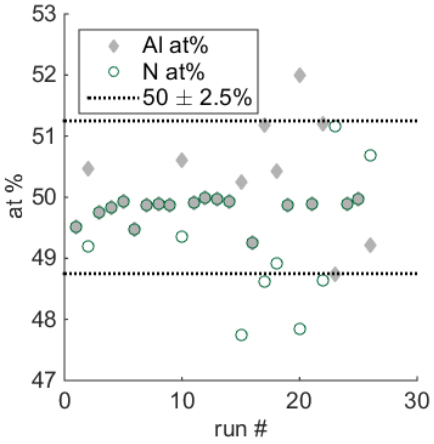
Reactive Confocal DC Magnetron Sputtering	
Ar:N_2	15:12
Pressure	5 µbar
Power	200 W (10W/cm^2)

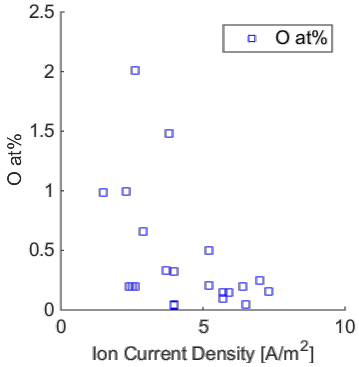
Varied Parameters	
Ion to Neutral Ratio	1↔ 44
Ion Current Density	1.5 ↔ 70 A/m^2
Temperature	100 ↔ 500 °C

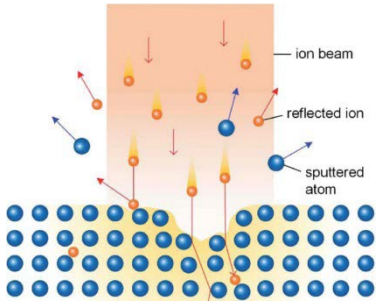
AlN Thin Film Properties

AlN Thin Film Properties

film composition







[1] Zhi-Ye Qiu et al. (2014), DOI: 10.1093/rb/rbu007

- **Stochiometric films**
  Metal non-metal ratio not affected by ion bombardment

- **Oxygen** incorporation **reduced** for higher plasma densities

  Explanation:

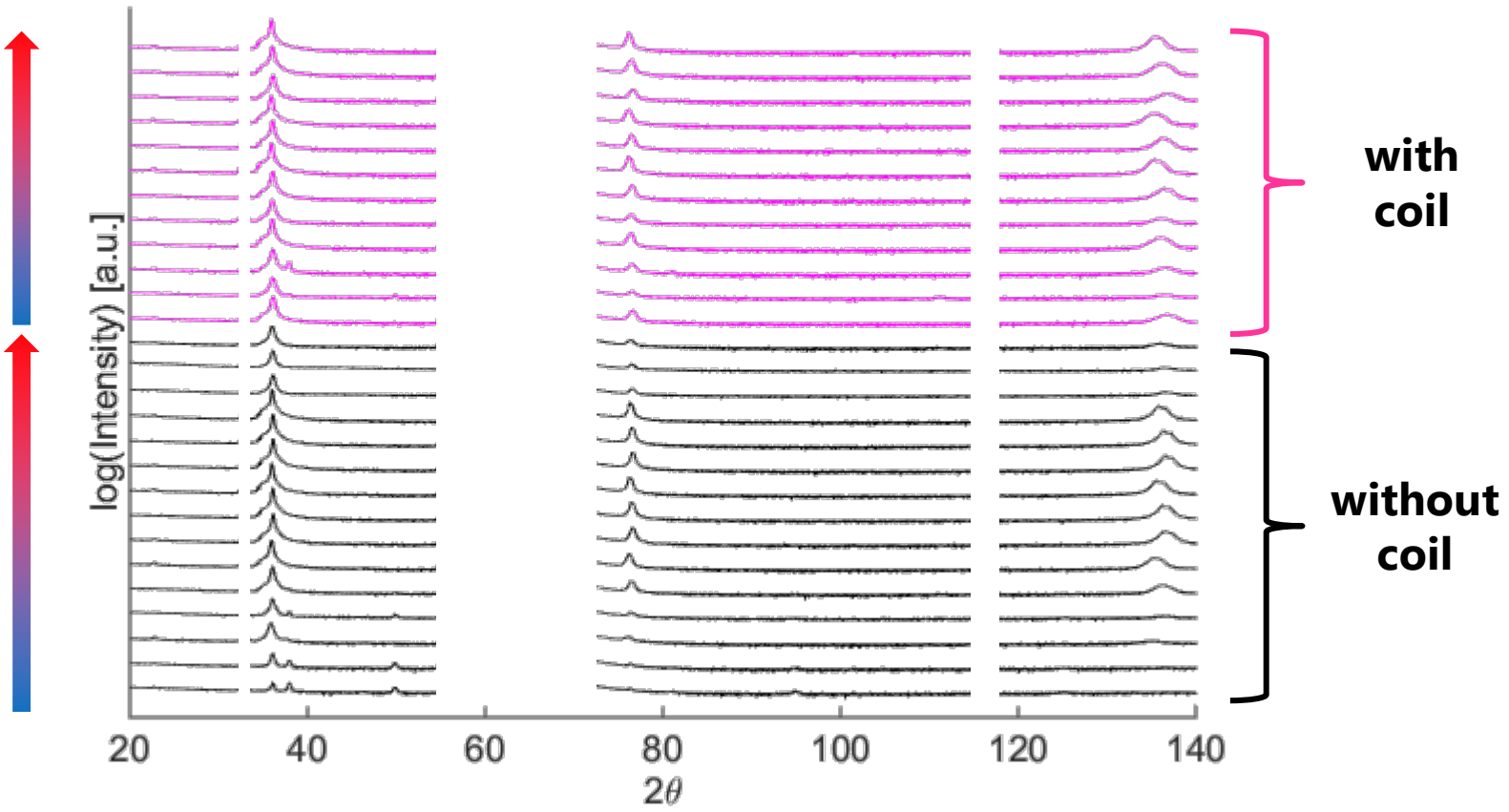
  Higher reactivity of N_2 in plasma environment

- **No Ar implantation** through increased ion bombardment (<0.07 at% ,RBS+ERDA)

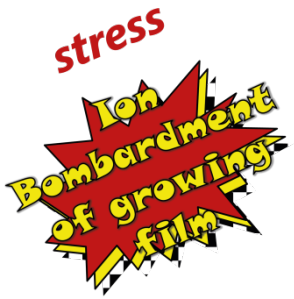
  Low energy ion bombardment!

AlN Thin Film Properties

Empa
Materials Science and Technology

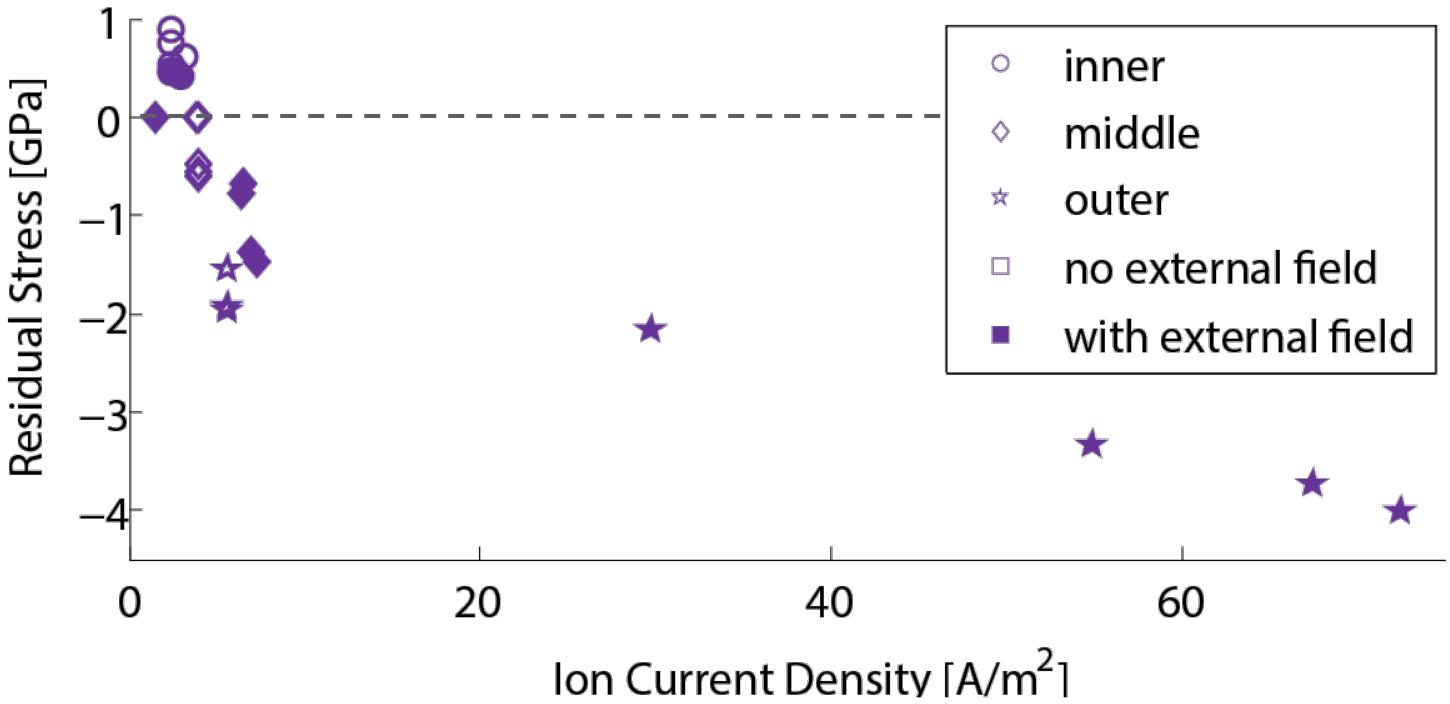


(almost) all samples show prefered (002)-orientation



AlN Thin Film Properties

Empa
Materials Science and Technology

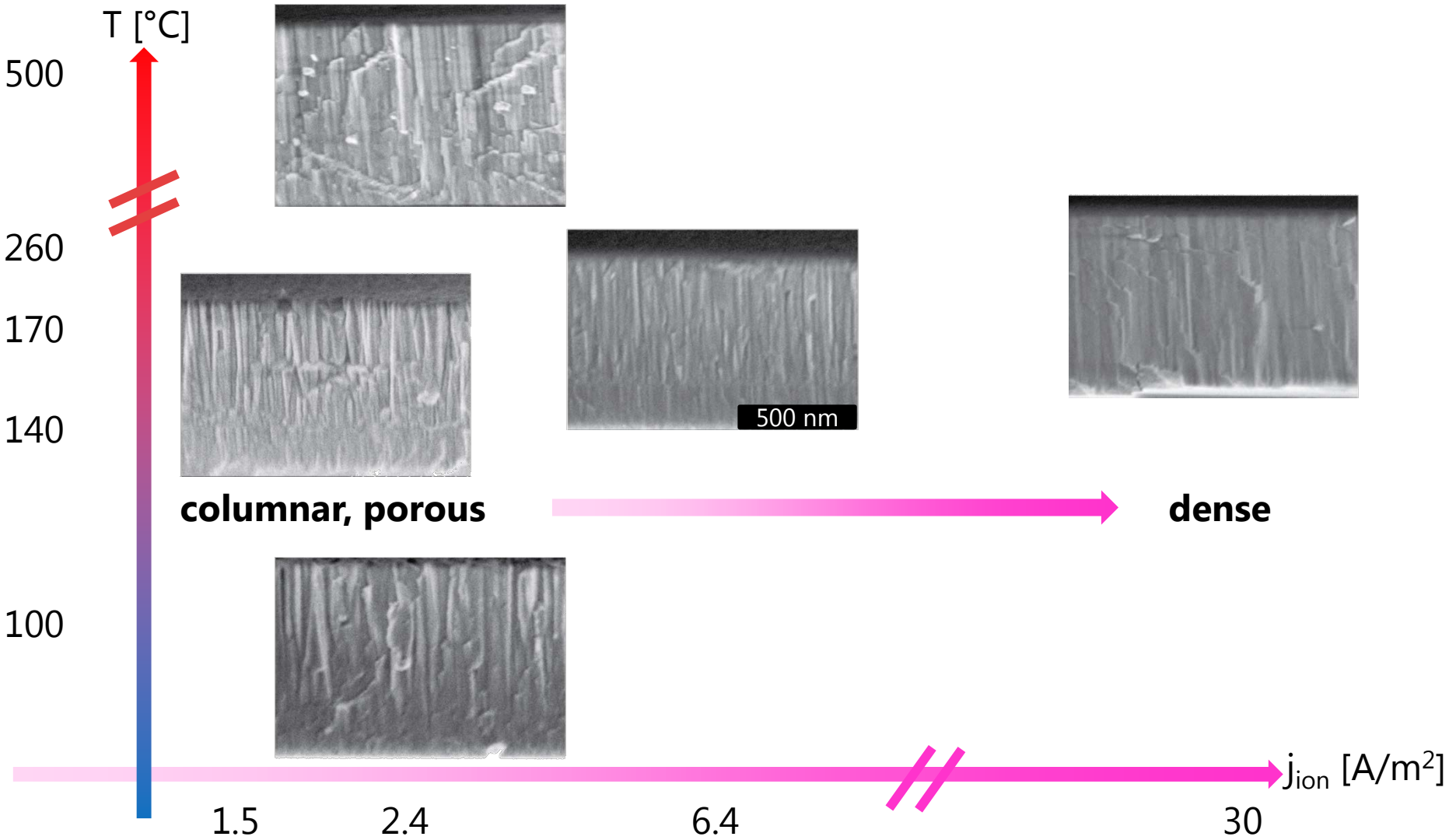


AlN Thin Film Properties

Empa
Materials Science and Technology

Ion Bombardment of growing film

growth morphology



Conclusions

Empa
Materials Science and Technology

- Variation of ion flux density with additional magnetic field in confocal DCMS.
  - j_{ion} tunable over more than one order of magnitude
  - Considerable influence on temperature

- Comparison of influence of Ion Bombardment and Temperature on AlN thin film growth
  - (002) orientation: 100 °C < T < 500 °C
    $1 < j_{ion}/j_{neutral} < 30$
  - Stress: tensile → compressive with increasing j_{ion}
  - Microstructure: columnar, porous → dense with increasing j_{ion}

FNSNF
Swiss National Science Foundation

Outro

Empa
Materials Science and Technology