Coatings voor toepassingen binnen het CERN

Wil Vollenberg

TE-VSC-SCC-thin films lab

Thanks to colleagues Pedro C.P. and Matthias van Gompel for several slides

- Introductie
- Wat zijn coatingen
- Hoe maken we coatingen
- Belangrijke toepassing:
    - NEG
    - amorphous Carbon

Cern is een onderzoekscentrum voor deeltjes fysica

Materiaalkunde onderzoek en ontwikkeling ter ondersteuning van versnellers en detectoren

Materiaalkundige ondersteuning:

- Keuze van materialen
- bewerken van materialen (warmte / chemisch / mechanisch)
- Coaten van materialen

Van Dale: Coaten is het aanbrengen van een deklaag.

Meeste gevallen is dat een dunne laag.

Voor onze toepassingen: 10 nm – 5 µm

M.b.v. coaten veranderen we de oppervlakte eigenschappen van een materiaal.

80 nm Al

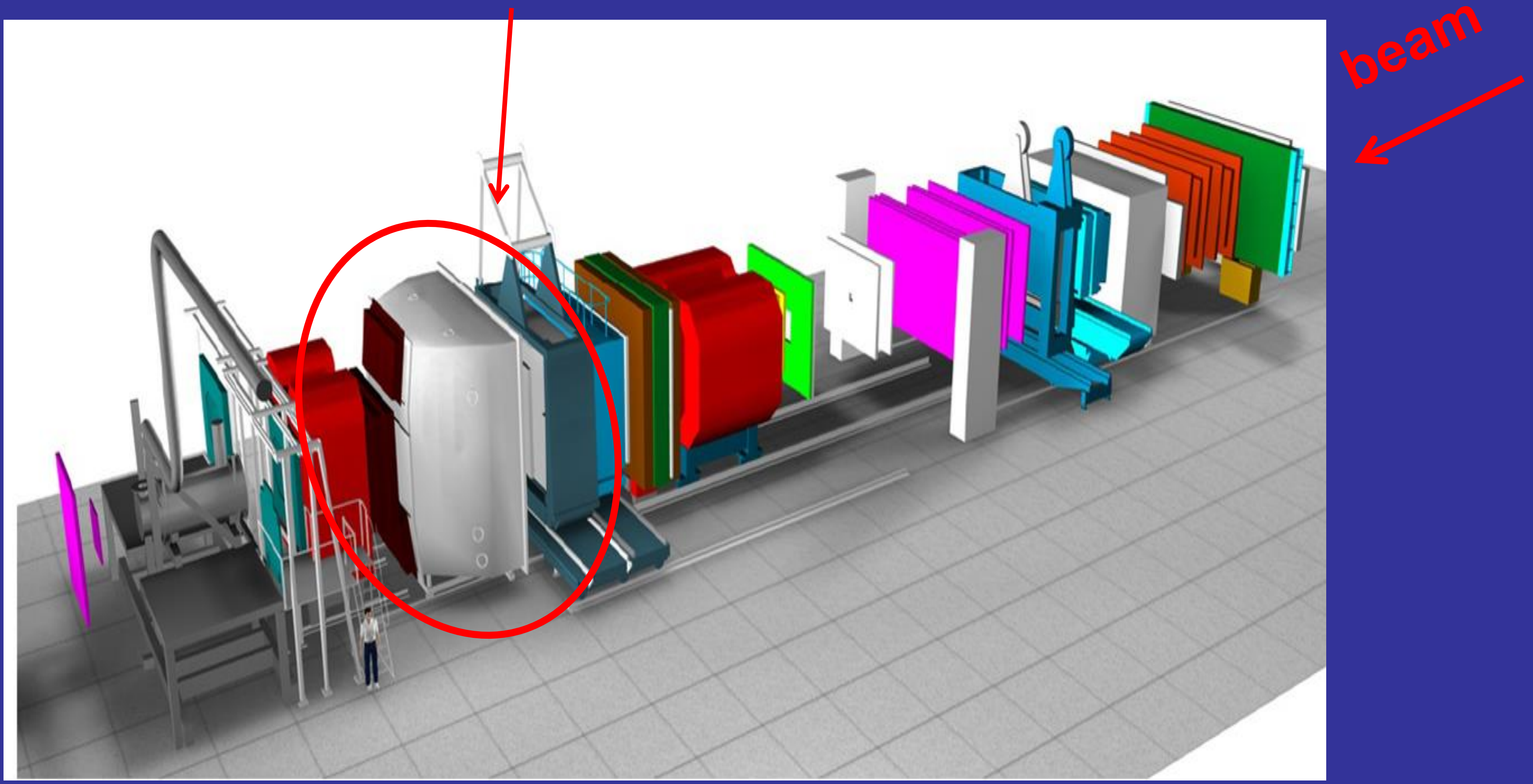
+

30 nm MgF_2

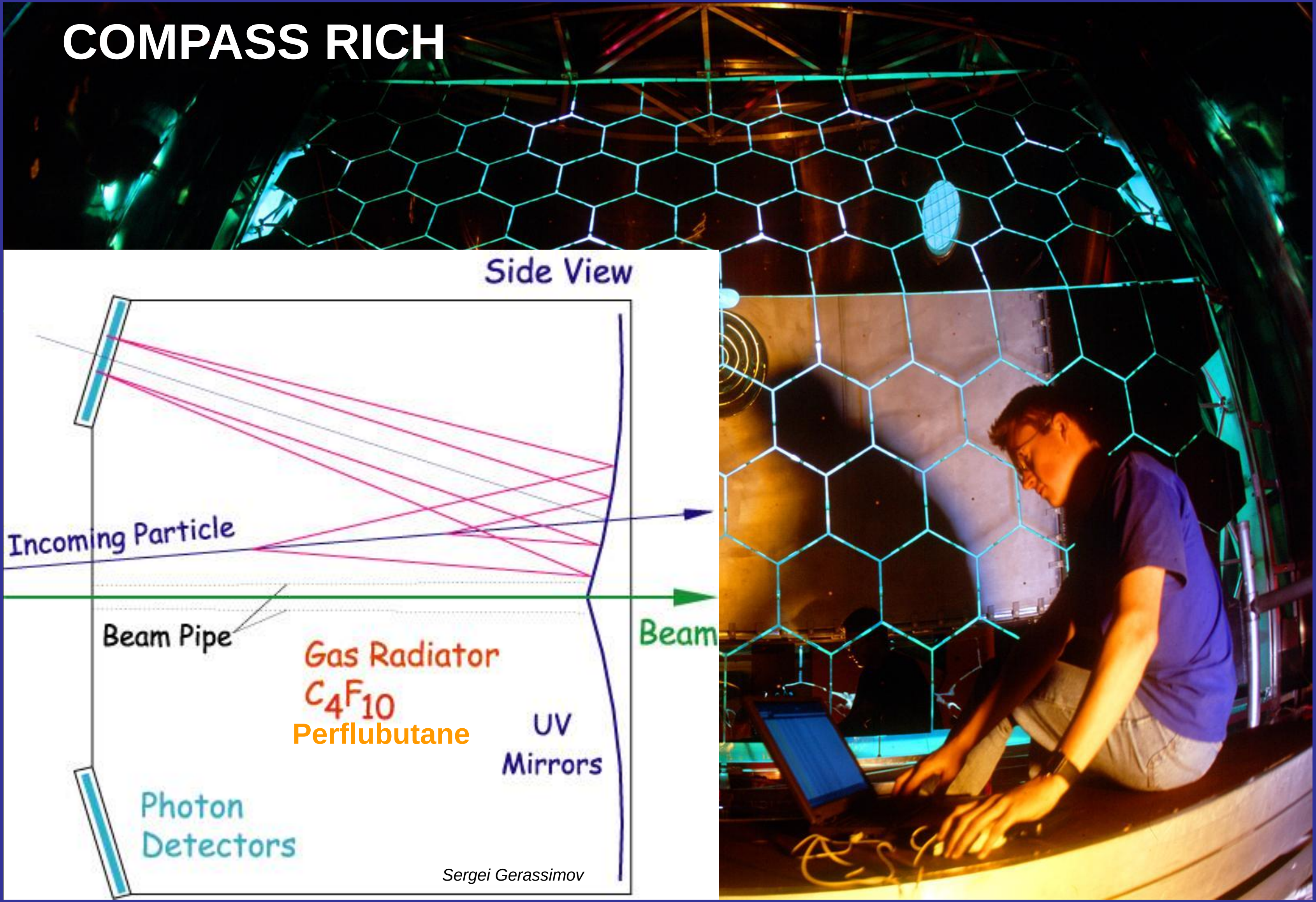
Reflectiviteit:

90 – 95 %

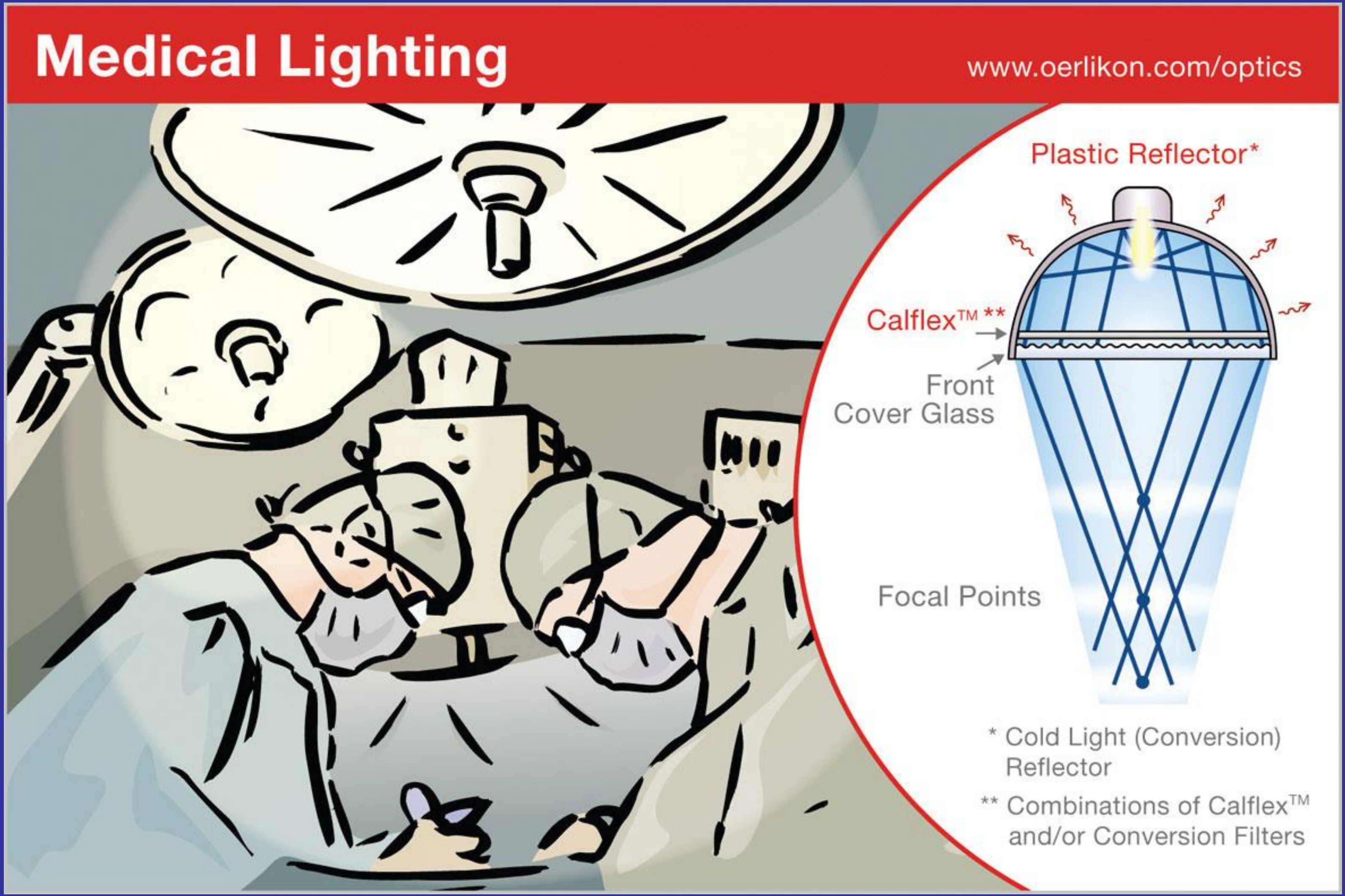
COMPASS RICH



COMPASS RICH



Sergei Gerassimov

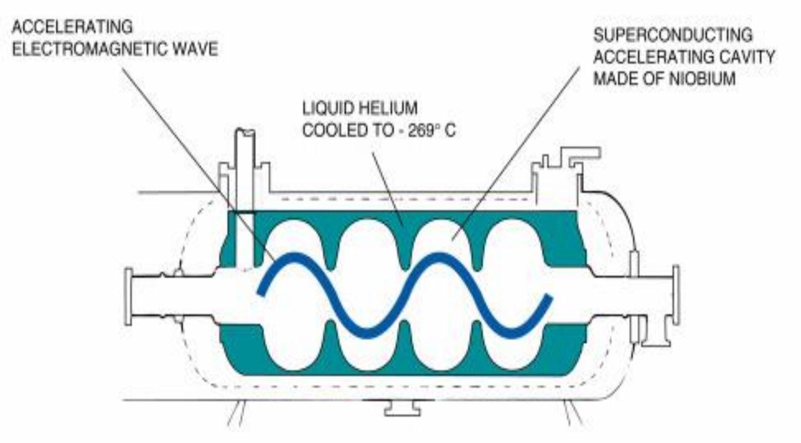


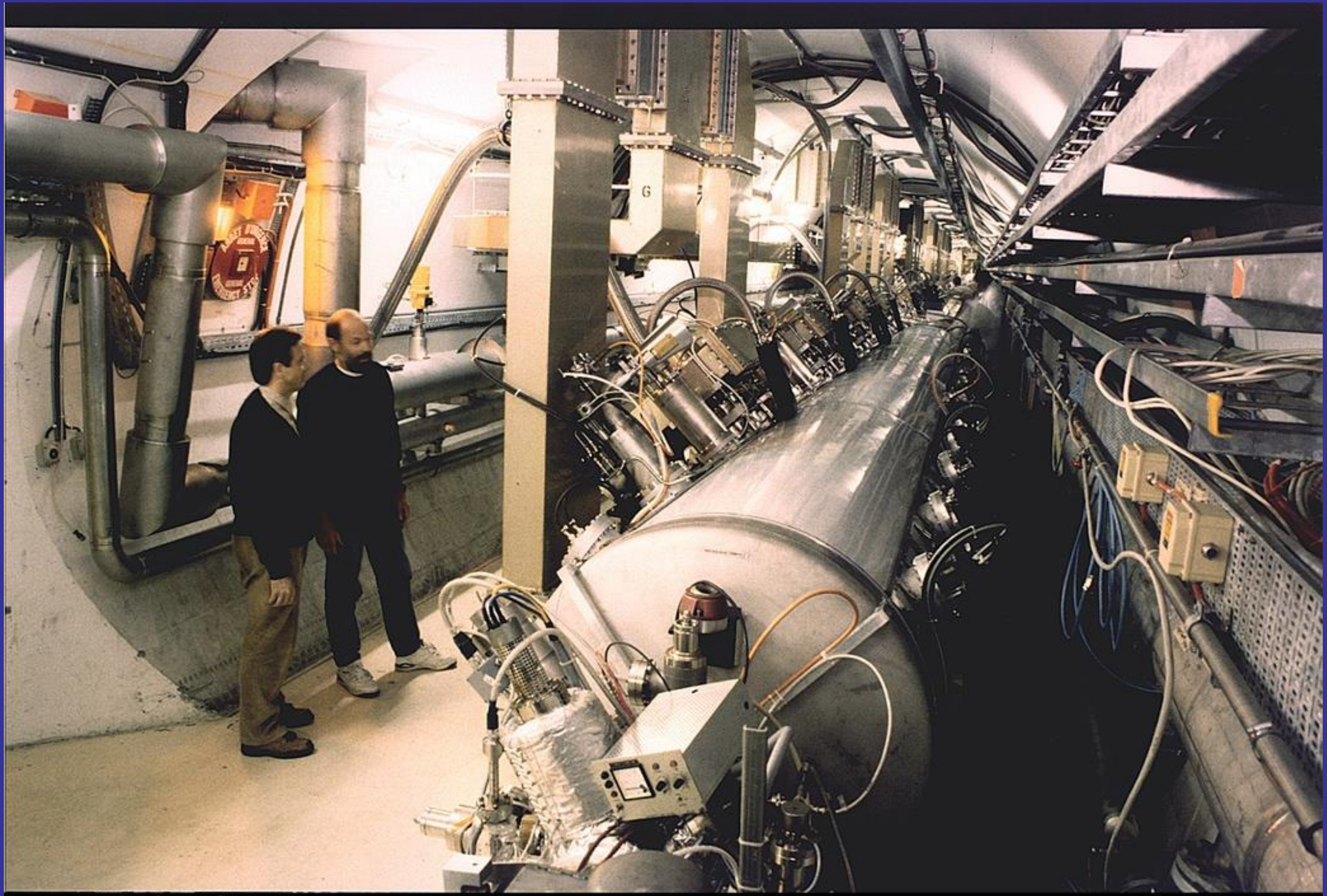
Medical Lighting

www.oerlikon.com/optics

* Cold Light (Conversion) Reflector

** Combinations of Calflex™ and/or Conversion Filters


ACCELERATING ELECTROMAGNETIC WAVE
SUPERCONDUCTING ACCELERATING CAVITY MADE OF NIOBIUM
LIQUID HELIUM COOLED TO - 269° C



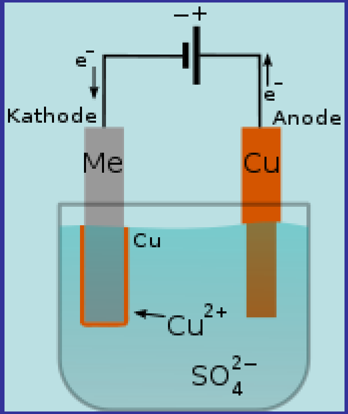
CERN AC/LC713/18-4-95

Hoe maken we coatingen

- Galvanisch,

- CVD ,

Silicium



Redox-reactie

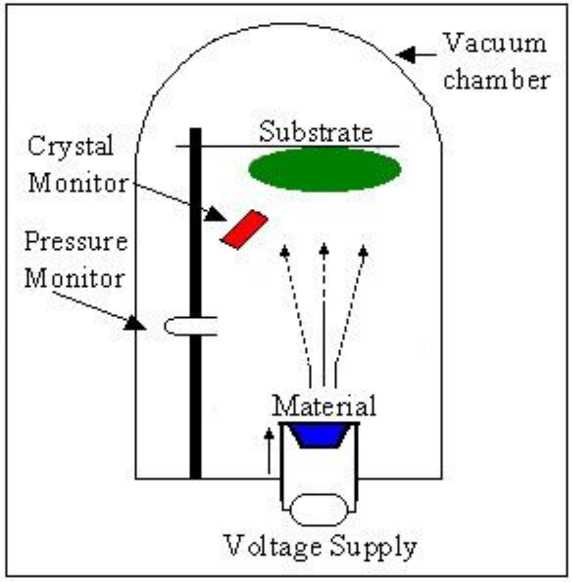
Toelichting:

- opdampen

- Plasma coaten

VACUUM

Thermisch opdampen

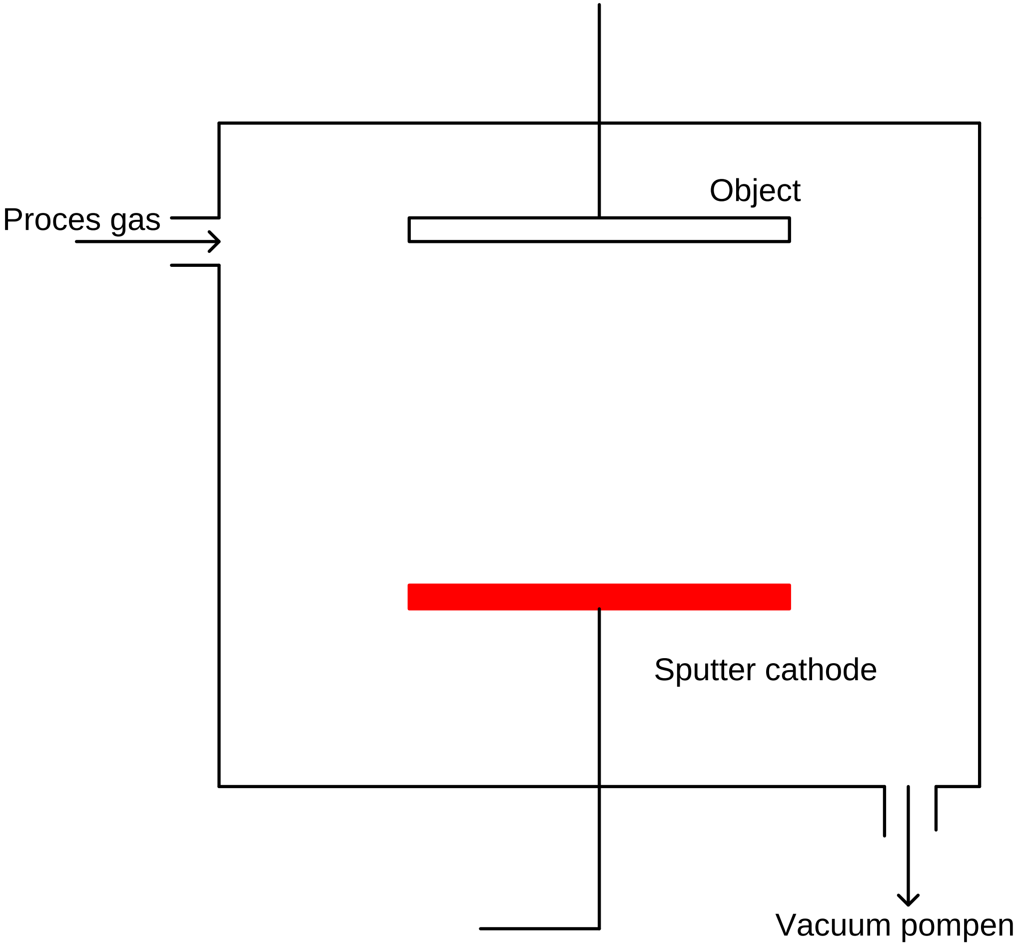


Opdampen: vaste stof → vloeibaar → damp

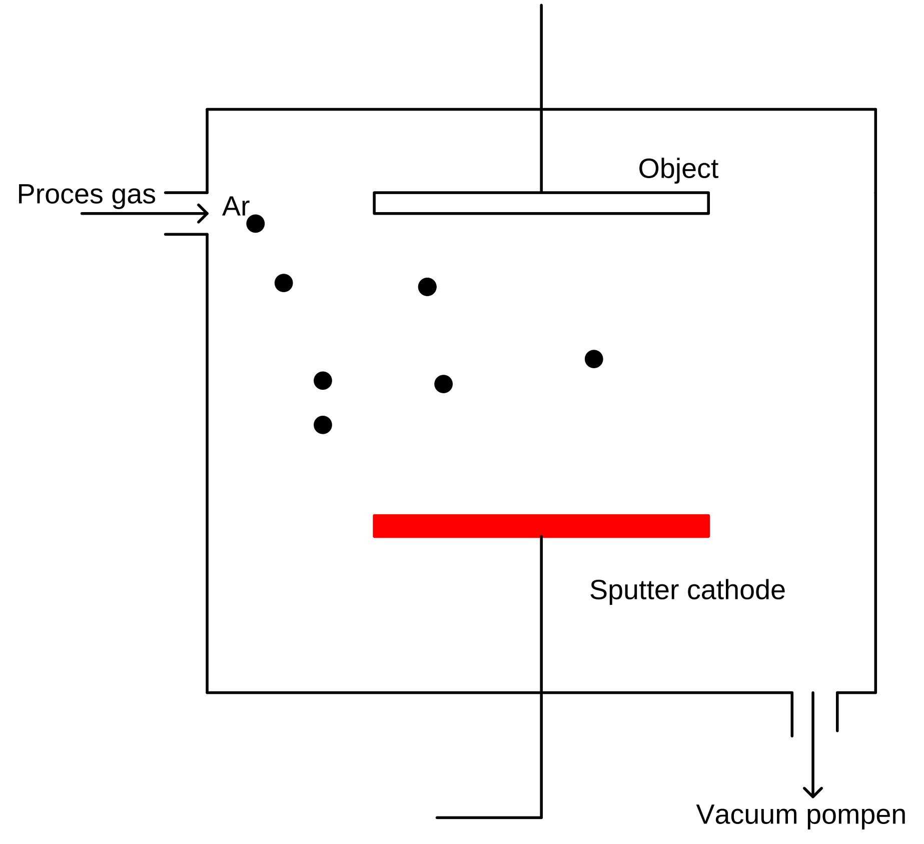
condensatie geeft coating

Waarom onder vacuum?

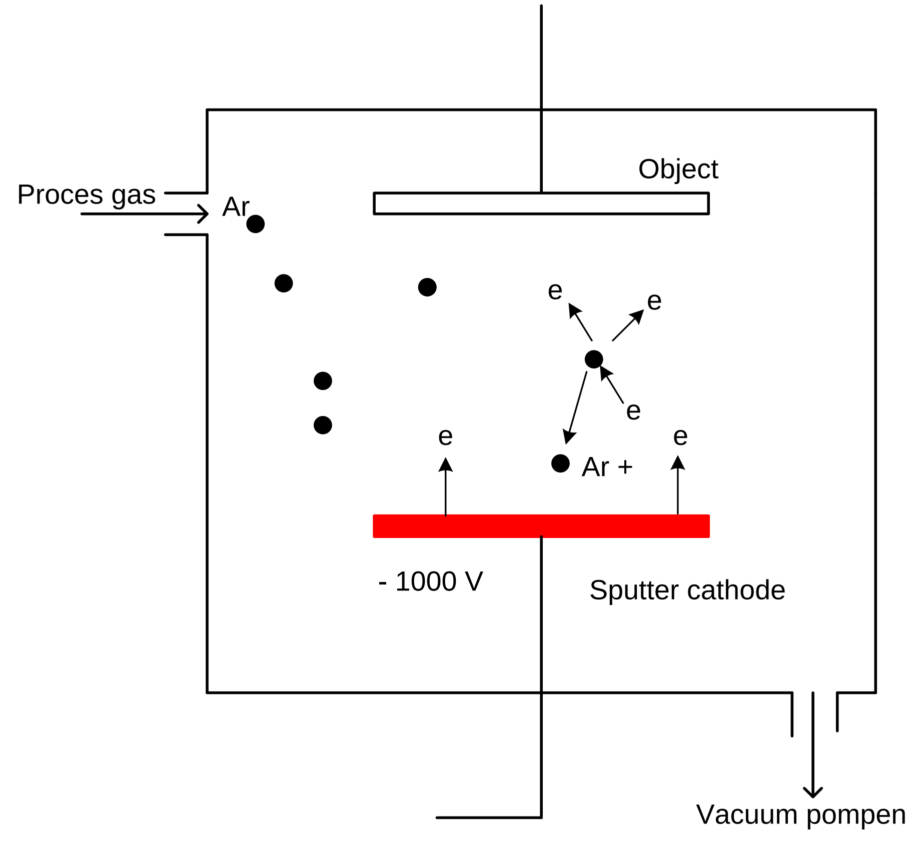
Plasma coaten (sputter process)



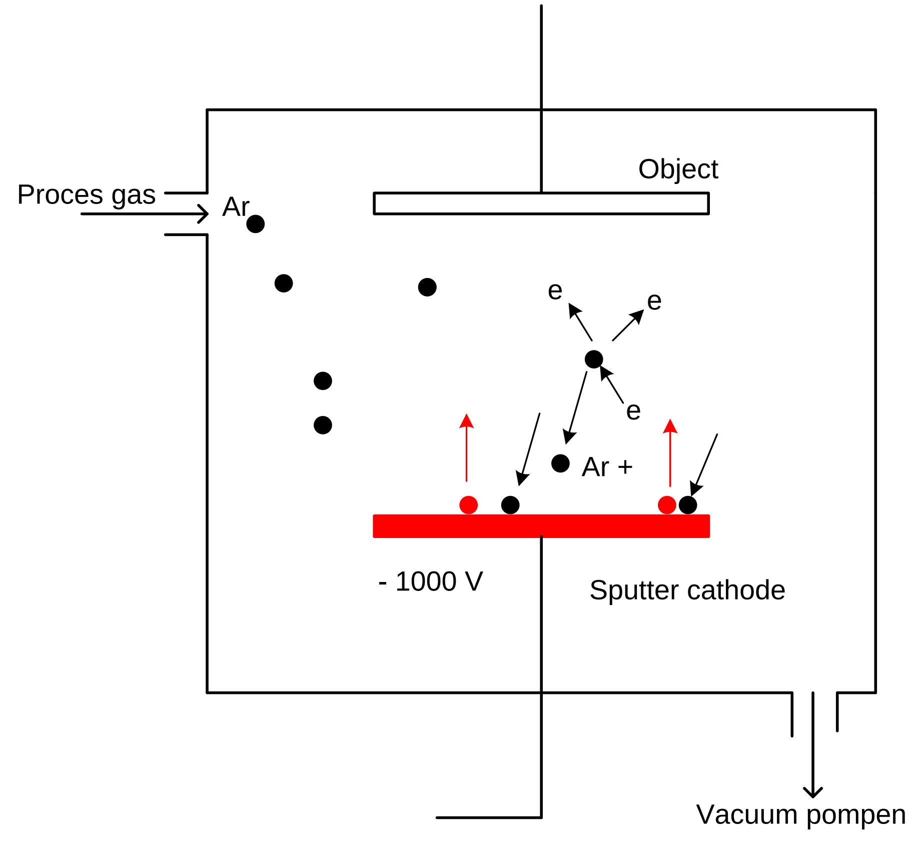
Plasma coaten (sputter process)



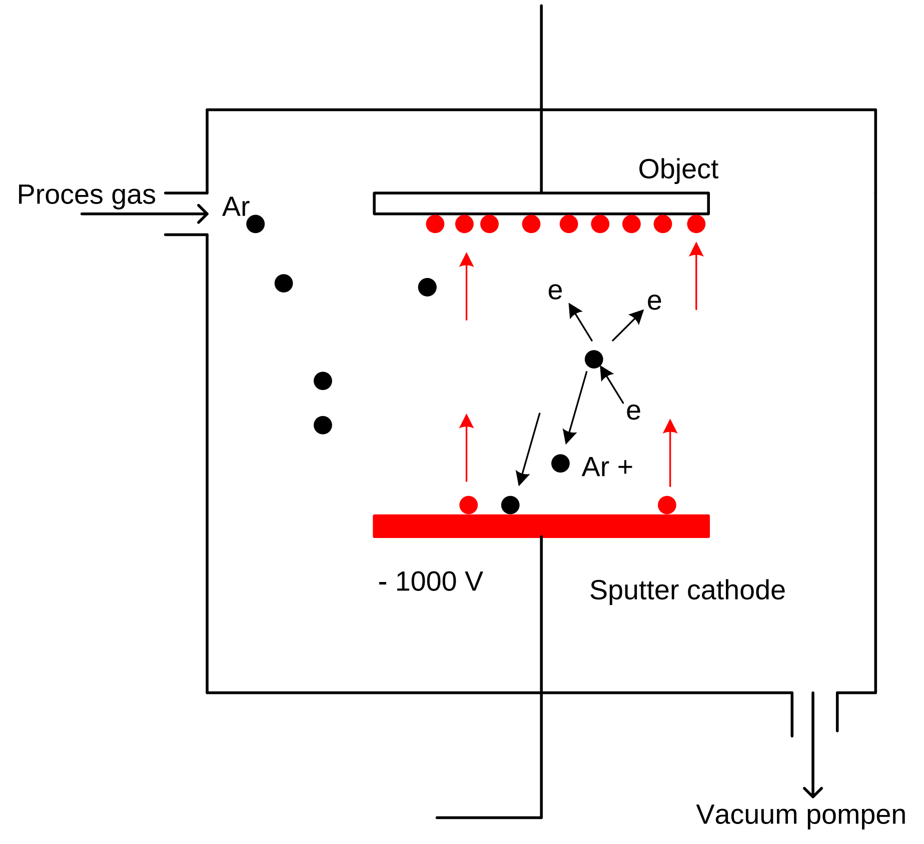
Plasma coaten (sputter process)



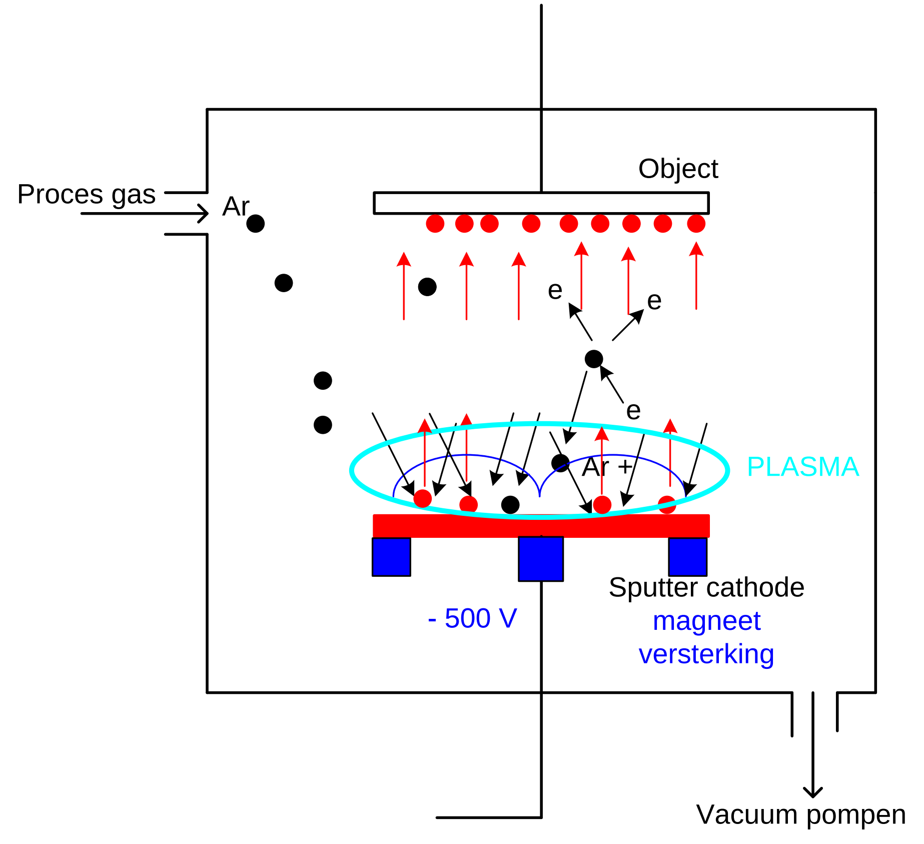
Plasma coaten (sputter process)



Plasma coaten (sputter process)



Plasma coaten (sputter process) *met magneet versterking*



Fundamentals of Sputtering principle

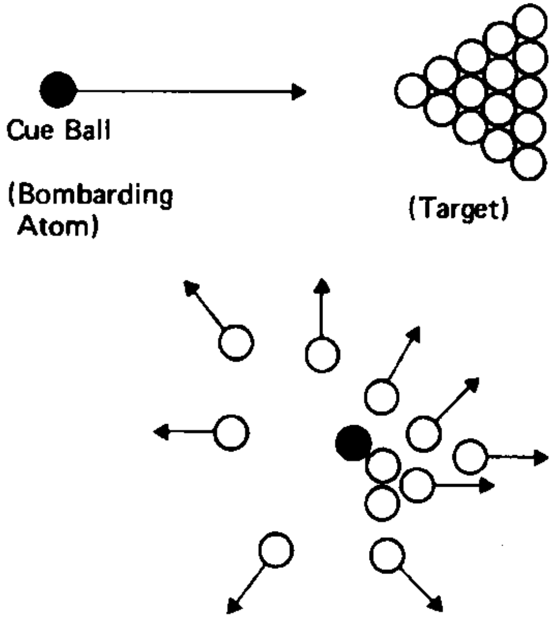


Figure 6-2. Sputtering – the atomic billiards game

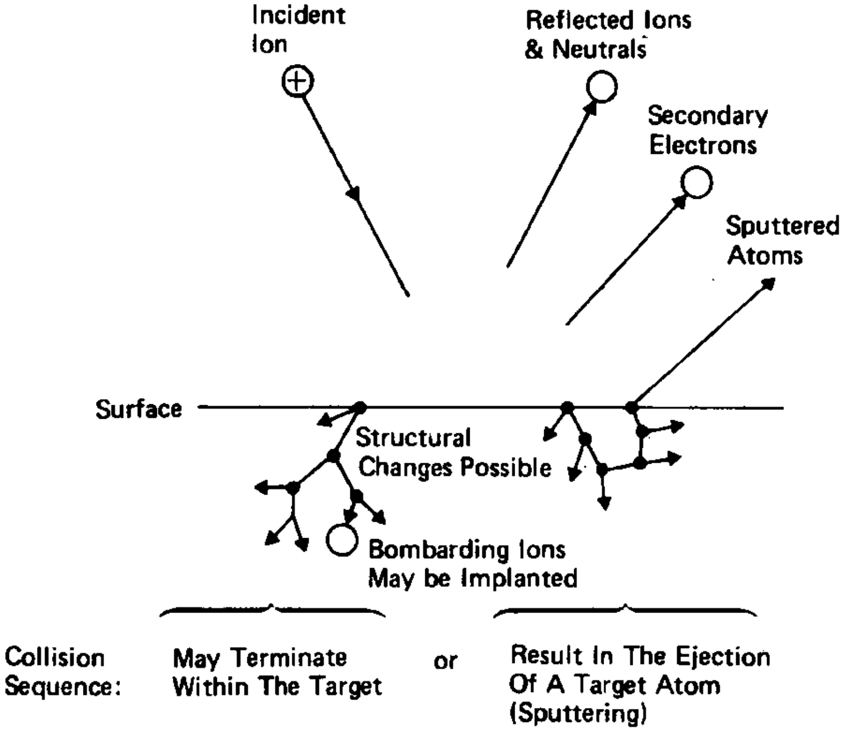
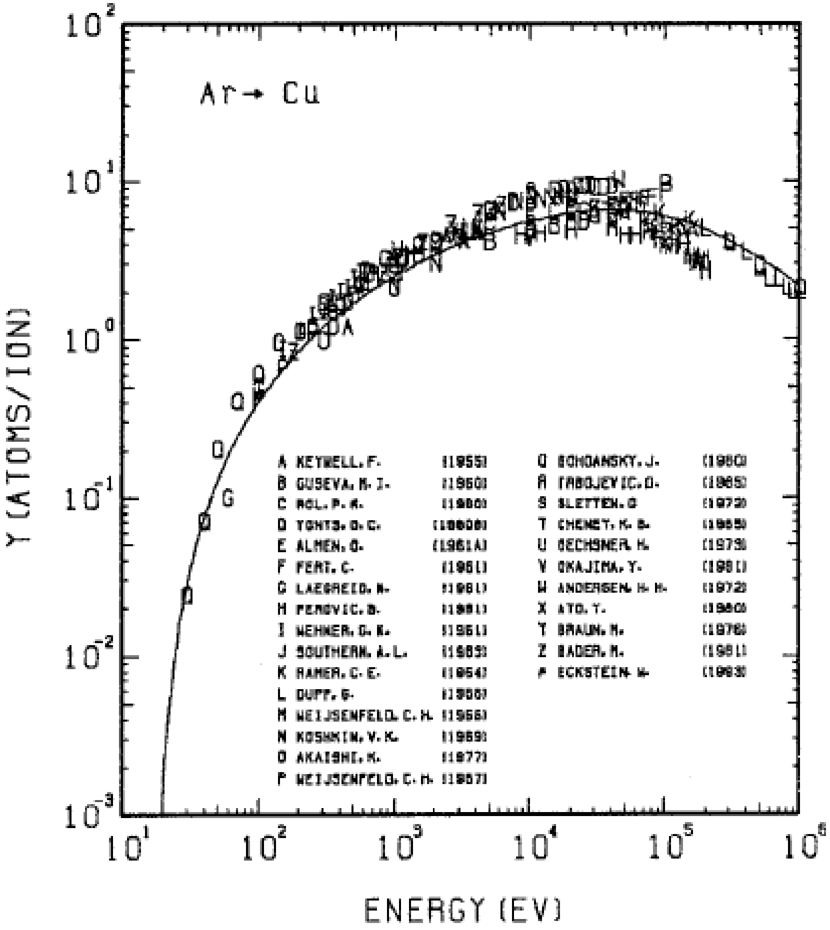
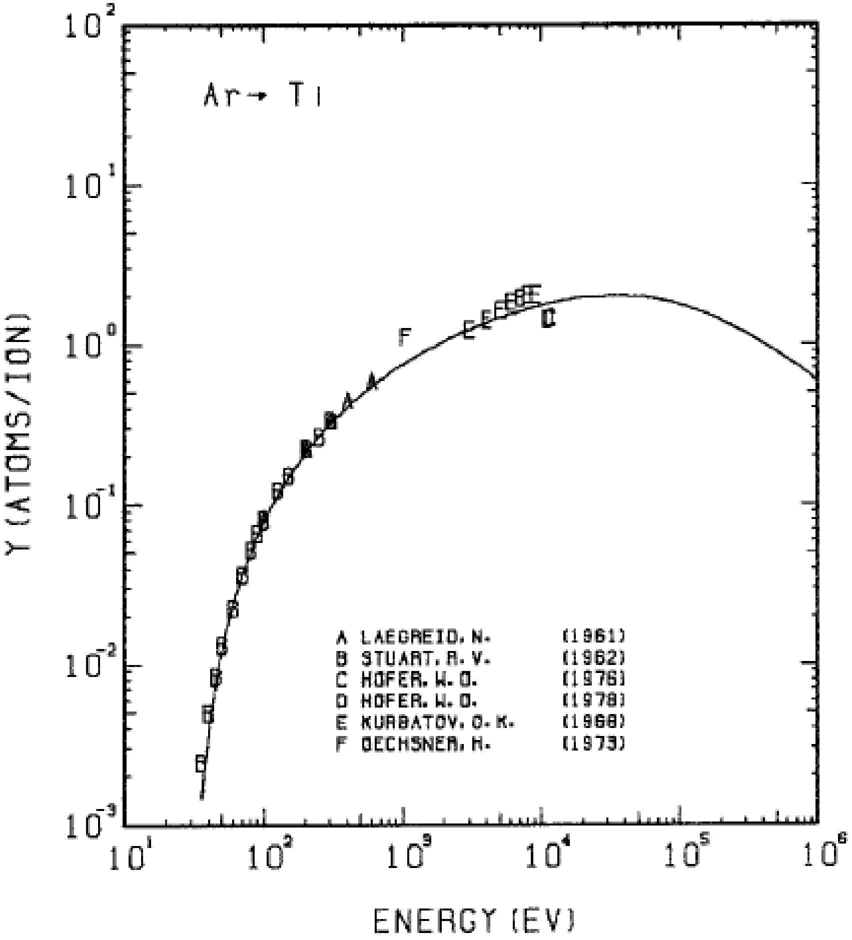


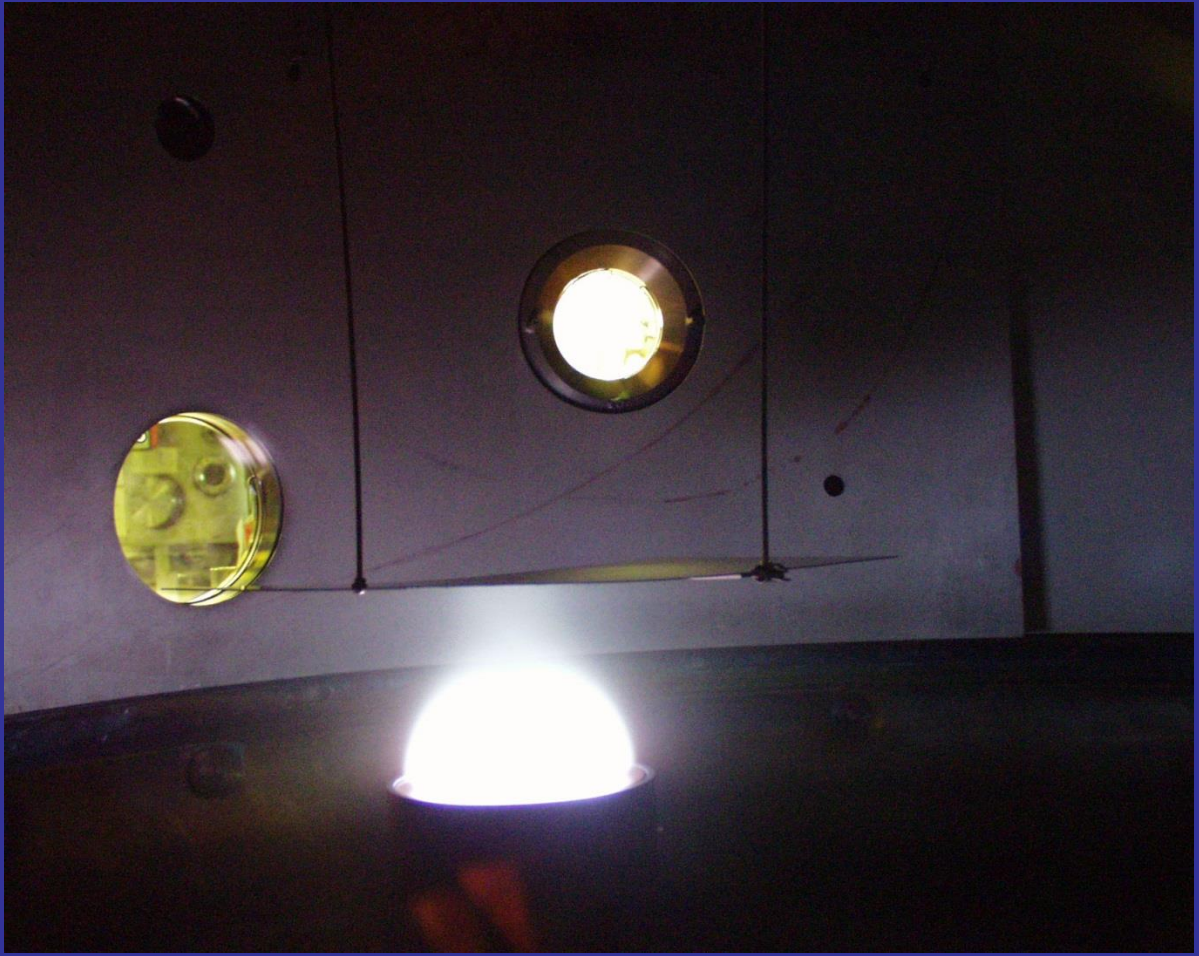
Figure 6-1. Interactions of ions with surfaces

Sputtering yields

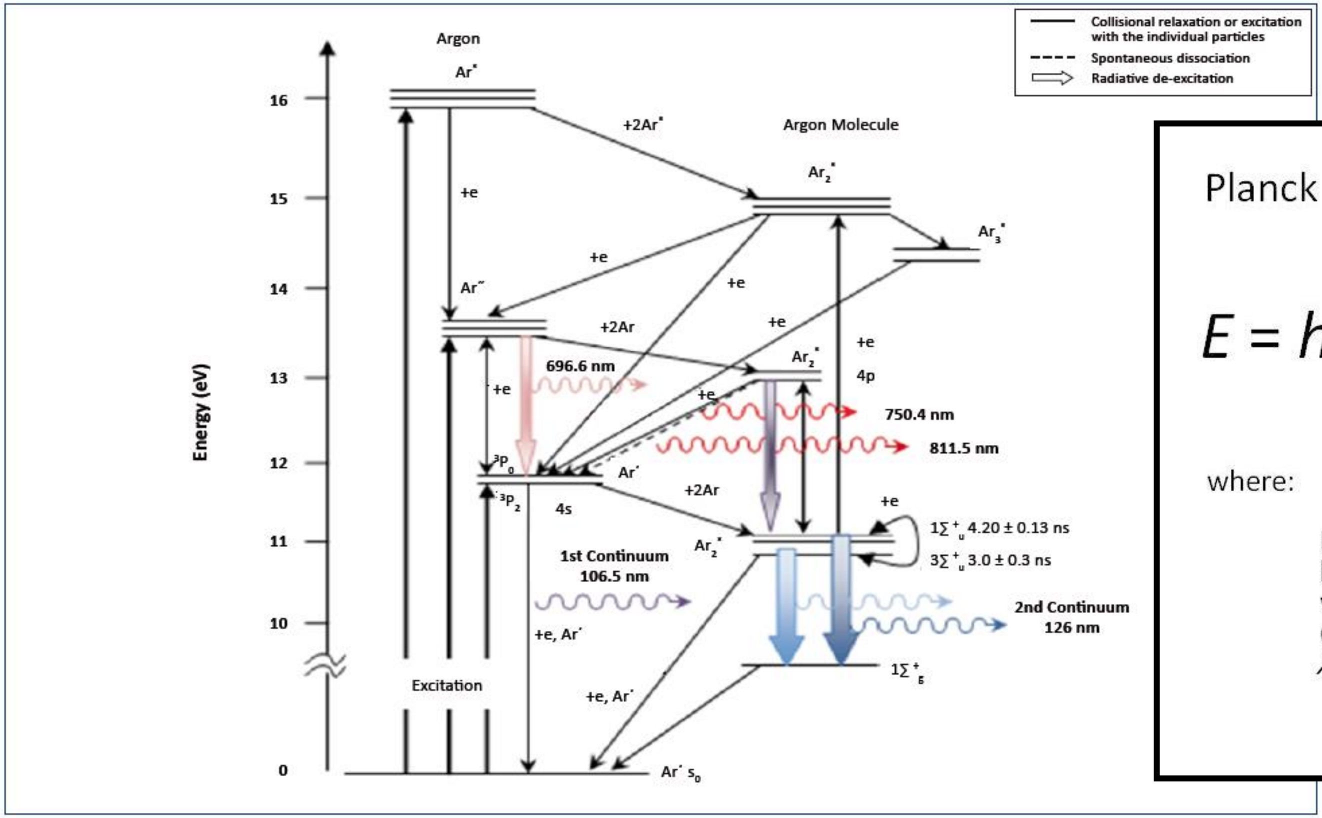




Plasma coaten (sputter process) *met magneet versterking*



Aangeslagen toestand → foton emissie



The $3p^5 4s$ level is drawn as a doublet, with the non-metastable members ignored.

FIGURE 1: Energy level for atomic and molecular argon excited by a dielectric barrier discharge, showing transitions leading to the 126 nm, 750.4 nm and 811.5 nm emissions.

Planck relation:

$$E = h\nu = \frac{hc}{\lambda}$$

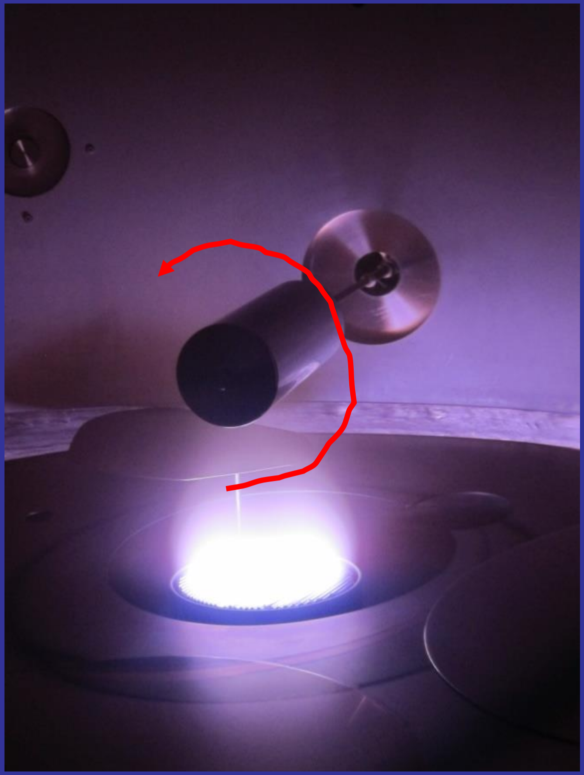
where:

E = energy
h = Plank constant
v = frequency
c = speed of light
λ = wavelength

Erosie van kathodes

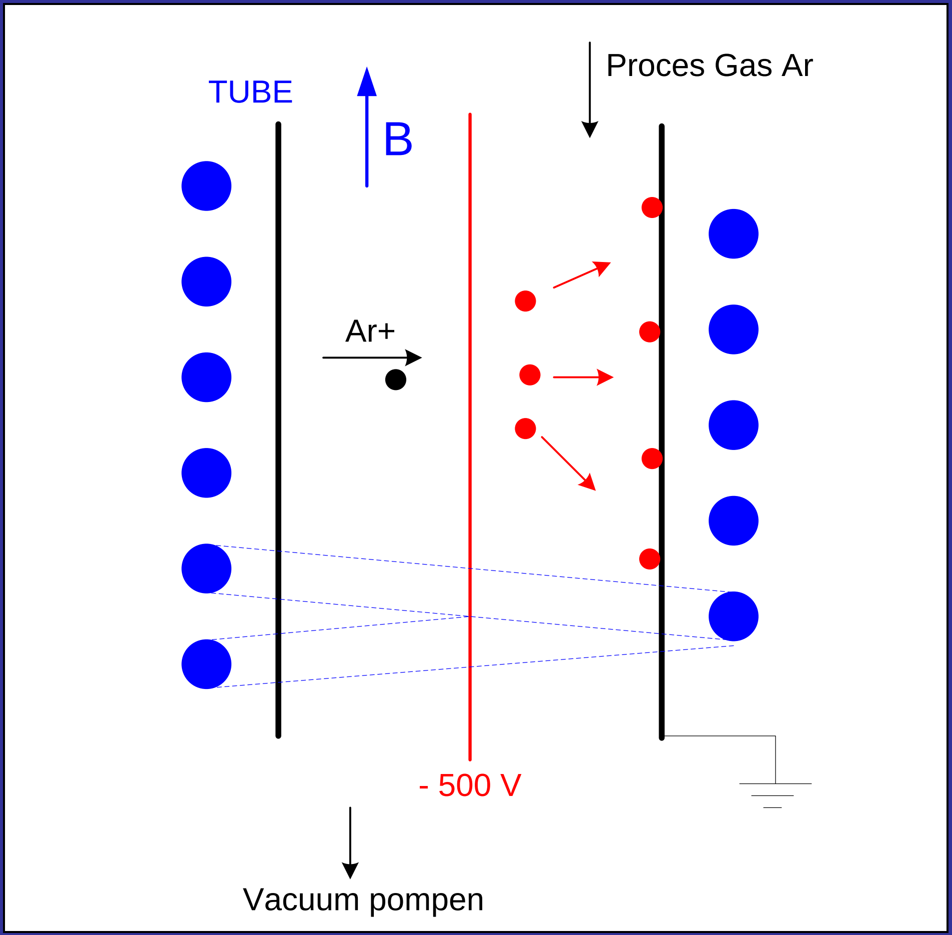
Niet vlakke objecten

3 D objecten

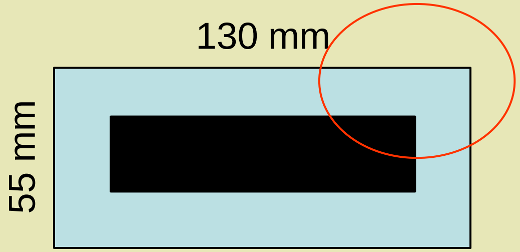


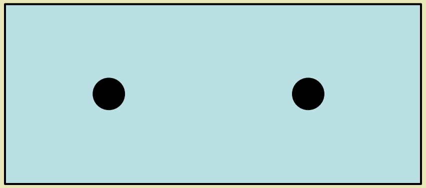
Uitwendig coaten van cylinder

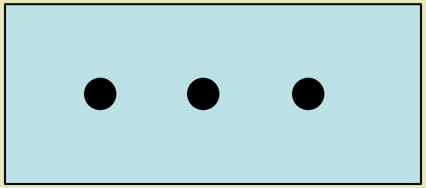
Plasma coaten in cylindrische configuratie: coaten van binnenkant cylinder



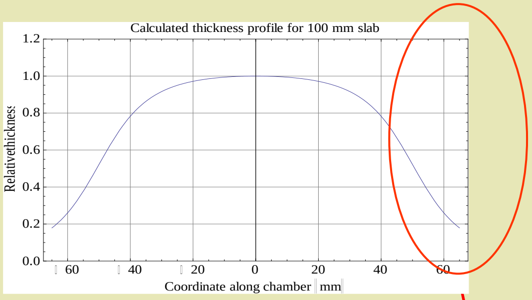
Simple examples: rectangular chamber

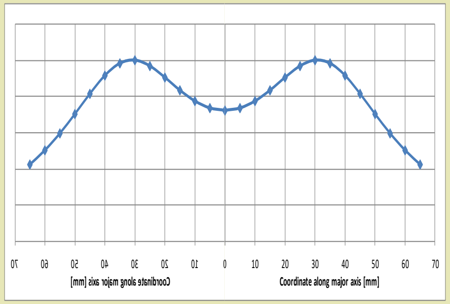


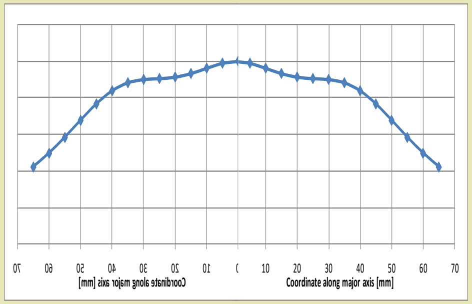




Which cathode gives the most uniform thickness profile?







Edge effect

Advantages of coatings by sputtering

- Vacuum coatings are flexible: we can coat almost all metals, produce oxides and nitrides by chemical reactions in vacuum (adding gas)

- The atoms that make up the coatings have a large energy: this promotes adhesion, by giving activation energy for a chemical reaction to take place, and usually a good structure.

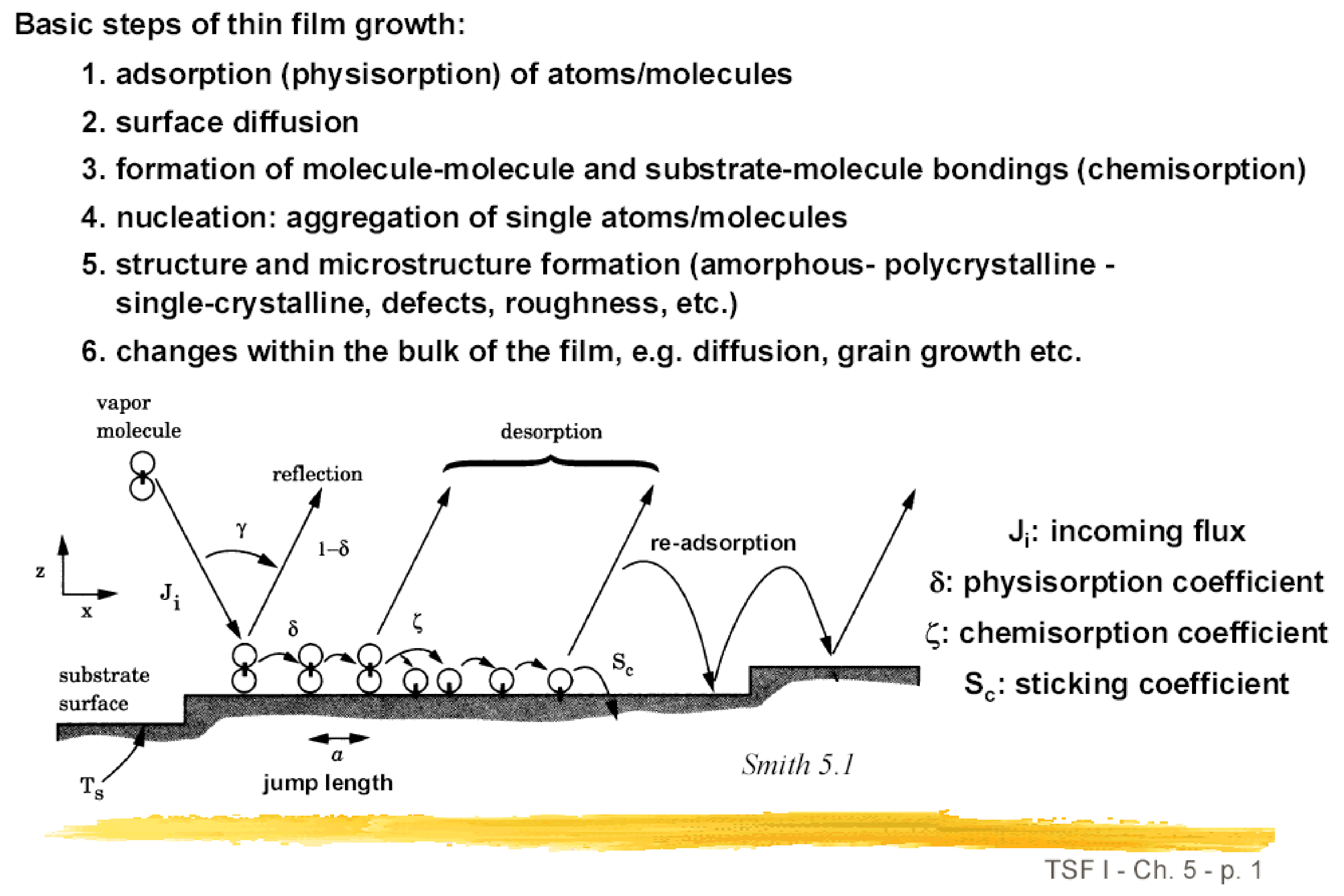
- Can be a “primer” for a galvanic coating

Disadvantages of coatings by sputtering

- Coatings only in line-of-sight: complex movements of pieces are needed, in vacuum

- The coating rate is very slow: 1 µm/ hour is the order of magnitude. Because of this we need HV or UHV

- The coatings are often under stress due to the coating process itself. This goes against good adhesion.



Basic steps of thin film growth:

1. adsorption (physisorption) of atoms/molecules
2. surface diffusion
3. formation of molecule-molecule and substrate-molecule bondings (chemisorption)
4. nucleation: aggregation of single atoms/molecules
5. structure and microstructure formation (amorphous- polycrystalline - single-crystalline, defects, roughness, etc.)
6. changes within the bulk of the film, e.g. diffusion, grain growth etc.

J_i: incoming flux

δ: physisorption coefficient

ζ: chemisorption coefficient

S_c: sticking coefficient

Smith 5.1

TSF I - Ch. 5 - p. 1

Different types of adhesion

- Chemical adhesion:
  - The film and the substrate make a chemical bond. This can be of two natures: covalent or ionic
  - Covalent: it is usually the case of a metal film on top of an oxidised metal (gemeenschappelijke electronenparen)
  - Ionic: it is usually the case between two metals without oxide in between (metaalbinding)

- Wetting or thermodynamical or Van der Waals adhesion:
  - Two surfaces in close contact experience short range forces, which are not due to chemical actions but rather to adsorption-like phenomena.
  - Typical of oxides on oxides, or of polymer films

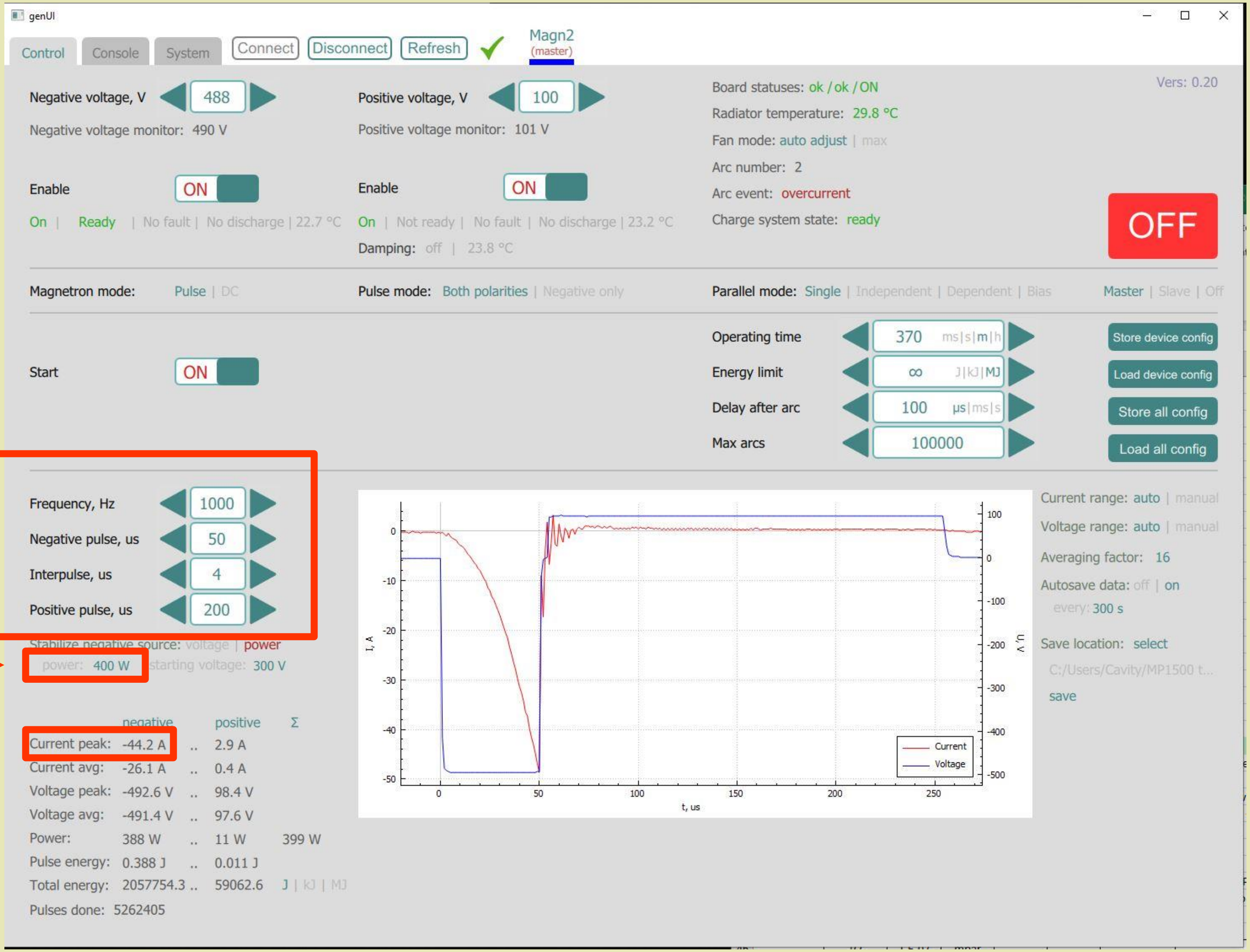
- Mechanical adhesion:
  - Roughness, interlocking of substrate and layer. Used for paints etc. Sandblasting of surfaces

More on chemical adhesion

- Example of covalent adhesion: niobium on copper
  - Enthalpy of formation: Nb_2O_5 = -1899.54 kJ/mol
    CuO_2 = -156.06 kJ/mol
  - Niobium has a good adhesion on copper
  - Copper has a bad adhesion on niobium!
  - Niobium can break copper oxide. The contrary will not work!!
  - Good cases: Ti/S.Steel, NEG/Cu, Ti/Al_2O_3, Al/glass
  - Bad cases: Cu/S.Steel, Cu/glass
- Ionic adhesion is stronger than covalent adhesion
  - Remove the oxide from the substrate and put pure metals in contact
  - Put first a coating which has a very good adhesion followed, without exposing to air, by the "functional" coating.
  - Example: Cu/Ti/S.steel. (Titanium is often the "magic" tool)

HiPIMS

High Power Impulse Magnetron Sputtering



Vers: 0.20

Negative voltage, V 488

Negative voltage monitor: 490 V

Enable ON

On | Ready | No fault | No discharge | 22.7 °C

Positive voltage, V 100

Positive voltage monitor: 101 V

Enable ON

On | Not ready | No fault | No discharge | 23.2 °C

Damping: off | 23.8 °C

Board statuses: ok / ok / ON

Radiator temperature: 29.8 °C

Fan mode: auto adjust | max

Arc number: 2

Arc event: overcurrent

Charge system state: ready

Magnetron mode: Pulse | DC

Pulse mode: Both polarities | Negative only

Parallel mode: Single | Independent | Dependent | Bias

Master | Slave | Off

Start ON

Operating time 370 ms | s | m | h

Energy limit ∞ J | kJ | MJ

Delay after arc 100 µs | ms | s

Max arcs 100000

Frequency, Hz 1000

Negative pulse, us 50

Interpulse, us 4

Positive pulse, us 200

Stabilize negative source: voltage | power

power: 400 W starting voltage: 300 V

	negative		positive	Σ
Current peak:	-44.2 A	..	2.9 A	
Current avg:	-26.1 A	..	0.4 A	
Voltage peak:	-492.6 V	..	98.4 V	
Voltage avg:	-491.4 V	..	97.6 V	
Power:	388 W	..	11 W	399 W
Pulse energy:	0.388 J	..	0.011 J	
Total energy:	2057754.3	..	59062.6	J | kJ | MJ

Pulses done: 5262405

Current range: auto | manual

Voltage range: auto | manual

Averaging factor: 16

Autosave data: off | on

every: 300 s

Save location: select

C:/Users/Cavity/MP1500 t...

save

= Power DC →

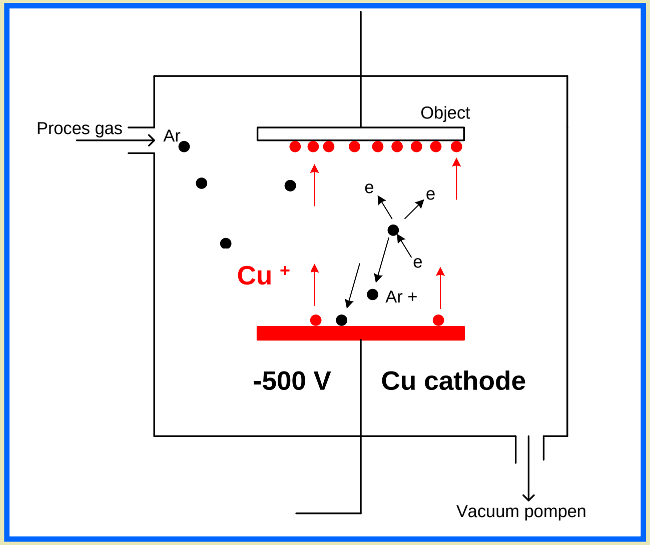
HiPIMS

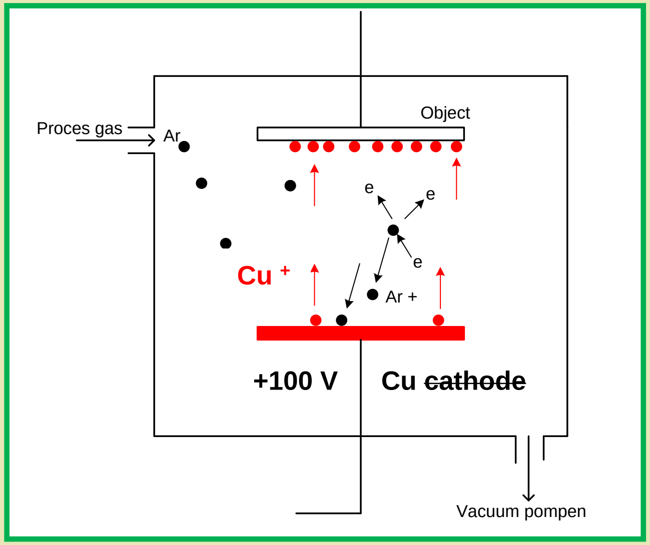
High Power Impulse Magnetron Sputtering

DCMS: Cu atomen
HiPIMS: > Cu ionen

Negatieve puls: sputtering

Positieve puls: transport of Cu ionen: kick energy



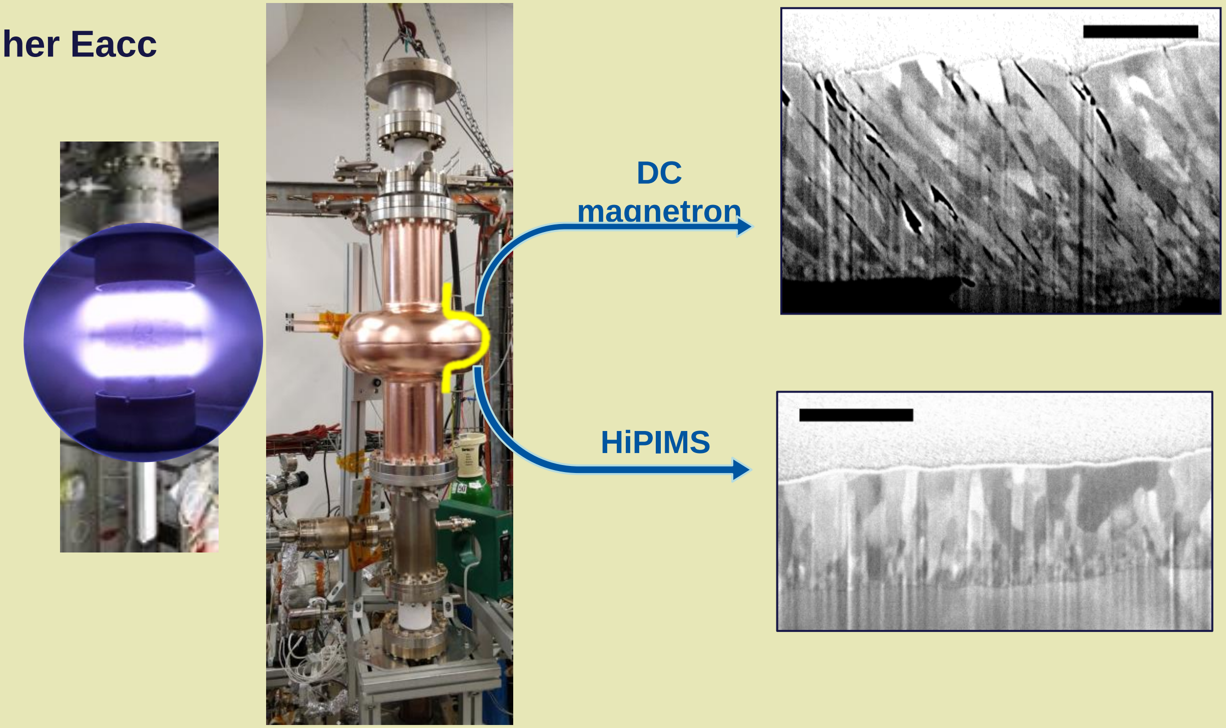


Thin films in CERN accelerators: Nb for accelerating cavities

Superconducting Radio Frequency (SRF) acceleration

Challenges for FCC -ee:

- **Improve Q0 for Nb films at higher Eacc**

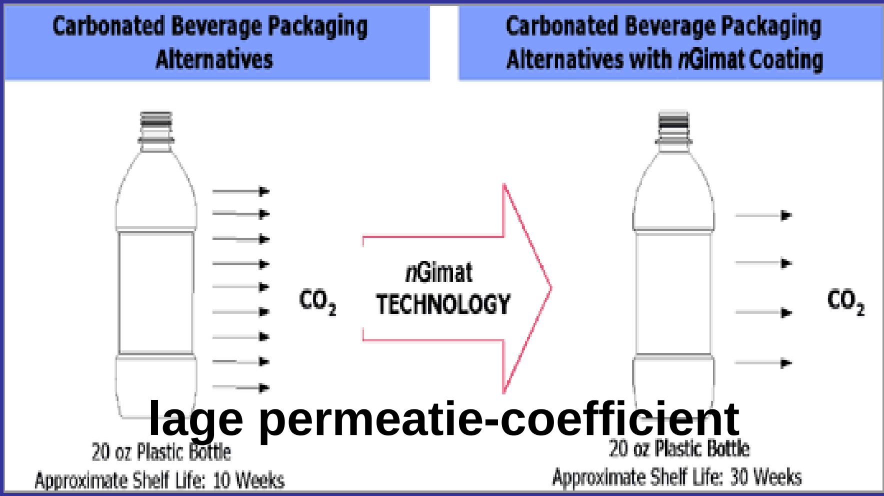


Voorbeelden van coatingen in industrie

Harde / slijtvaste coating

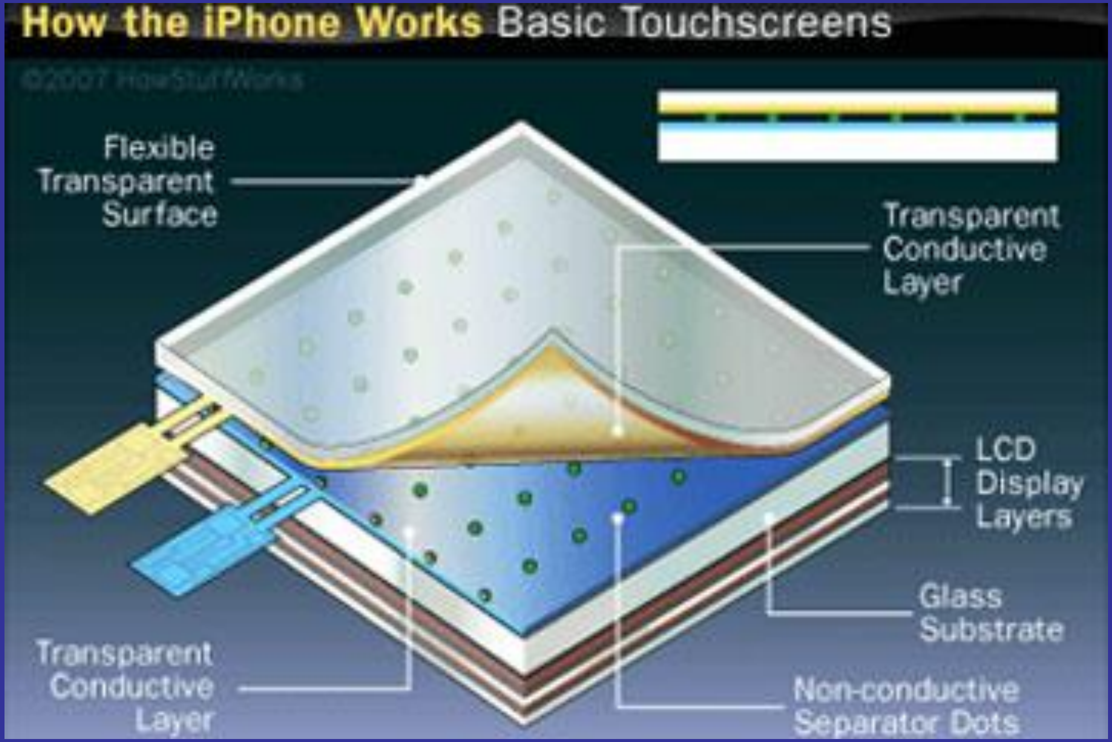
lage wrijvings-coefficient

lage transmissie



lage permeatie-coefficient

Voorbeelden van coatingen in industrie



Een ander toepassing op CERN :

NEG COATING: pompende coating

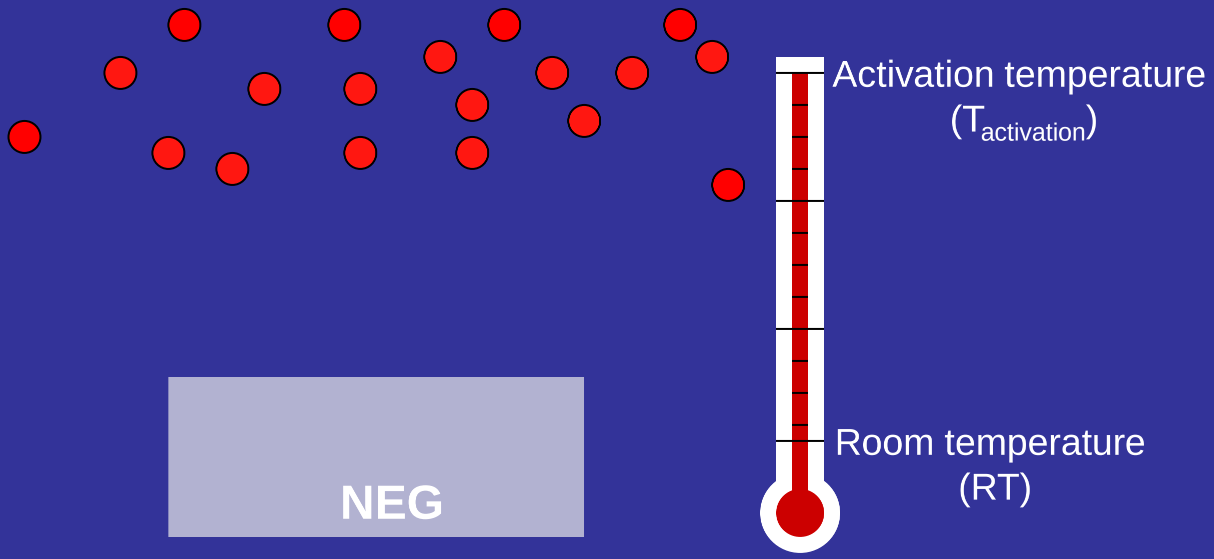
LHC: Beam pipe: Pressure $< 1*10^{-11}$ mbar ($1*10^{-9}$ Pa)

What is a Non Evaporable Getter (NEG)?

A NEG material presents a reactive surface to some gas species, adsorbing (*gettering*) impinging molecules.

Once saturated, the *gettering* activity ceases and no more gas is pumped.

The NEG can than be regenerated by heating to its activation temperature during a certain time.



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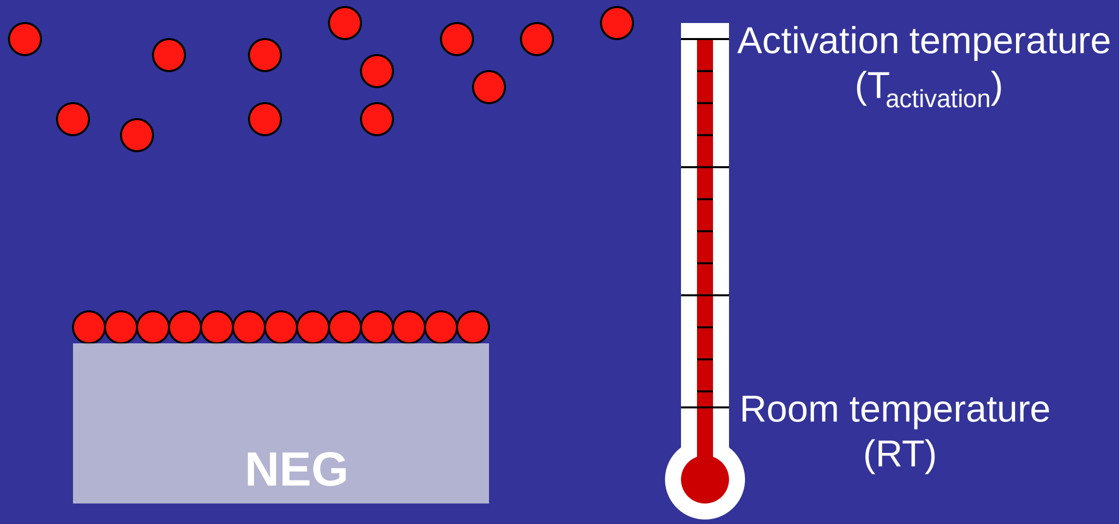
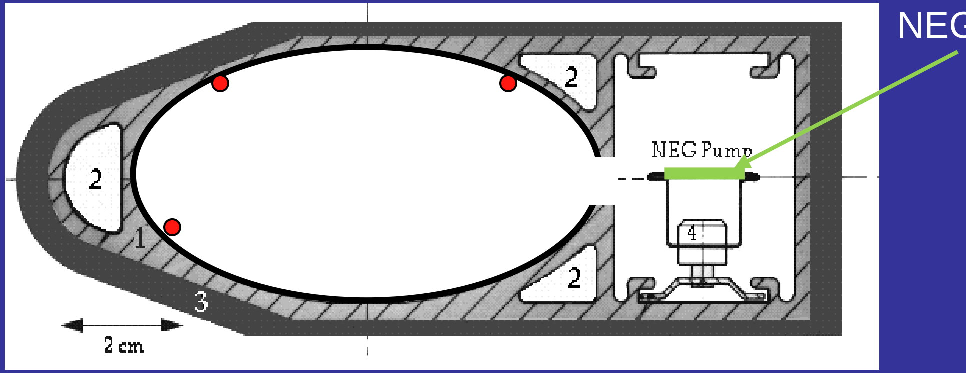


Back to room temperature (RT) the NEG recovers its pumping capabilities.

The solution was to integrate the vacuum pump in the beam pipes by inserting a strip of NEG. This NEG strip could be activated by resistive heating and pump molecules desorbed all along the beam pipe.

Cross section of the LEP dipole vacuum chamber



NEG strip

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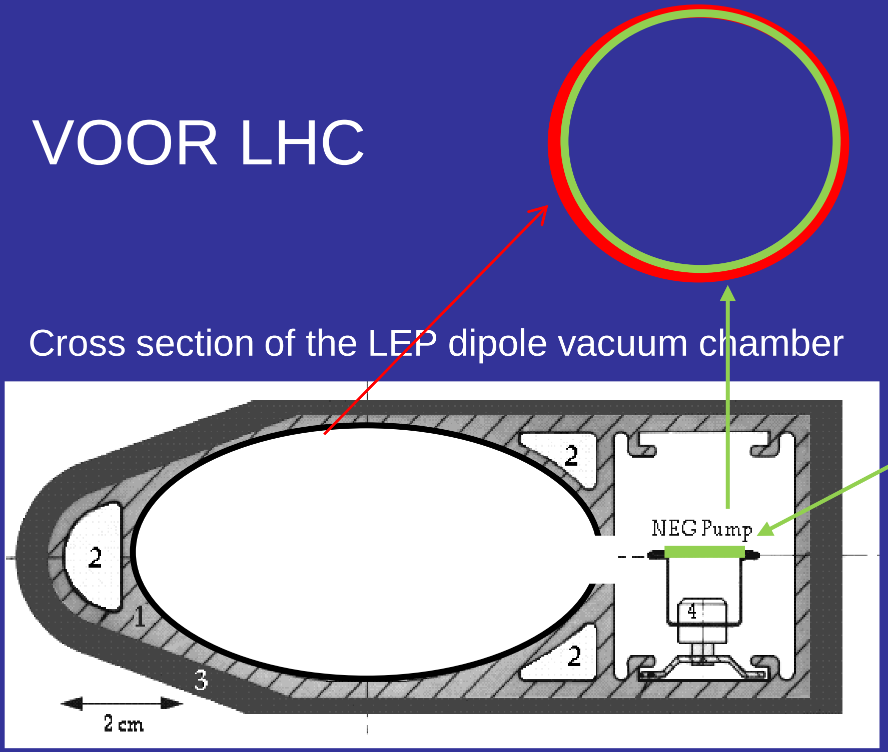
VOOR LHC



Cross section of the LEP dipole vacuum chamber

NEG strip

R & D

Research:

- legering met een “lage” activatie temperatuur.

De laagste activatie temperatuur is gevonden in een ruim gebied van composities met:

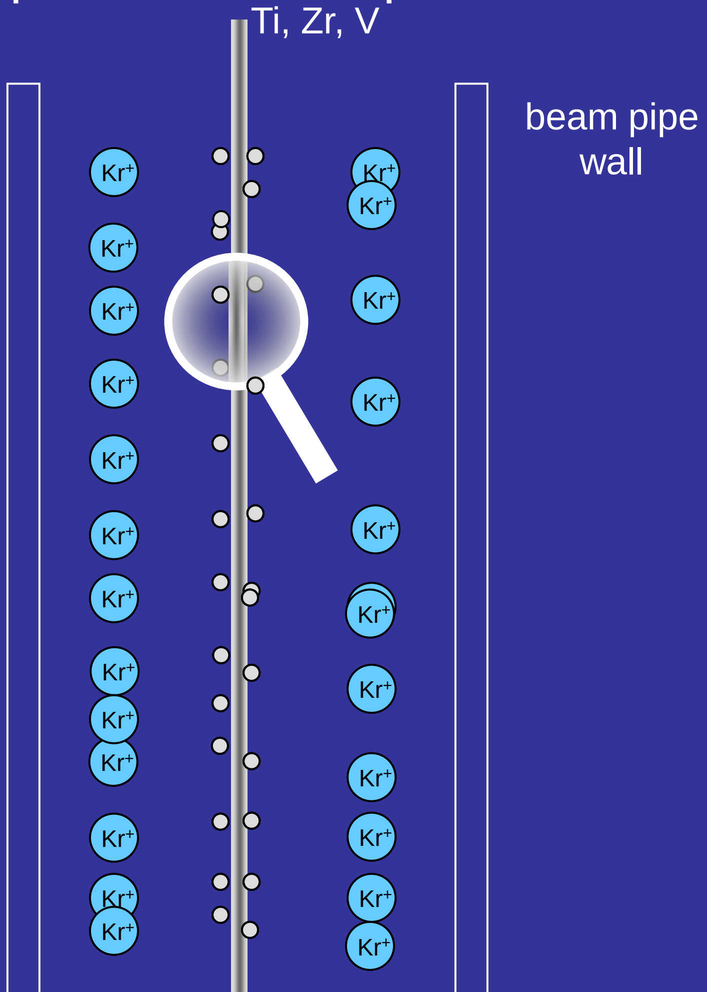
Titanium, Zirconium en Vanadium

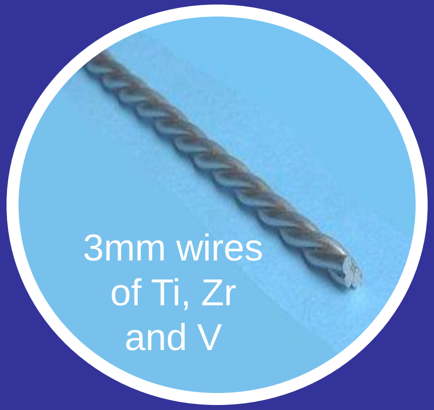
en is 180 ºC ; 24 uur

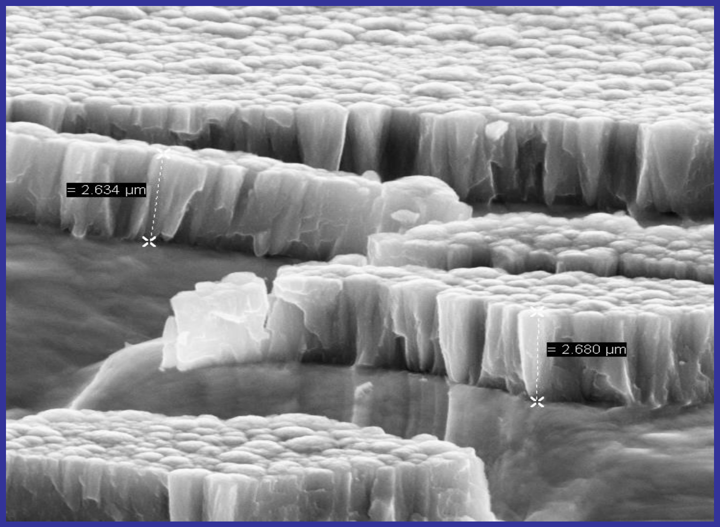
- onderzoek naar coating parameters (T , Power, Gasses)

  - Lange termijn effecten (activatie cycli)

This NEG thin film is obtained by bombarding a target made of inter twisted wires of titanium, zirconium and vanadium, with ions. The atoms of the target are then sputtered and deposited in the beam pipe walls.





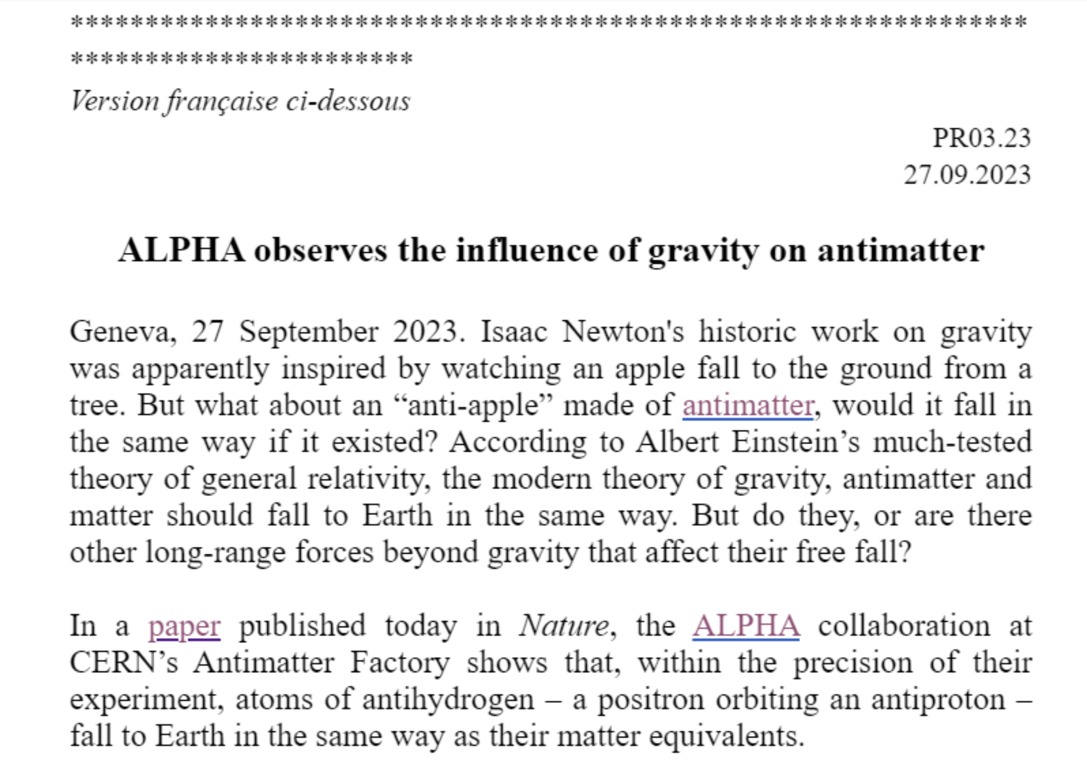


Totale project:

van Research tot installatie in LHC

≈ 7 km NEG coated

10 jaar
5 mensen



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Version française ci-dessous

PR03.23
27.09.2023

ALPHA observes the influence of gravity on antimatter

Geneva, 27 September 2023. Isaac Newton's historic work on gravity was apparently inspired by watching an apple fall to the ground from a tree. But what about an "anti-apple" made of antimatter, would it fall in the same way if it existed? According to Albert Einstein's much-tested theory of general relativity, the modern theory of gravity, antimatter and matter should fall to Earth in the same way. But do they, or are there other long-range forces beyond gravity that affect their free fall?

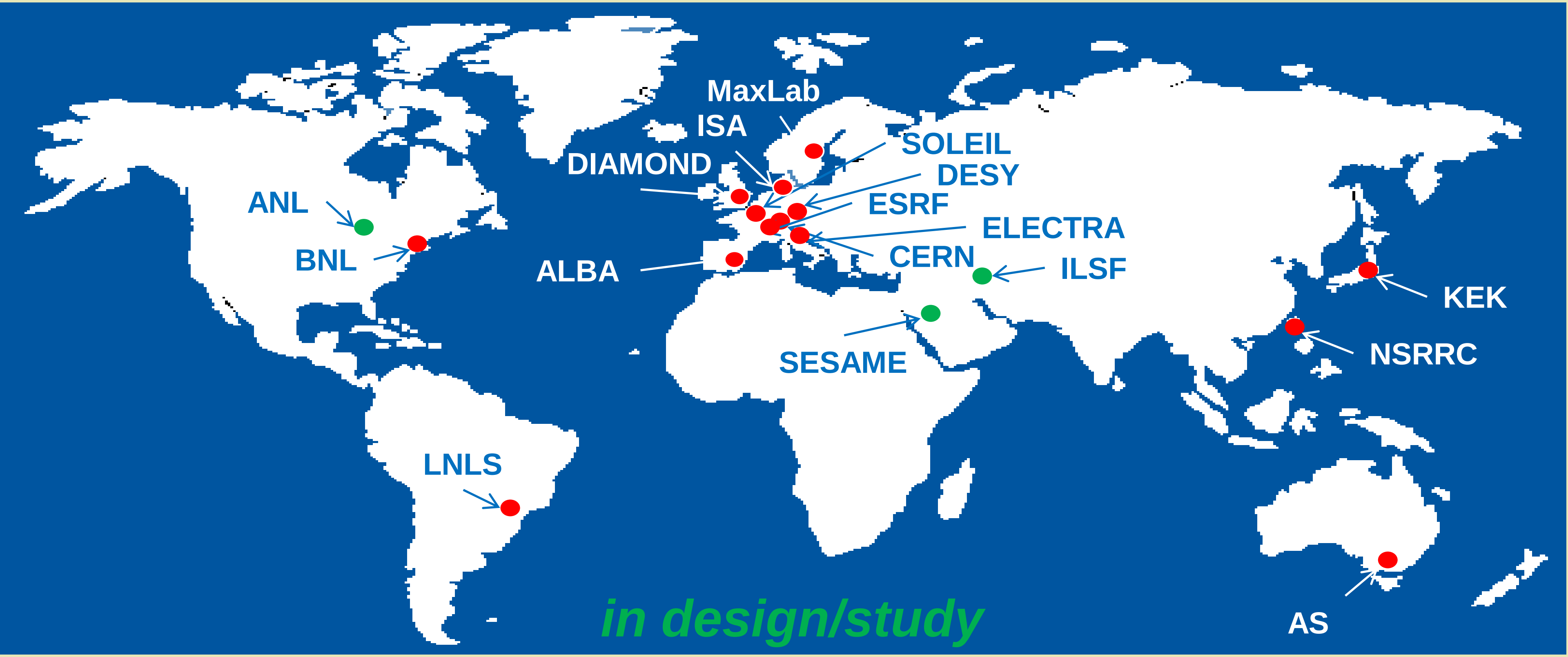
In a paper published today in *Nature*, the ALPHA collaboration at CERN's Antimatter Factory shows that, within the precision of their experiment, atoms of antihydrogen – a positron orbiting an antiproton – fall to Earth in the same way as their matter equivalents.

The "de-accelerator" where the antiprotons are prepared is fully coated with NEG.

Courtesy: Pedro C.P. ; CERN

2- Thin films in CERN accelerators: NEG for vacuum (and e-cloud)

NEG thin films widely used in synchrotron light sources



Courtesy: Pedro C.P. ; CERN

Wat nu :LHC werkt

“upgrade” van LHC: HL-LHC

diverse onderdelen

Onderdrukking van Electronen emissies van pijpwanden in voor versnellers (SPS: 1976 , 6.9 km):

Mogelijke oplossing:

Koolstof coating

1. Introduction / Motivation; why?

The formation of electron clouds in particle accelerators.

🔴 Proton bunch (charge +)

● Gas molecule

🟡 Electron (charge -)

Secondary electron Yield (SEY) = $\dfrac{\text{Number of emitted electrons}}{\text{Number of impinging electrons}}$

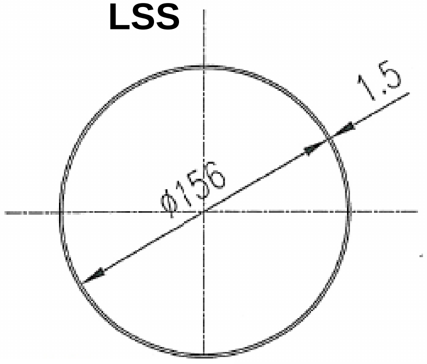
1. Introduction / Motivation;   why?

Threshold for SEY for e-cloud:

Depending of geometry, and energy

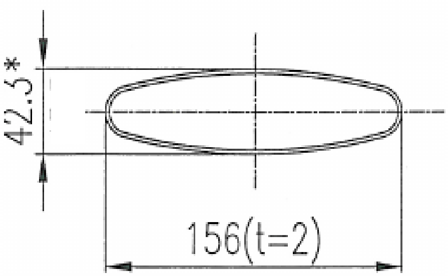
For SPS different geometries

LSS



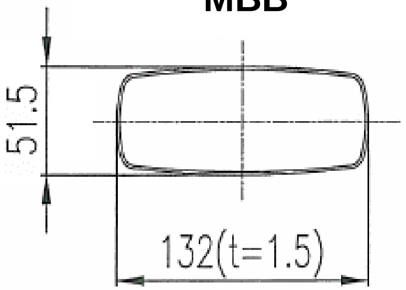
1.20

QF



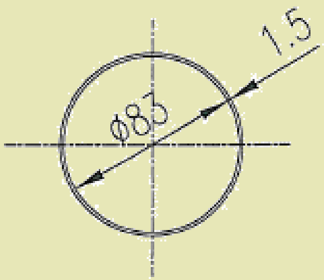
1.25

MBB



1.25

QD



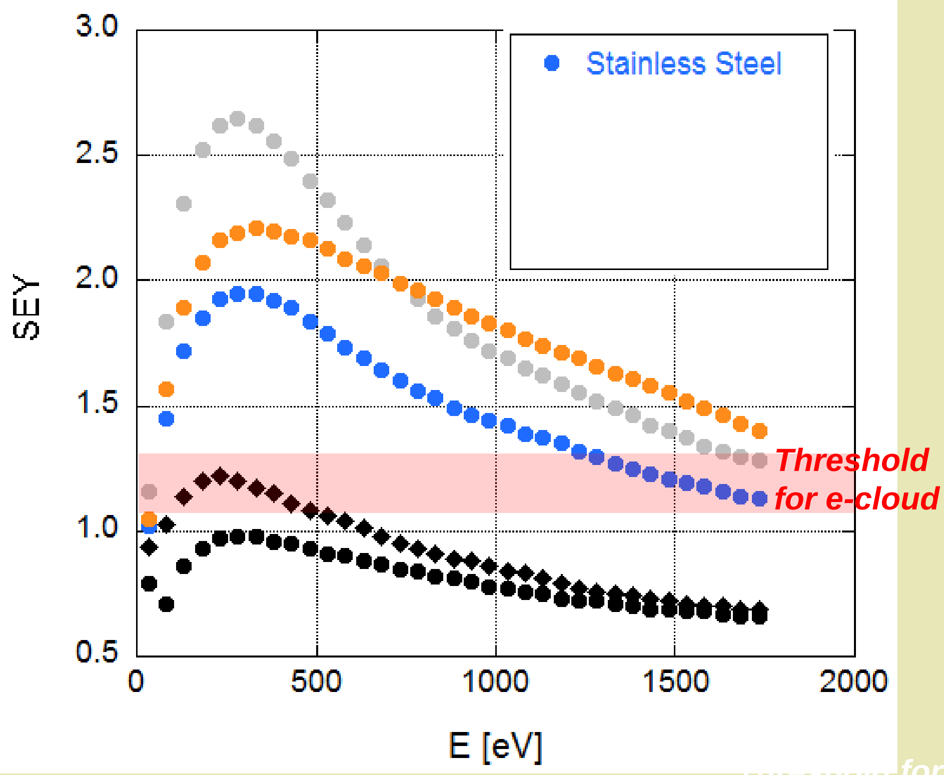
1.05

***: Giovanni Iadarola: LIU SPS scrubbing review; 8-9 September 2015, values for “worst” case scenari**

2. Method: How?

Development of carbon coatings (from 2007)

Why carbon? → **Graphite has a low SEY (secondary electron yield)**



Threshold for e-cloud

Alternatives:

- **Clearing electrodes**
- **LESS**

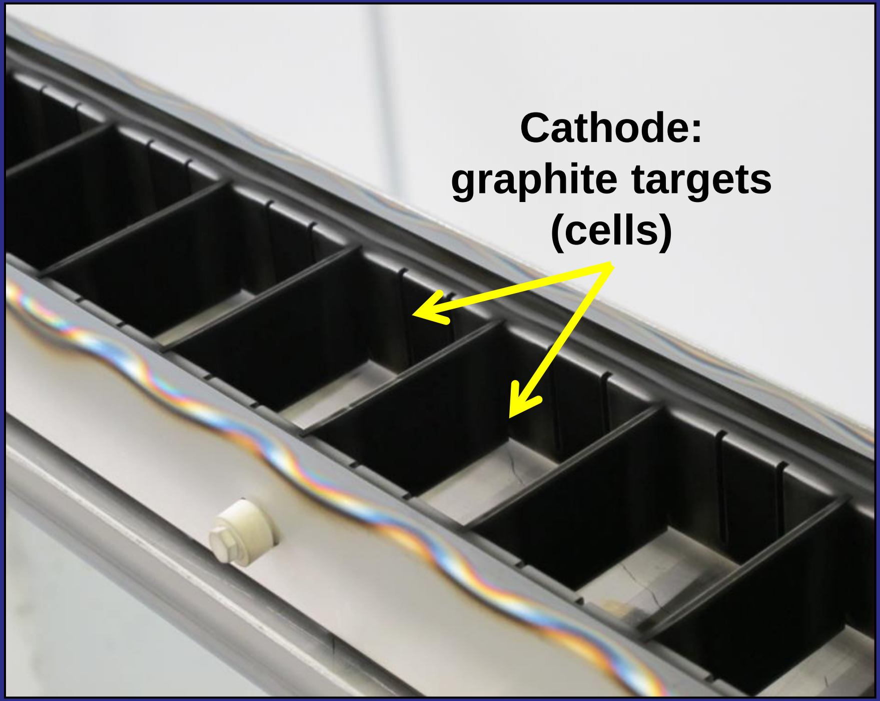
(Laser Engineered Surface Structures)

Ontwikkeling van Carbon coatings in vacuum pijp

Test opstelling in lab: 2013-2016

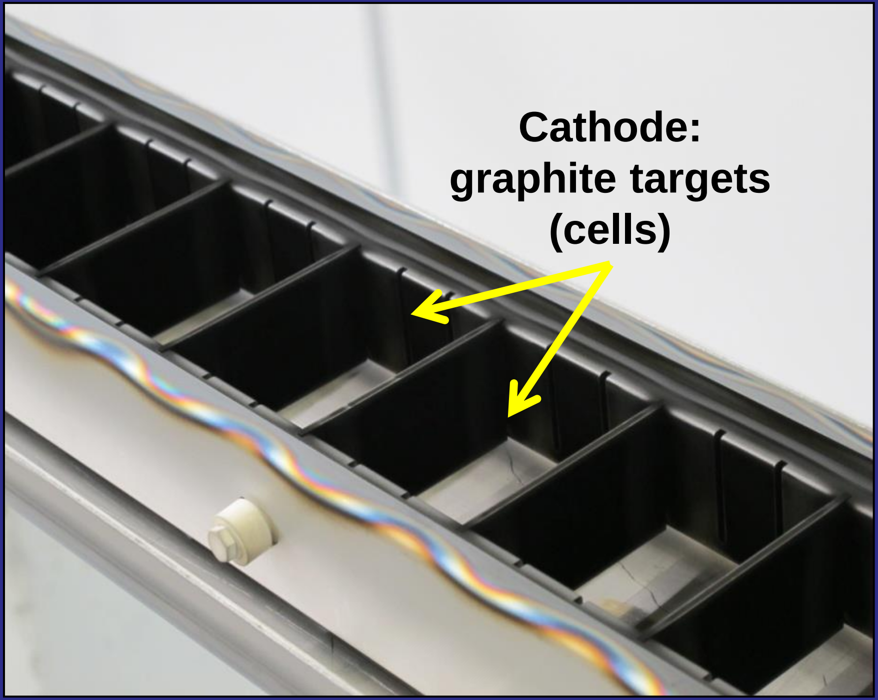
Ontwikkeling van Carbon coatings in vacuum pijp

Test opstelling in lab: 2013-2016



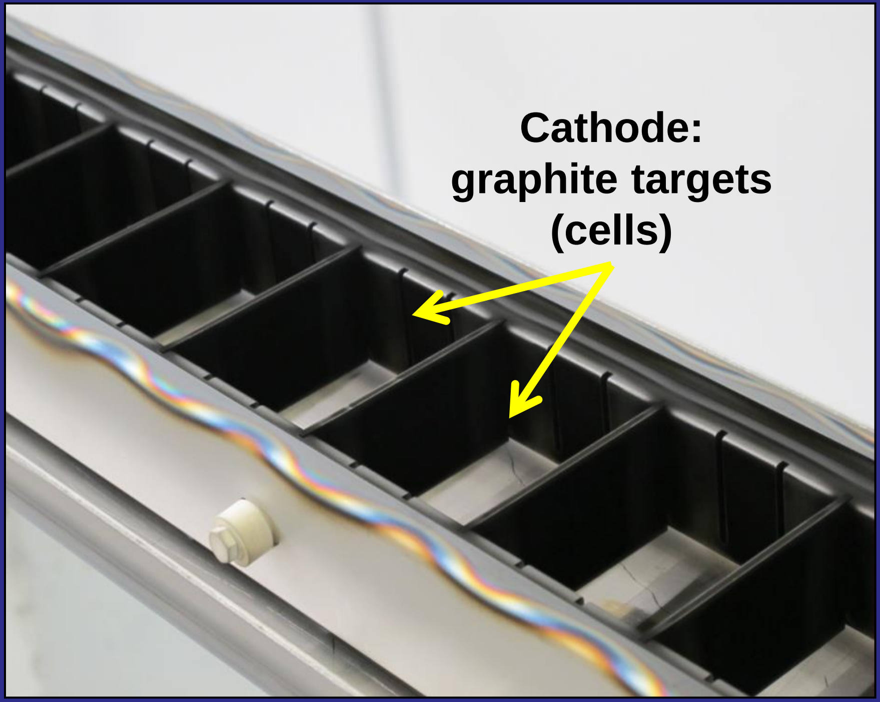
Ontwikkeling van Carbon coatings in vacuum pijp

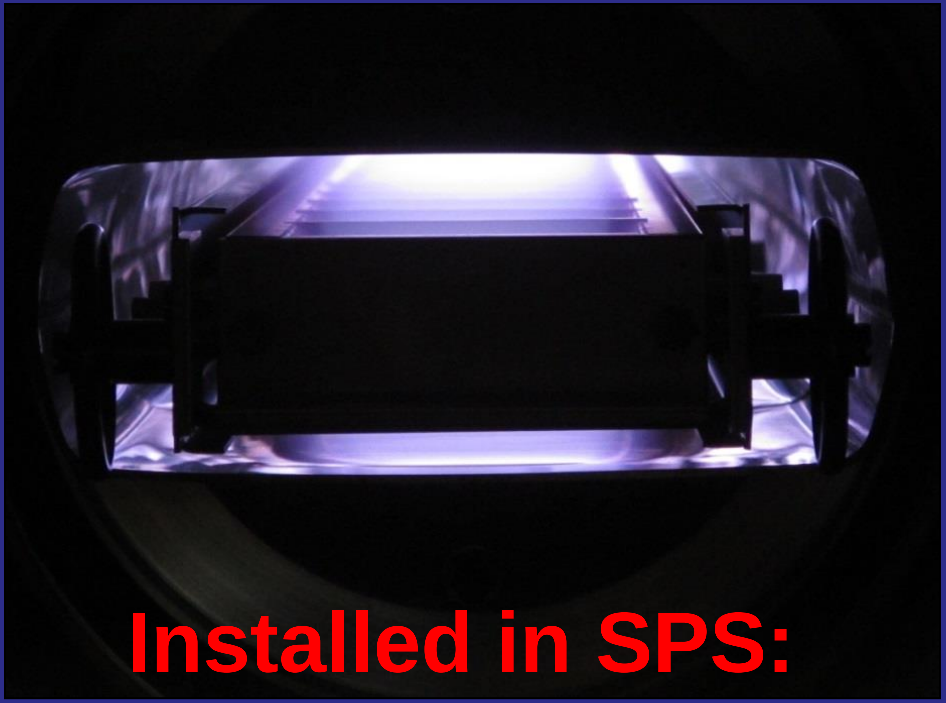
Test opstelling in lab: 2013-2016


Cathode: graphite targets (cells)

Ontwikkeling van Carbon coatings in vacuum pijp

Test opstelling in lab: 2013-2016



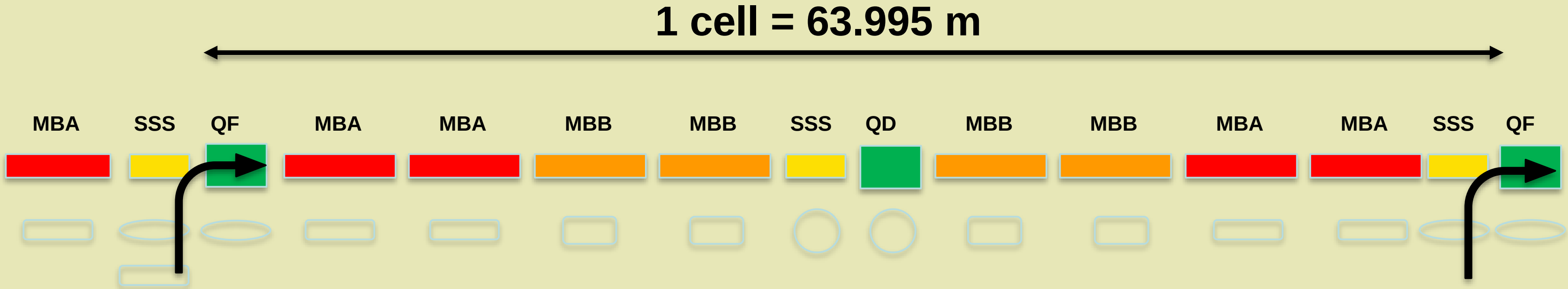


Installed in SPS:
GOOD RESULTS

Plan voor LS2: 2019-2020: coat magneten in tunnel

SPS ARC :
Herhaling van cell van 64 m
Niet mogelijk QF / MBB te verplaatsen

LS2: coating of alle QF + small magnets



Coating lab in surface building

+ drifts to 181

Insitu Carbon coatings in SPS

2017: 8 grote Magneten MBB
    9 “kleine” QF
2018: 3 grote Magneten
2019-2020: LS2
    - 88 QF
    - 102 magn. in lab

SPS operationeel sinds 2022: goede resultaten mbt electronen-wolk reductie

2- Thin films in CERN accelerators: a-C (anti-multipacting)

Challenges & Opportunities?

High Luminosity LHC: anti-multipacting to reduce the heat load to superconducting magnets.

Very restricted clearance:

150 mm gap to insert coating device

to coat 12 m long tubes

Ti & aC coating:

Ti for adhesion and

pumping of hydrogen