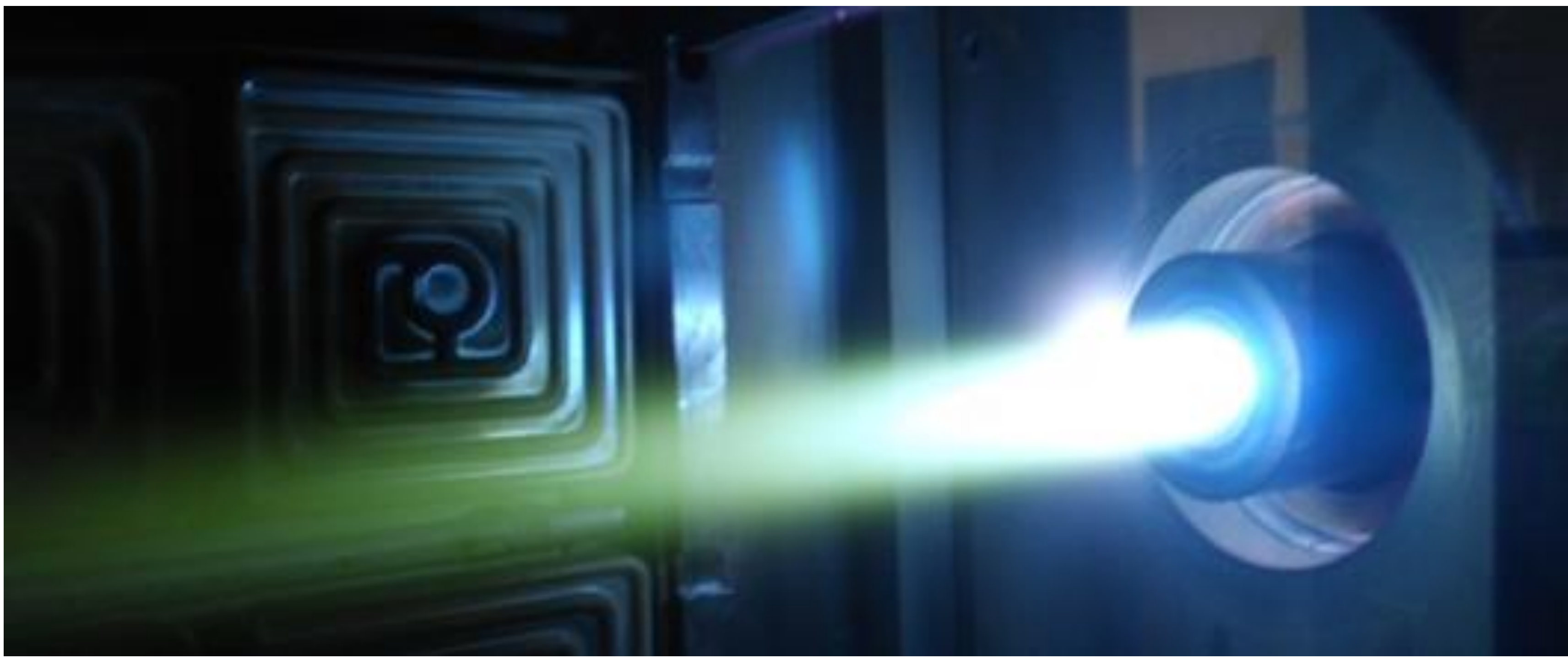
SOME RECENT DEVELOPMENTS IN SPUTTER TECHNOLOGY

G. Bräuer, R. Bandorf, M. Keunecke, A. Pflug, B. Szyszka, V. Sittinger, M. Vergöhl

www.ist.fraunhofer.de



Outline

- Introduction
- HIPIMS – ready for industry?
- Sputter technology for optical coatings
- Hollow cathode based sputter processes
- What comes next?
- Summary

Megatrends

- Climate Change
- Shortage of Resources
- Demographic Change
- Globalization

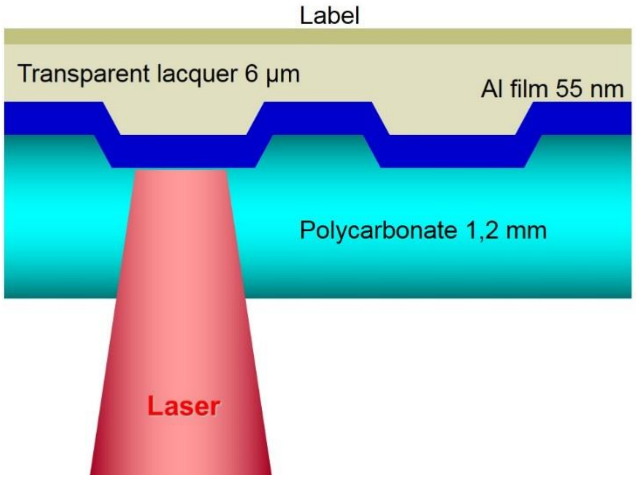
What people need – Tomorrow's opportunities

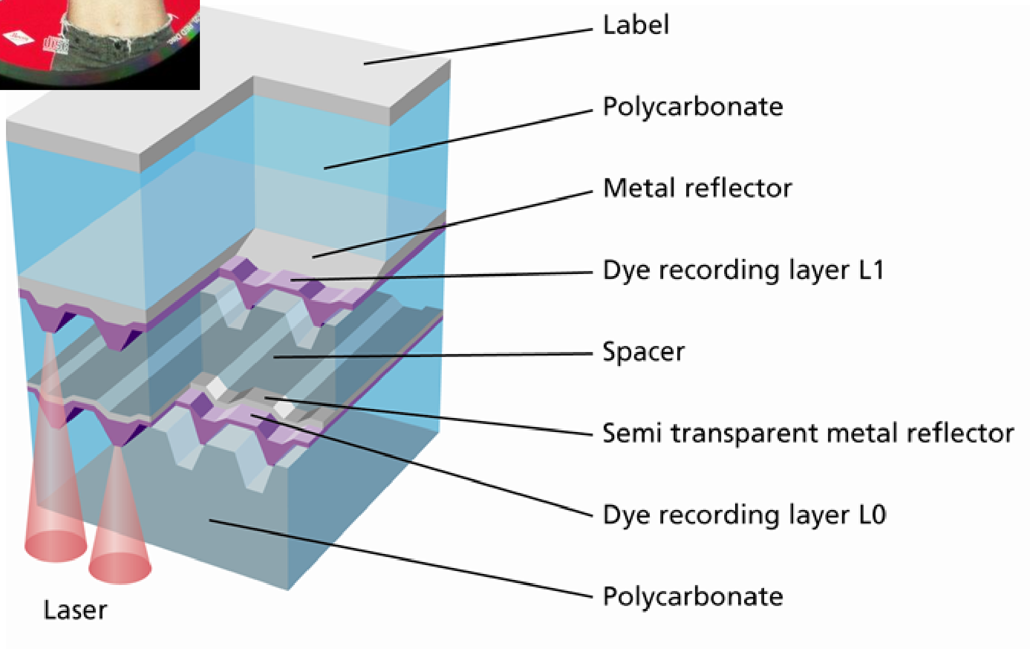
Health	Communication
Safety	Energy
Mobility	Environment

SURFACE TECHNOLOGY IS ONE OF THE KEYS.

Fraunhofer IST

Innovations through thin films– increasing complexity





Compact Disc (~ 1982), 0.65 GB, read only

Dual Layer DVD (~ 2002), 9 GB, recordable

Deposition rates for various coating technologies

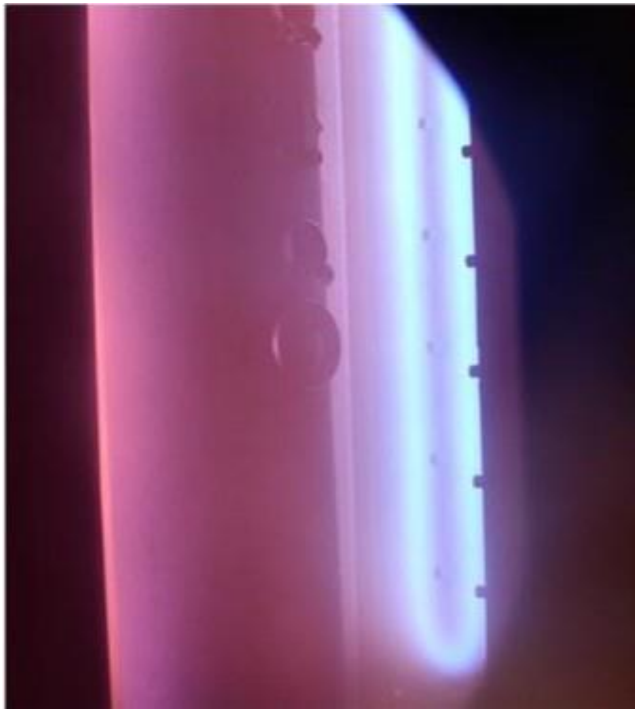
Technology	Deposition rate [nm/s]
Atomic Layer Deposition	**0,1**
Reactive pulse magnetron sputtering of TiO_2	**5**
Reactive pulse magnetron sputtering of SiO_2	**5 – 10**
Magnetron sputtering of metals	**10 – 100**
Plasmapolymerisation	**10 – 100**
Electron beam evaporation of metals	**100 – 1.000**
Thermal evaporation of metals	**500 – 5.000**
Electroplating of hard chrome	**10 - 12**
Electroplating of nickel	**15 – 150**
Atmospheric pressure plasma spraying	

Outline

- Introduction
- HIPIMS – ready for industry?
- Sputter technology for optical coatings
- Hollow cathode based sputter processes
- What comes next?
- Summary

What is HIPIMS?

- Plasma pulses with typical power from 1 MW up to 6 MW ("conventional": 50 kW)
- Voltage: 1 – 2 kV
  Current: up to 4 MA
- Duty Cycle 1 – 3 %
  → same mean power as for DC sputtering



Source: SVS Vacuum Coating Technologies

→ high amount (50 – 70 %) of ionized sputtered species forming high quality dense films

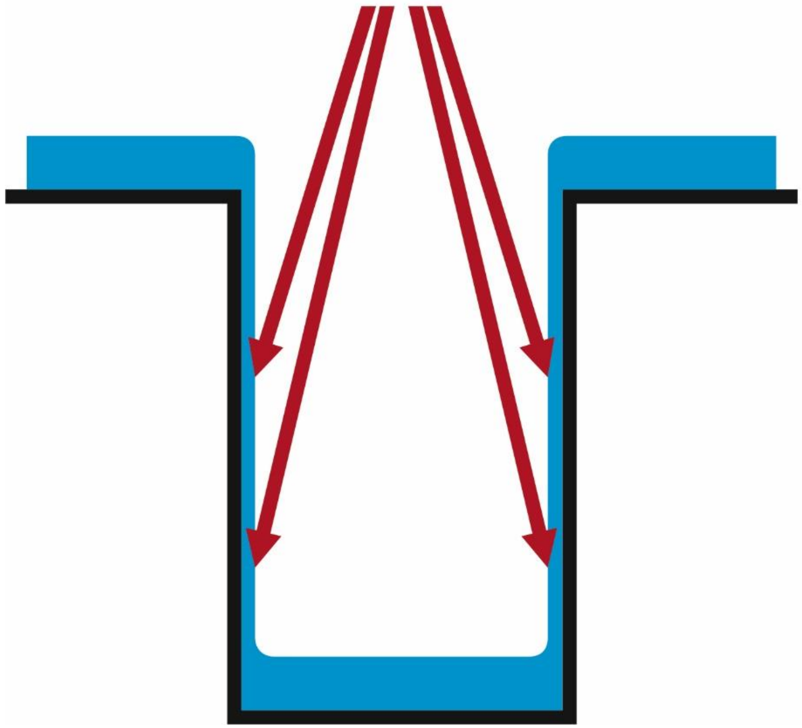
“Conventional“ magnetron sputtering and HIPIMS plasma

Application fields of HIPIMS coatings

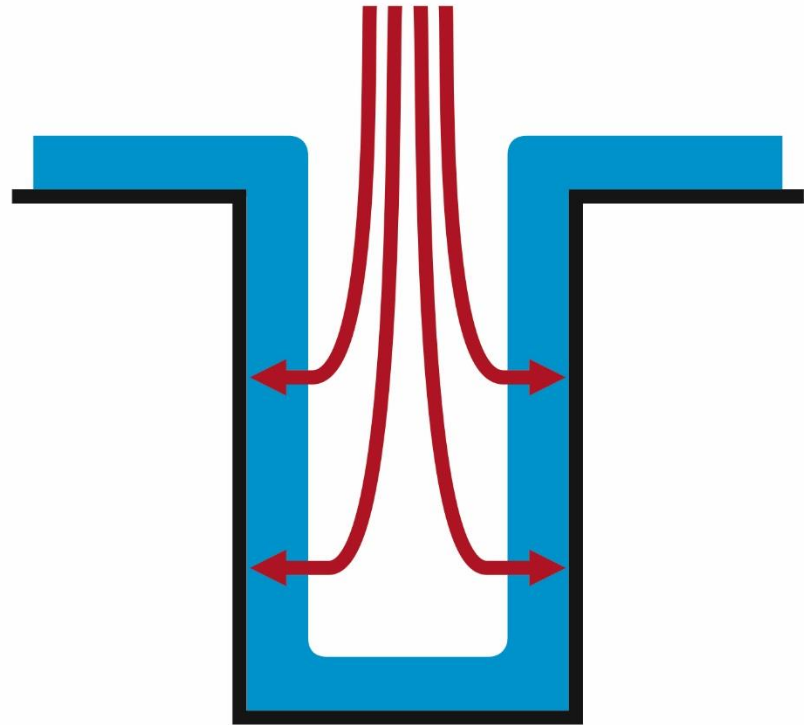
- Coating of 3D structures (filling of trenches)
- Hard coatings for tribological applications (e.g. TiAlN)
- Coatings for precision optics
- Glass coating, e.g. transparent conductive films
- Sensors

Coating of 3D structures (trench filling)

Conventional: film forming species are mainly neutrals



HIPIMS: film forming species are mainly ions

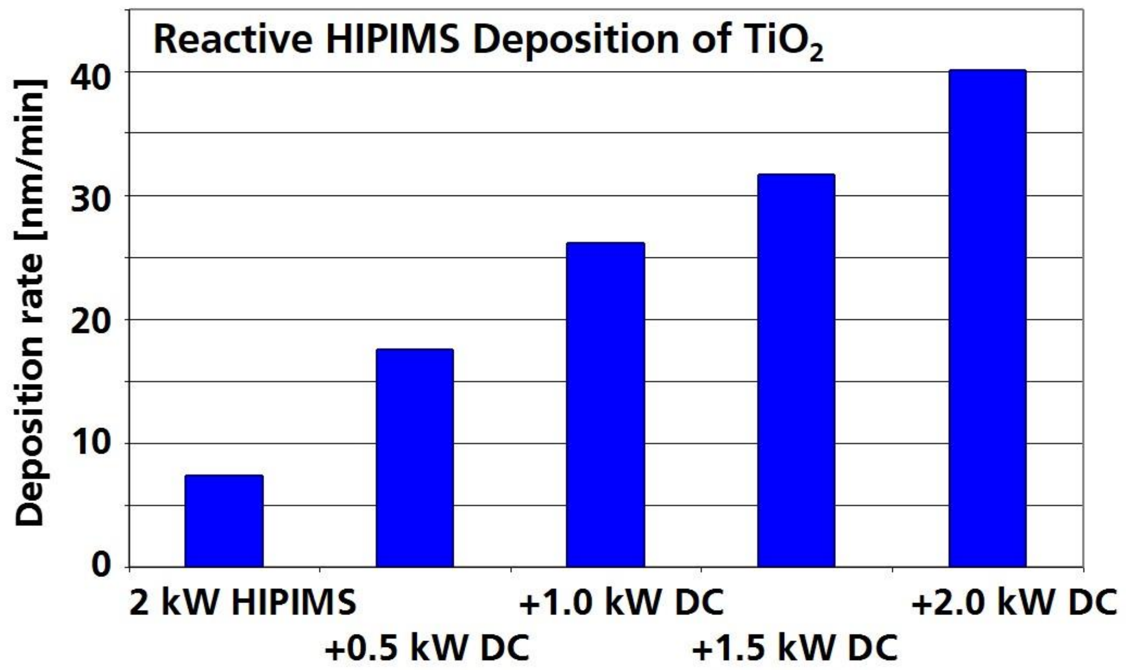


Source: Prof. Ulf Helmersson, Linköping University

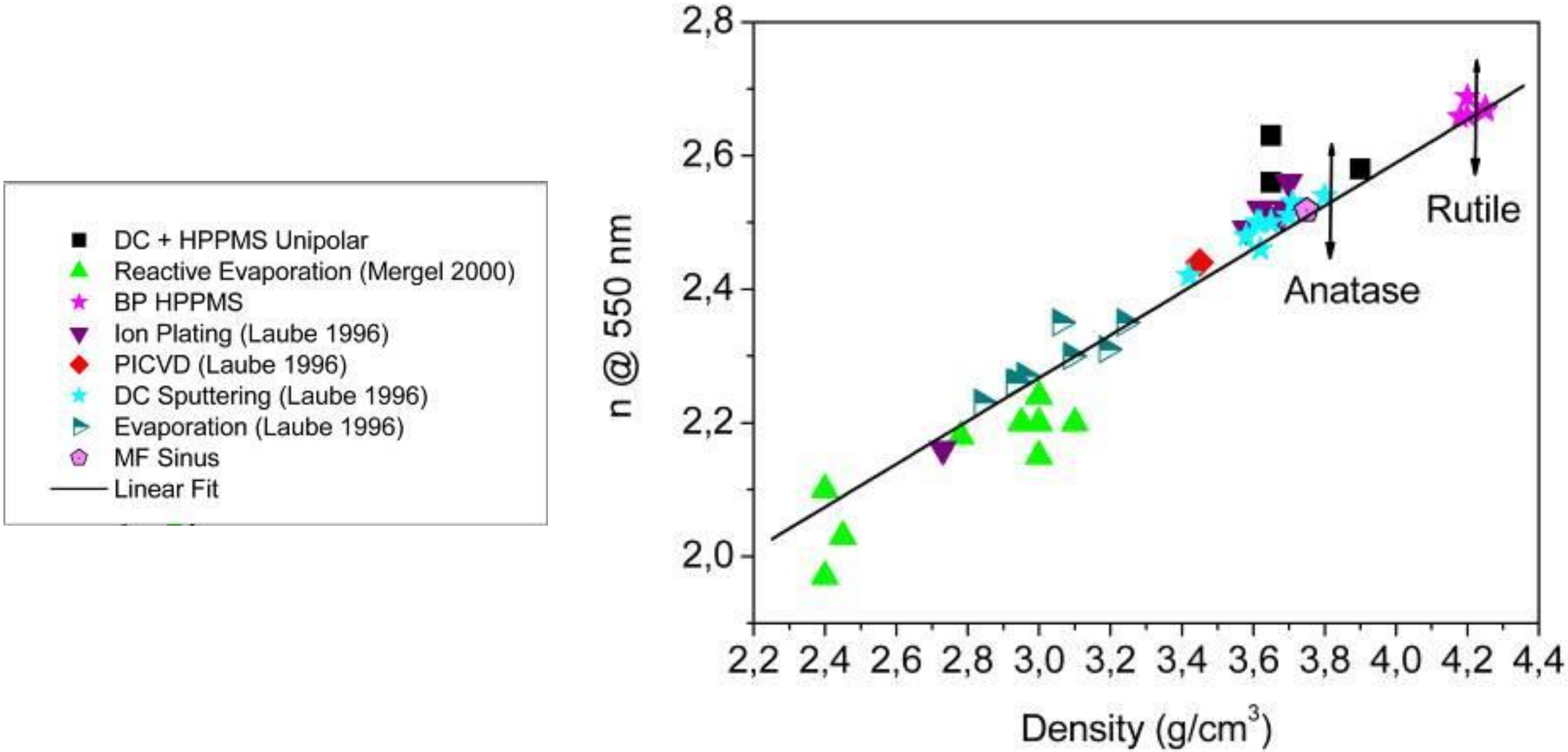
Deposition rates for HIPIMS

Low deposition rates can be improved by adding DC.

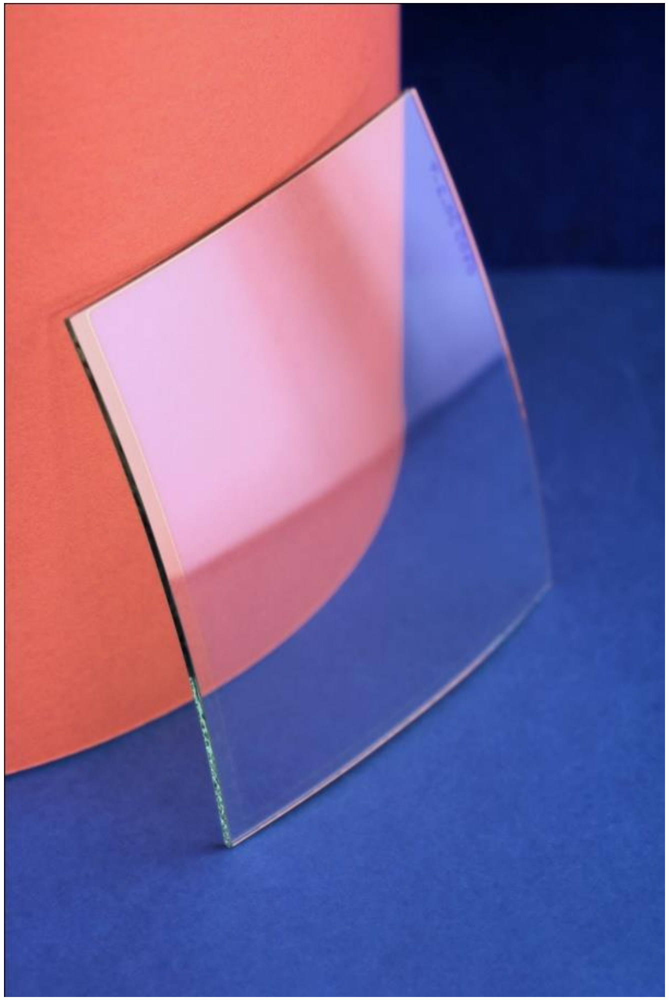
(Data taken from a planar magnetron 488 mm x 88 mm.)



TiO_2 deposition using various processes



HIPIMS ITO – coat and bend process for Low-E glass



Coat at room temperature

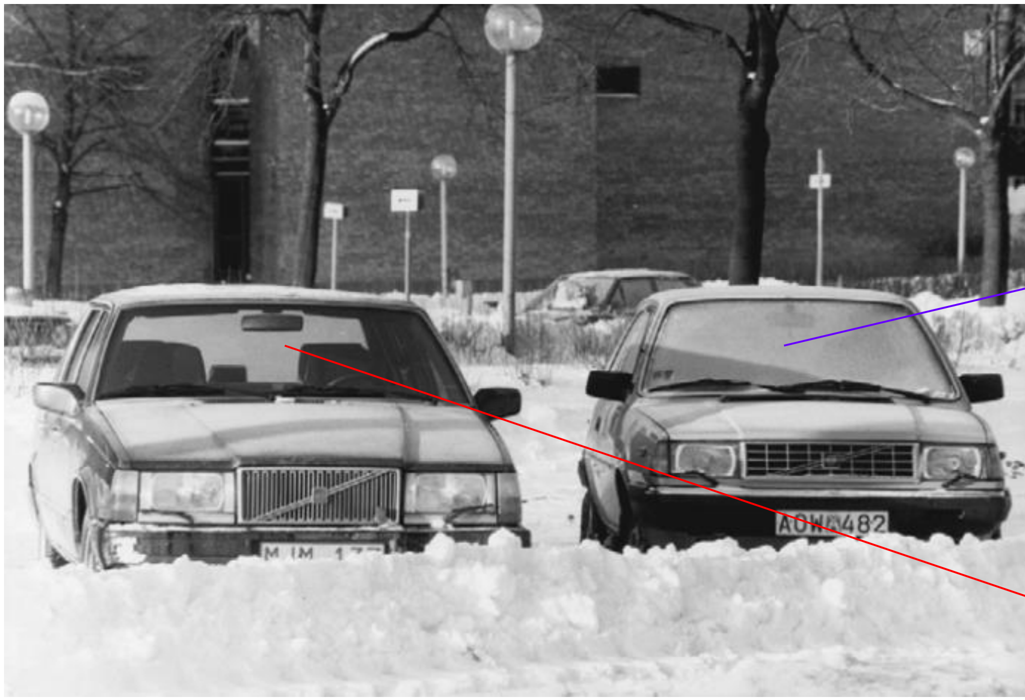
↓

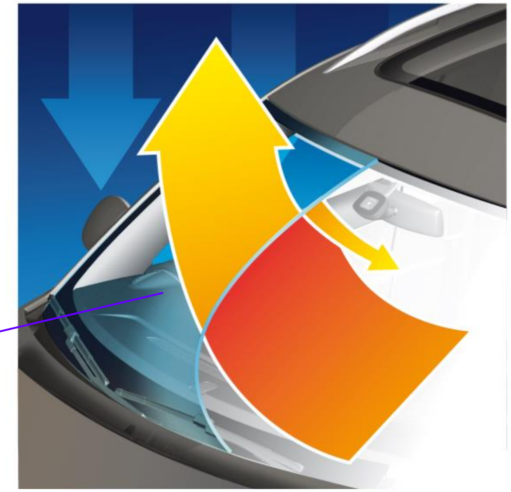
Bend process (650°C-750°C)

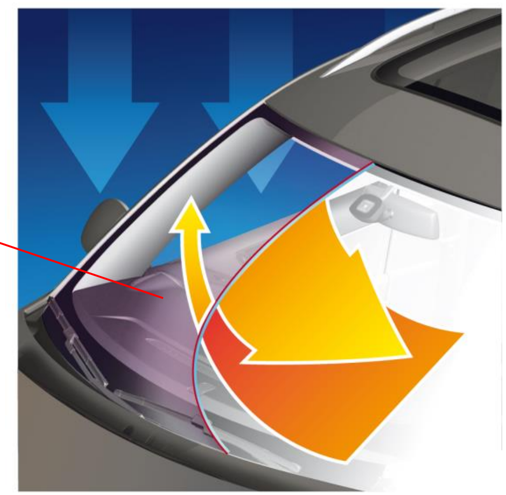
↓

Toughened glass pane with coating

The ice-free windshield

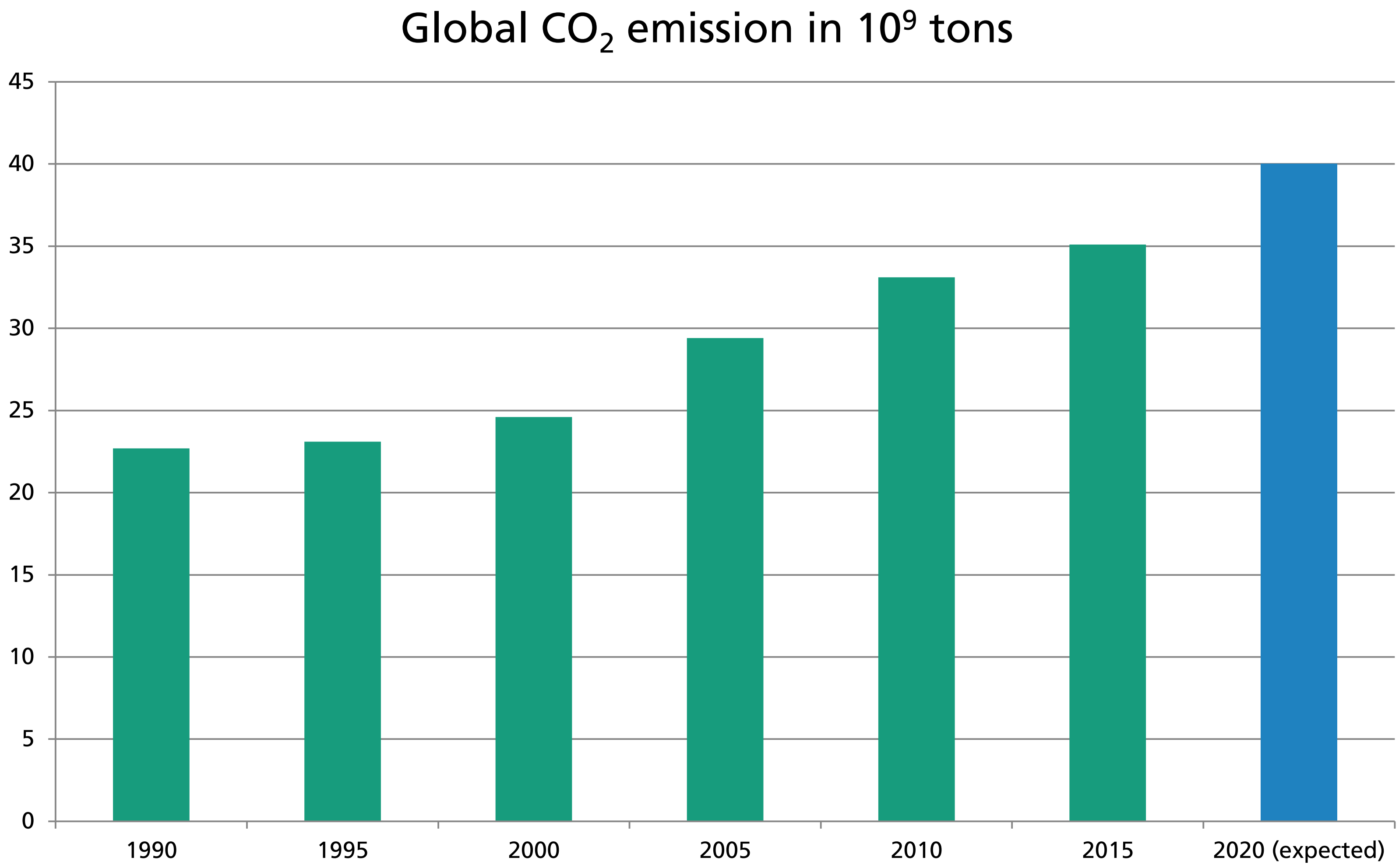






Source: Claes G. Granqvist, Transparent conductors as solar energy materials: A panoramic review, Solar Energy Materials & Solar Cells 91 (2007) 1529 - 1598

Increasing CO_2 emissions



Challenge: CO_2 reduction by friction reduction

Effects of the different parameters influencing fuel consumption and CO_2 emission in passenger cars can be summarized as:

10 % mass reduction	⇒ 8.3 %	reduction in energy demand
10 % rolling resistance reduction	⇒ 2 %	reduction in energy demand
10 % frontal area reduction	⇒ 2.2 %	reduction in energy demand
5 % speed reduction	⇒ 6 %	reduction in energy demand
5 % mechanical loss reduction	**⇒ 1.5 %**	**reduction in energy demand**

Global fuel consumption for passenger cars 2009: $63 \cdot 10^{10}$ liter (gasoline + diesel)

$\rightarrow$ 1,5 %: $9{,}5 \cdot 10^{9}$ liter $\rightarrow$ $23 \cdot 10^{6}$ t CO_2

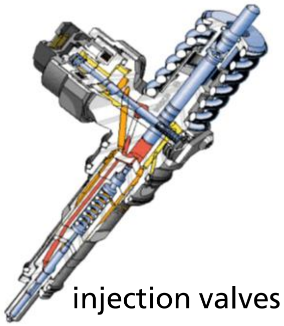
Source: K. Holmberg, P. Andersson, A. Erdemir, *Global energy consumption due to friction in passenger cars*, Tribology International 47 (2012) 221.

⇒ need for tribological optimized solutions

DLC coatings – From research to markets

- Cutting tools
- Forming / Moulding
- Automotive / Racing
- Medical
- Decorative
- Sensors

Application of a-C:H and a-C:H:Me

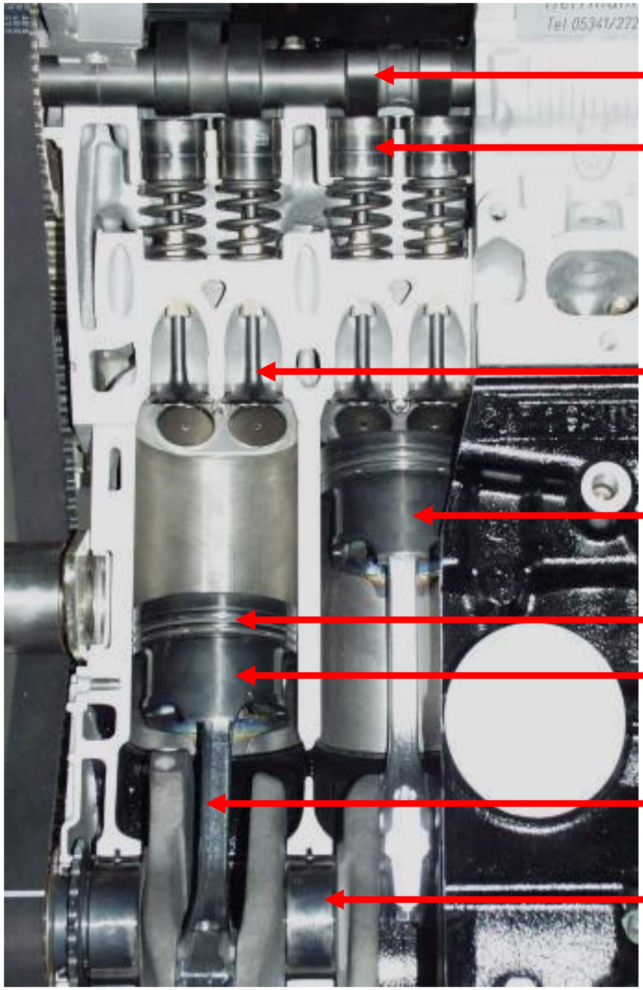


Automotive components

High performance applications (Car Racing)

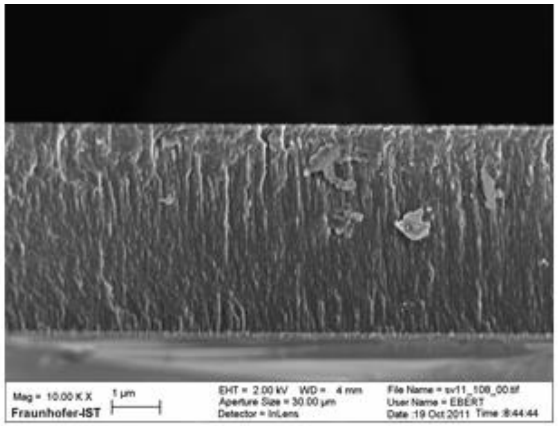
Mass volume production DLC

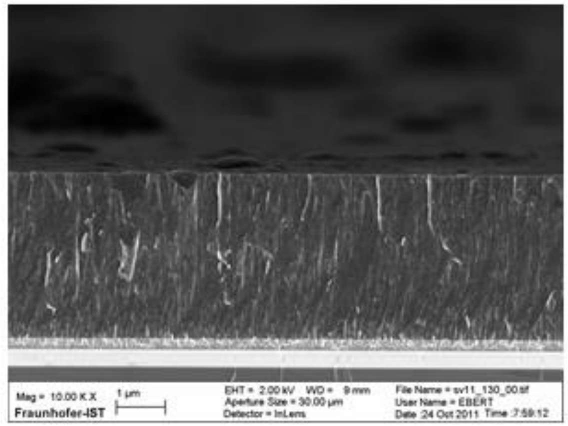
Mass volume other coatings

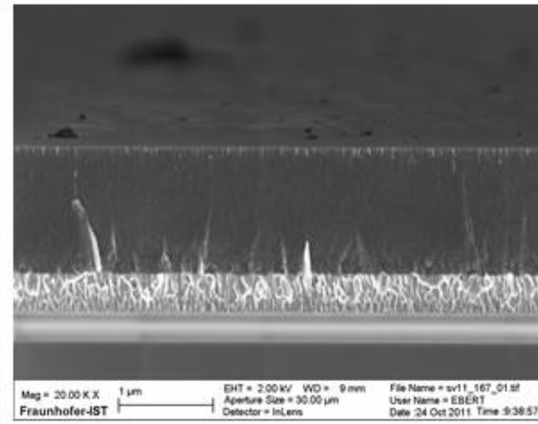


DLC films deposited with reactive HIPIMS

Graphite Target, gas mixture of Ar, Ne, C_2H_2







0% C_2H_2, 15 GPa **4% C_2H_2, 28 GPa** **5% C_2H_2, 53 GPa**

Outline

- Introduction
- HIPIMS – ready for industry?
- Sputter technology for optical coatings
- Hollow cathode based sputter processes
- What comes next?
- Summary

What means »precision« in precision optics?

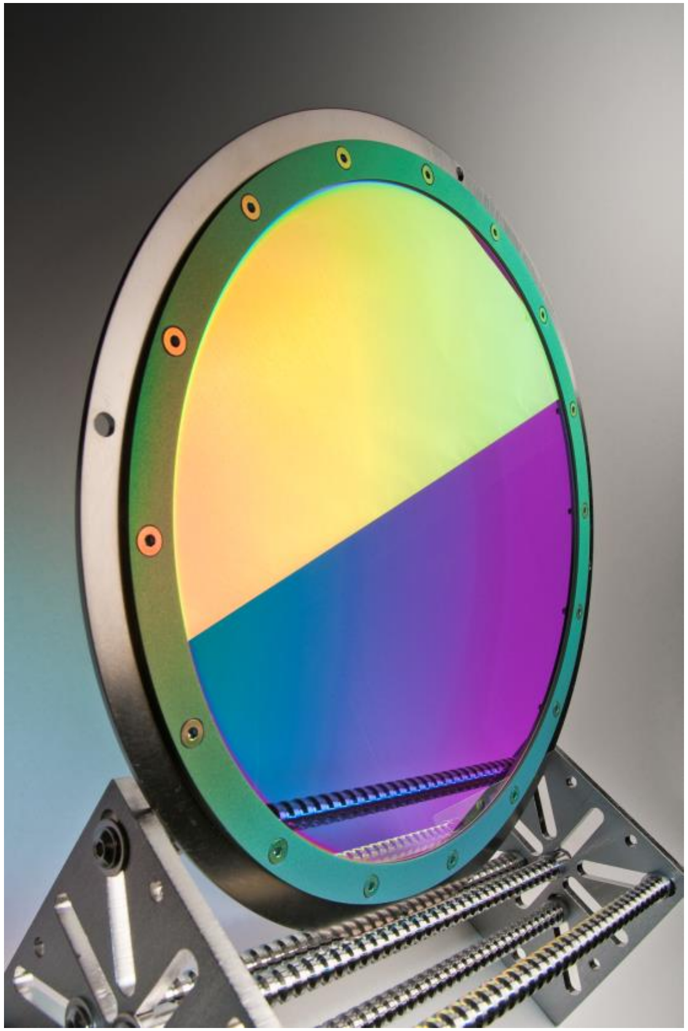
1980
2 – 3 % tolerance, 50+ layers

late 1990
< 1% tolerance, 100+ layers

JDSU 2012
~ 0.5% (±0.25%), 75 – 1000 layers
world record (JDSU): 4410 layers

Fraunhofer IST 2014
~ 0.2% (±0.1%), 100+ layers

(Georg Ockenfuss, ICCG9, Breda 2012)



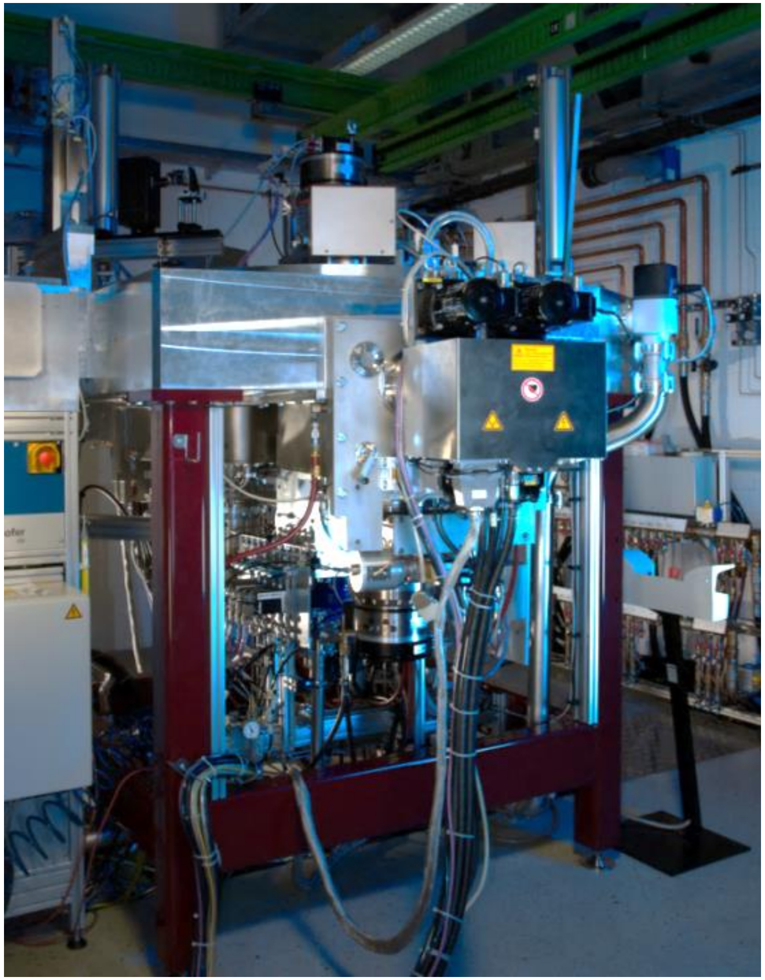
Magnetron sputtering as emerging deposition process for precision optics

Established:	»high end«:	emerging:
evaporation	ion beam sputtering	magnetron sputtering
high rate	low rate	high rate
limited performance	high performance	high performance

EOSS® – Enhanced Optical Sputter System

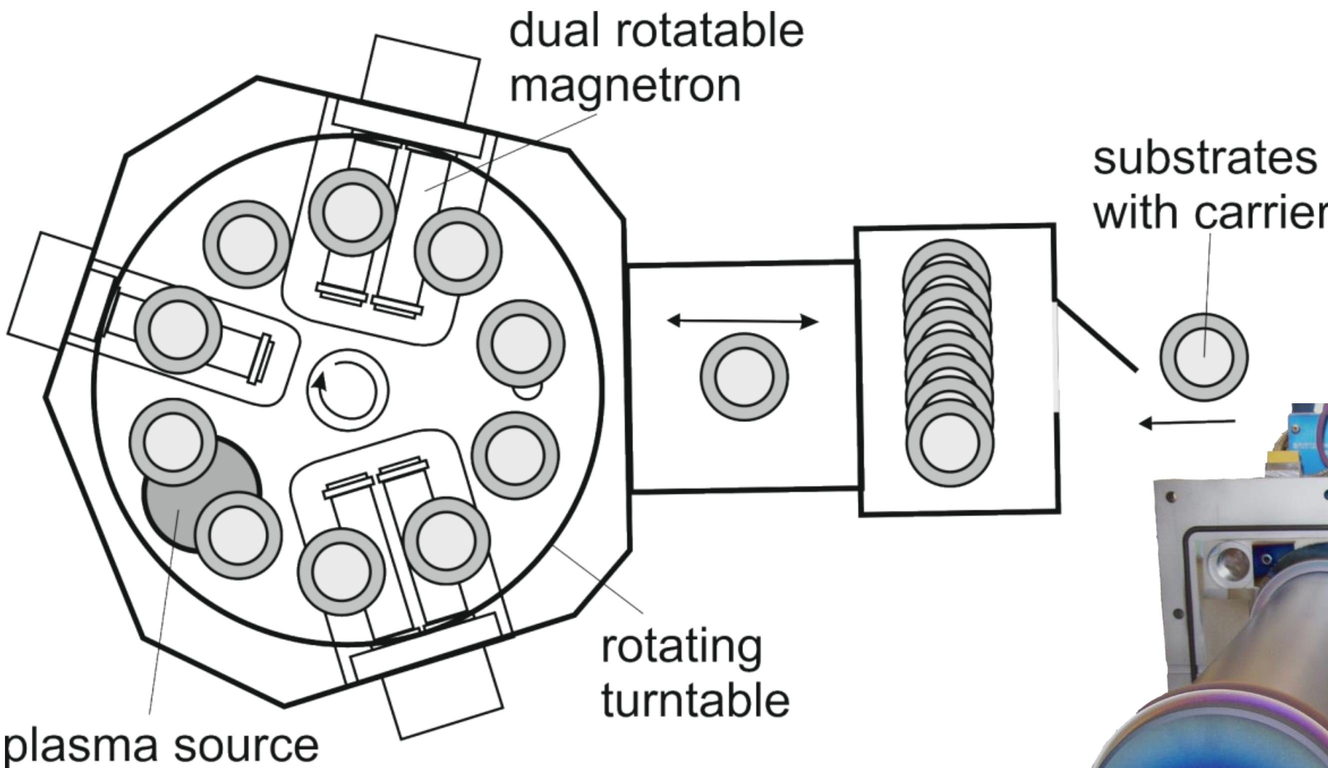
Main Features

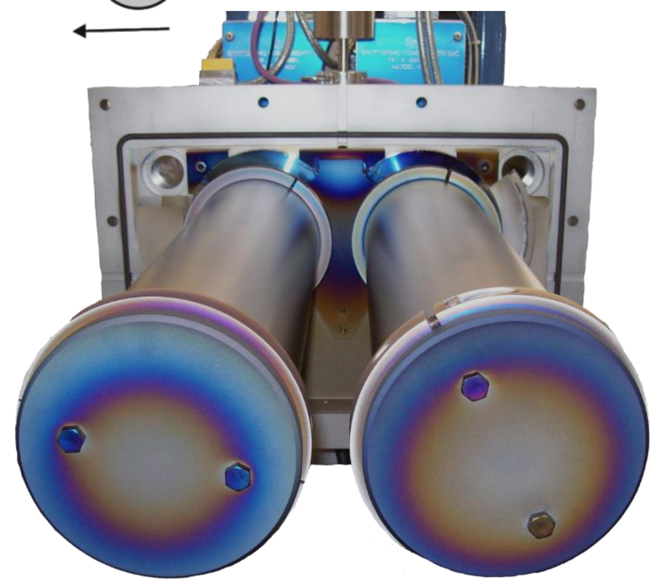
- dual cylindrical magnetrons
- batch size: 10 substrates with Ø 200 mm
- fast turntable 250 rpm
- sputtering in metallic (with post oxidation) or reactive mode
- full optical control and process automation



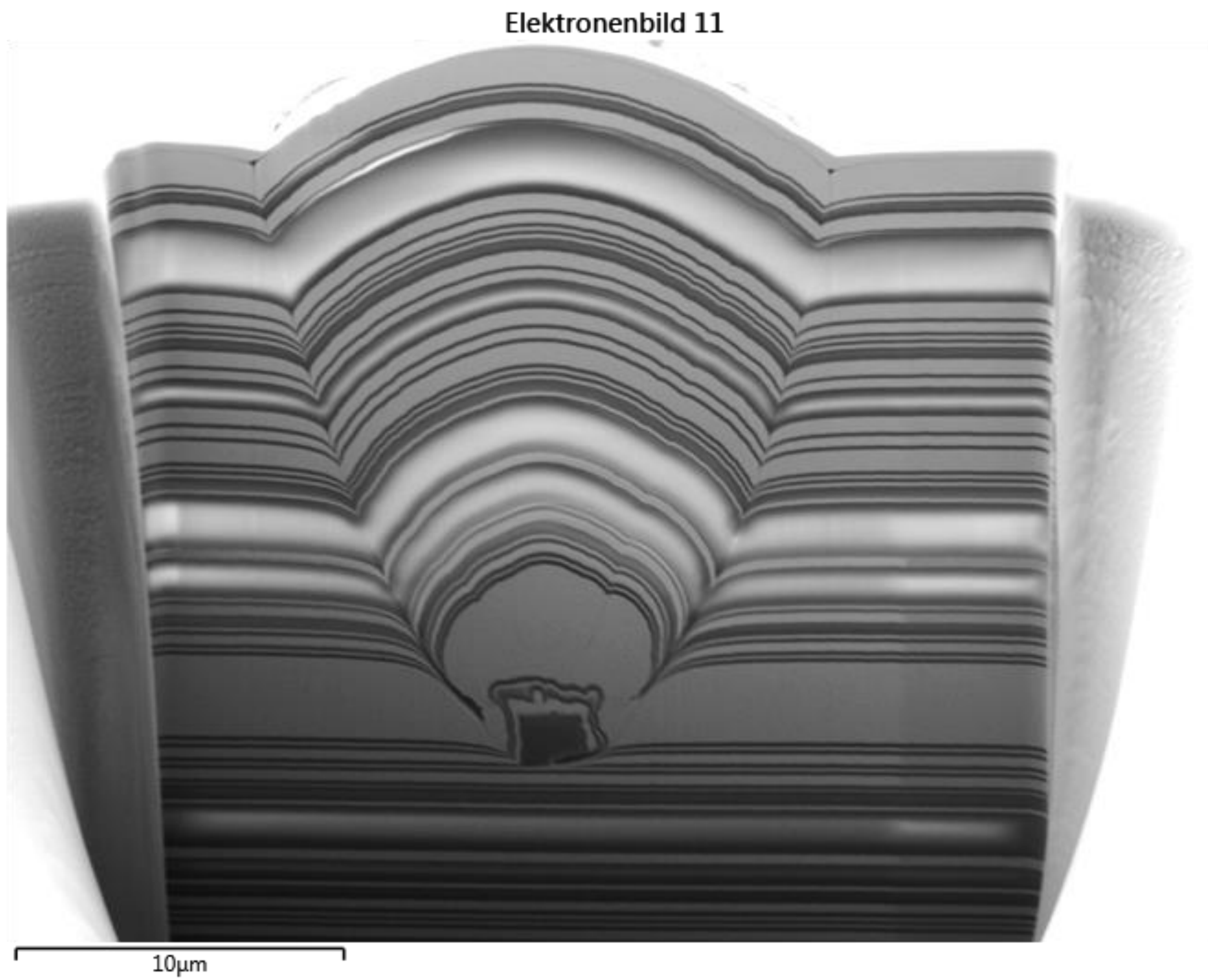
EOSS® – Enhanced Optical Sputter System

Setup at Fraunhofer IST





Cross fraction of a multilayer stack with included defect

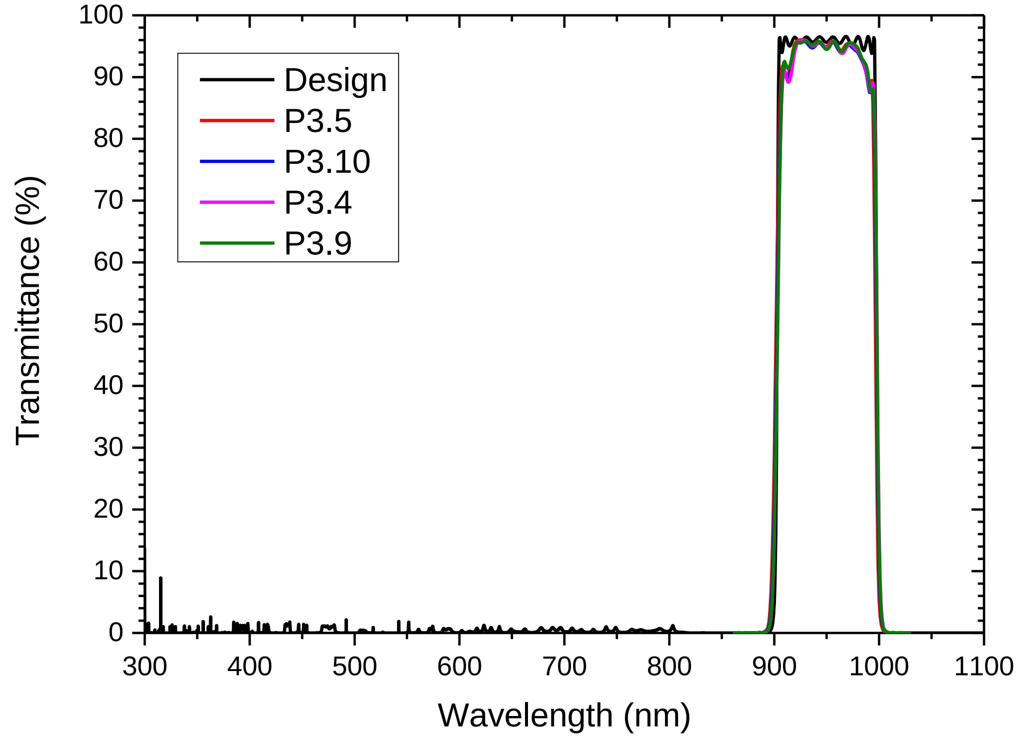


Fraunhofer IST

Precision optics made on EOSS®

Example: Bandpass filter for space mission

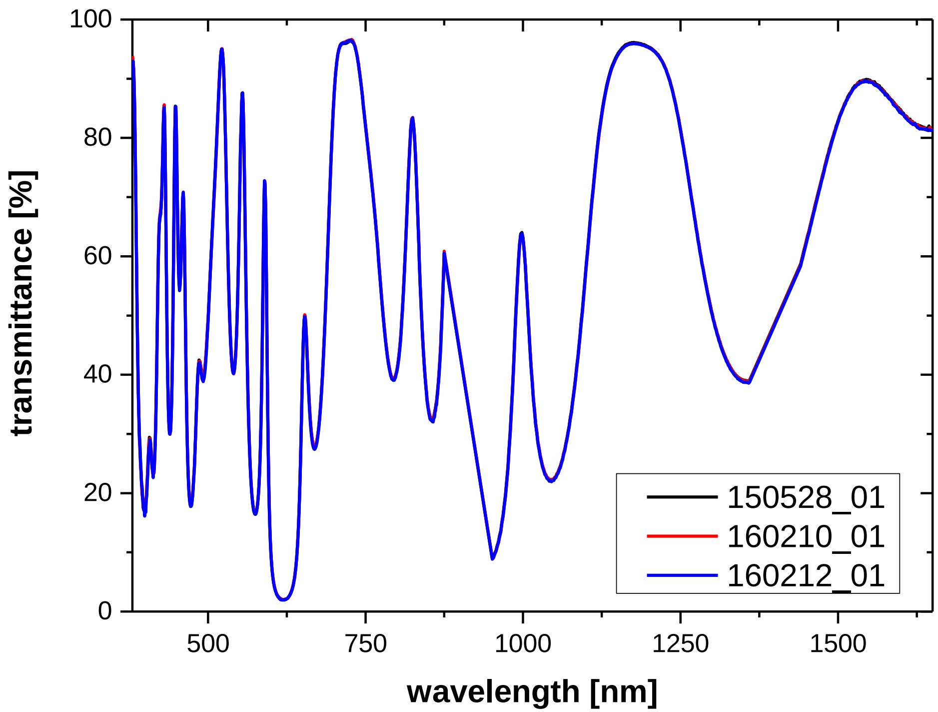
- IR bandpass filter
  - 137 layers
  - 14 µm total thickness
  - Ta_2O_5/SiO_2
  - Single side coating
- Broad blocking range 300-1100 nm
- Central wavelength tolerance 0,3% over several substrates
- High transmittance
- Space qualified



Precision optics made on EOSS®

Example: Test of process stability

- Spectrum shows back side coating of a customer's filter
- 3 runs within 9 months (incl.: 1 new target)
- Test glasses had:
  - 18 layers
  - 3,6 µm thickness
- No visual difference in spectra
- Demonstrates the extremely high stability of refractive index and deposition rate



Precision optics made on EOSS®

Example: Antireflecitve coating on aspherical lenses

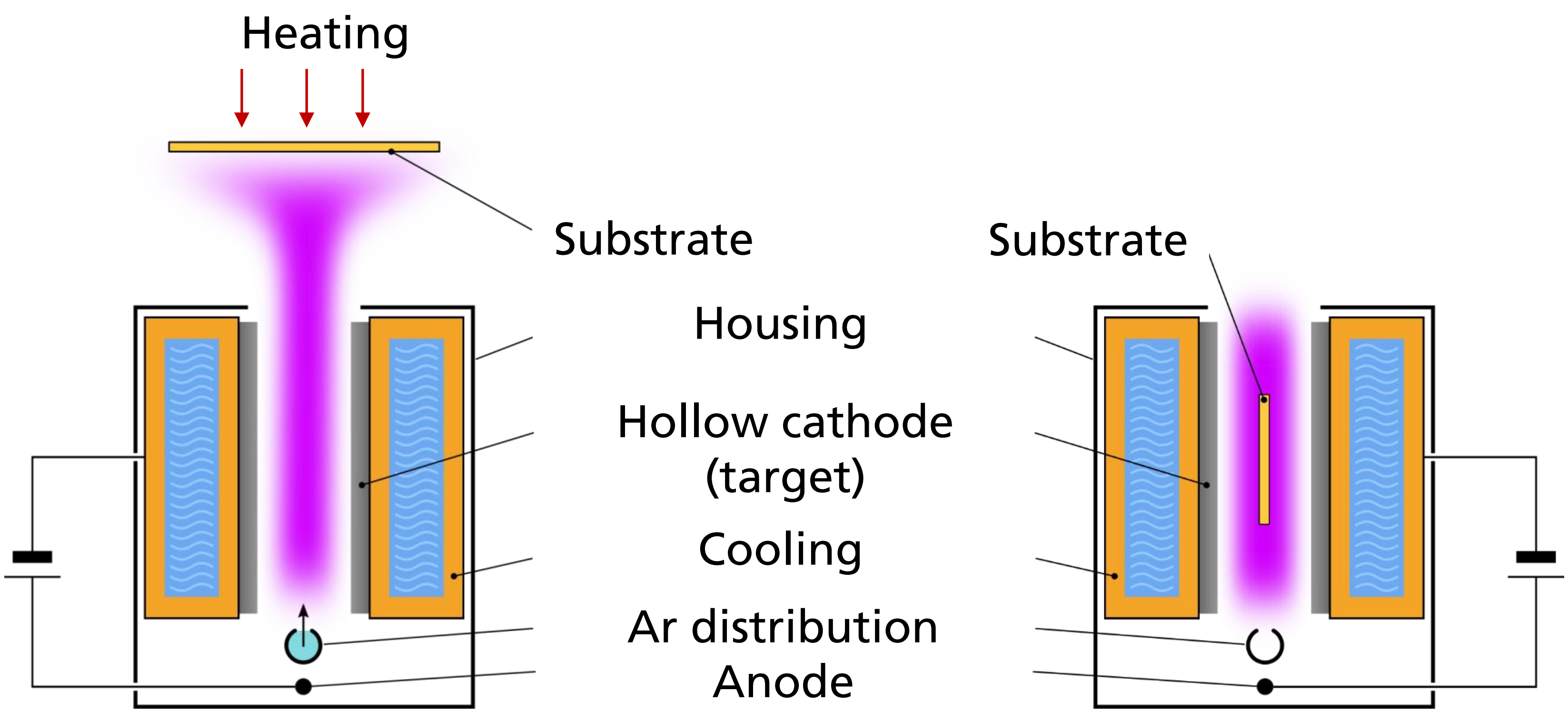
- Industrial application in retina scanners
- Strongly bended substrates
- Broad band AR in a wide range of angles required
- Complex stack: more than 50 layers
- Evaporation at its limit

Outline

- Introduction
- HIPIMS – ready for industry?
- Sputter technology for optical coatings
- Hollow cathode based sputter processes
- What comes next?
- Summary

Gas Flow Sputtering (GFS) and Inner Hollow Cathode Sputtering (IHC)

- Schematic GFS-Process
- Schematic IHC-Process



Example for technical application of magnetic thin films

- Use of magnetic thin films for high precision positioning systems
  - Compact
  - Insensitive against dust/contaminations
  - Resolution in the nanometer regime
  - Absolute positioning in the micrometer range
    - ➢ High demand on the fabricated magnetic thin films

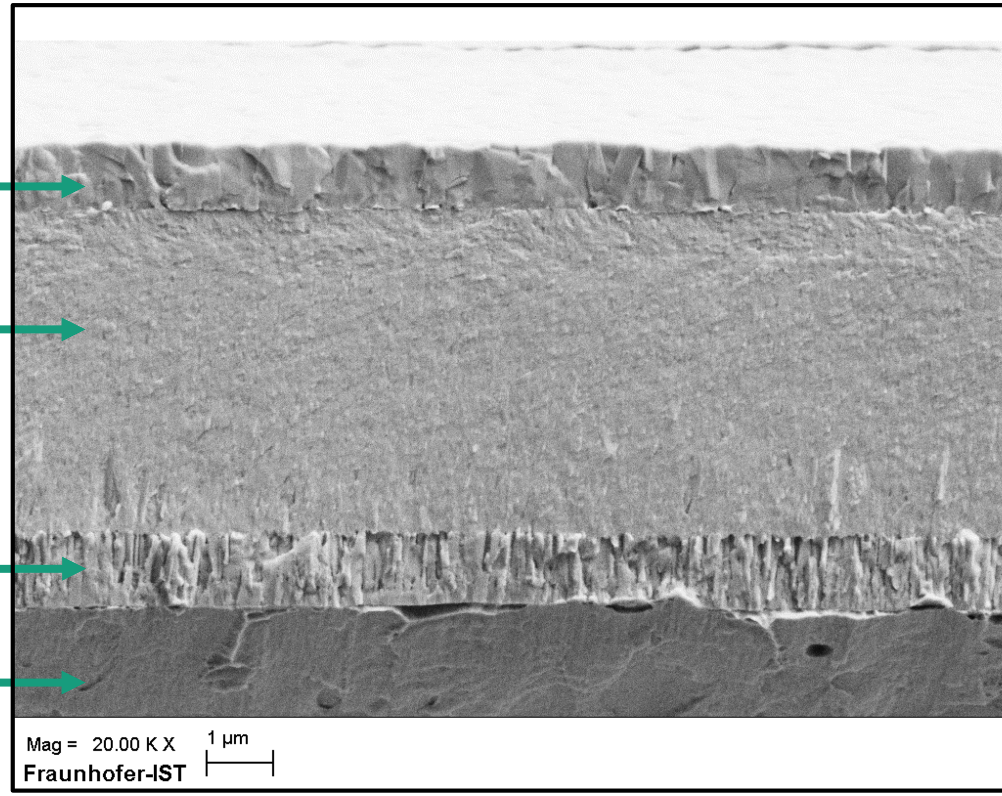
Magnetic multilayer system made by GFS

Cr protective topcoat

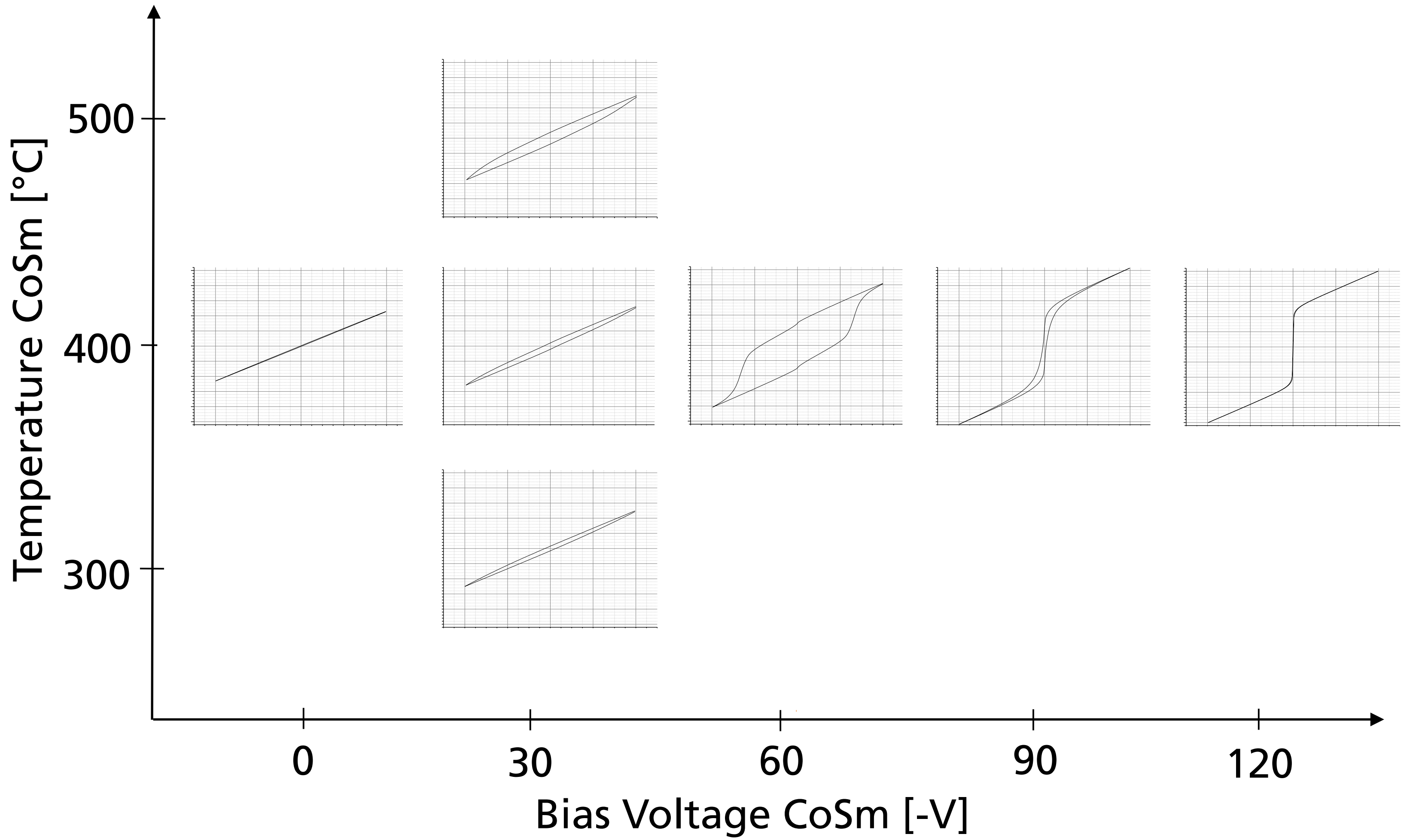
Co_xSm functional layer

Cr seed layer

Substrate: metal strip

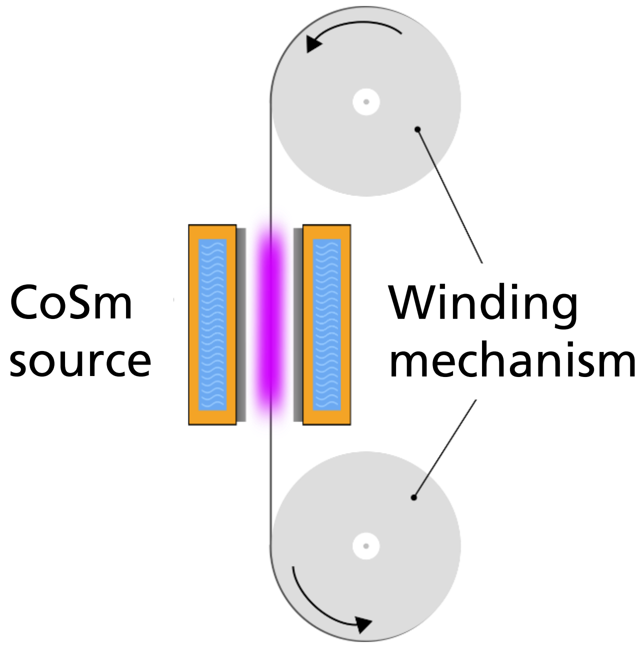


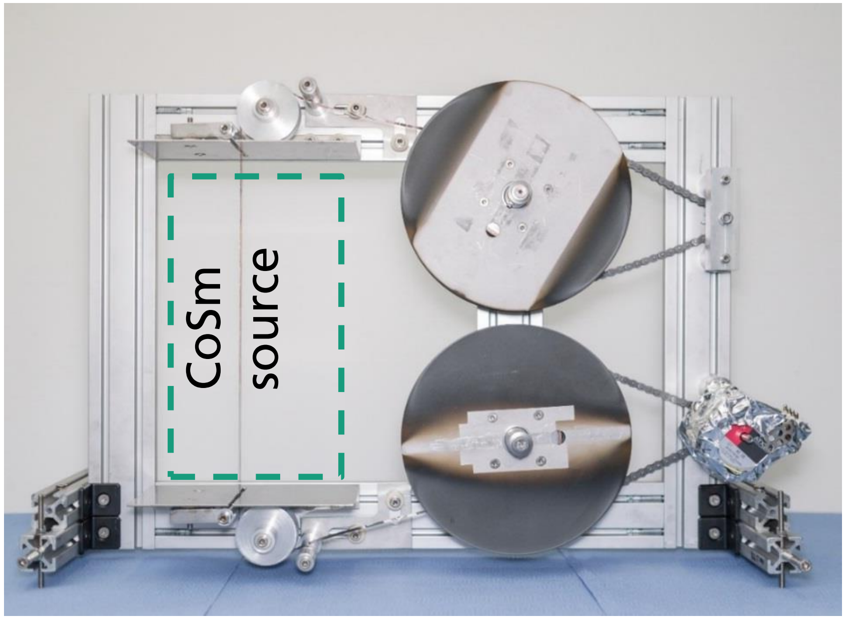
GFS: Magnetic hysteresis behaviour for different substrate temperatures and bias voltages



Dynamic IHC: Pilot production

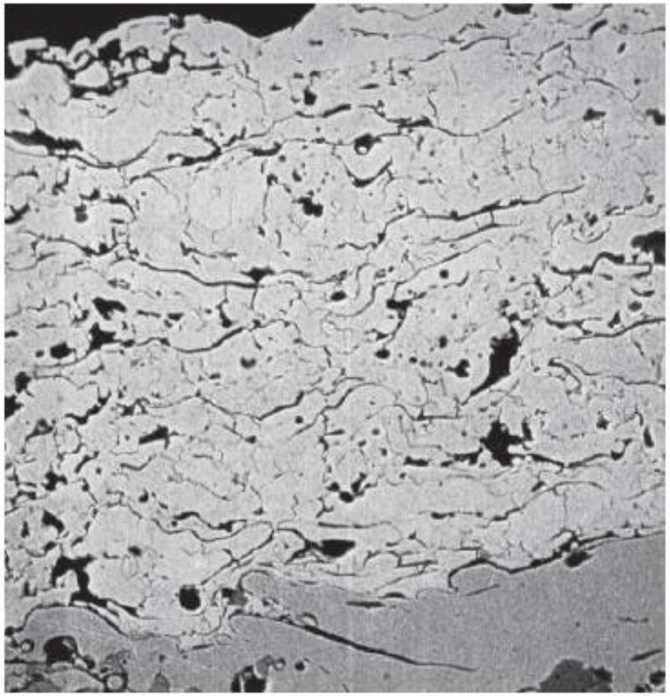
- Schematic of the setup for the dynamic deposition
- Reel-to-reel setup (driven by a stepper motor



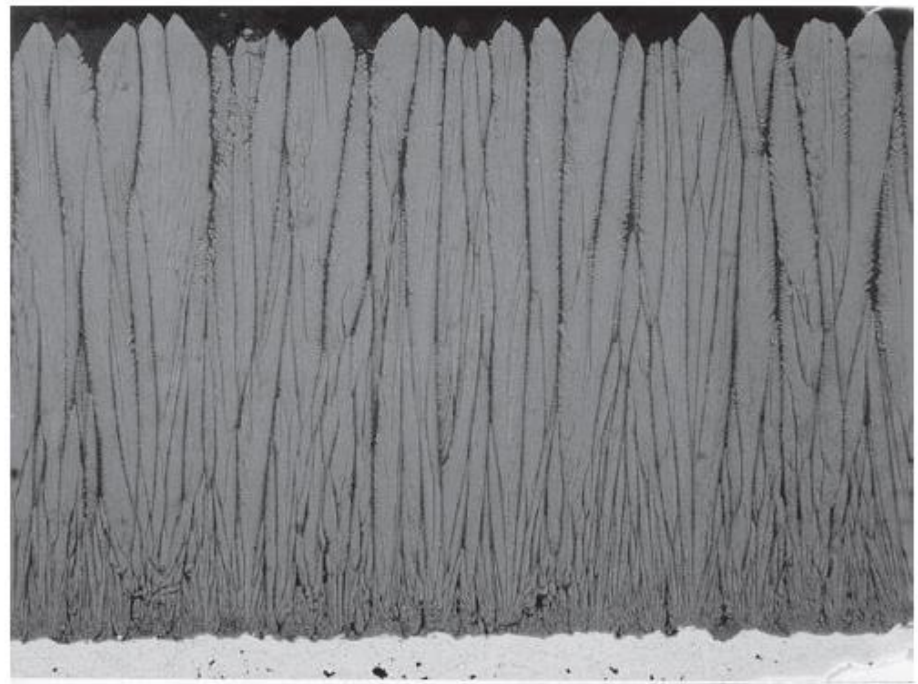


Thermal barrier coatings produced by GFS

Material: partly Y stabilized ZrO_2 (PYSZ)



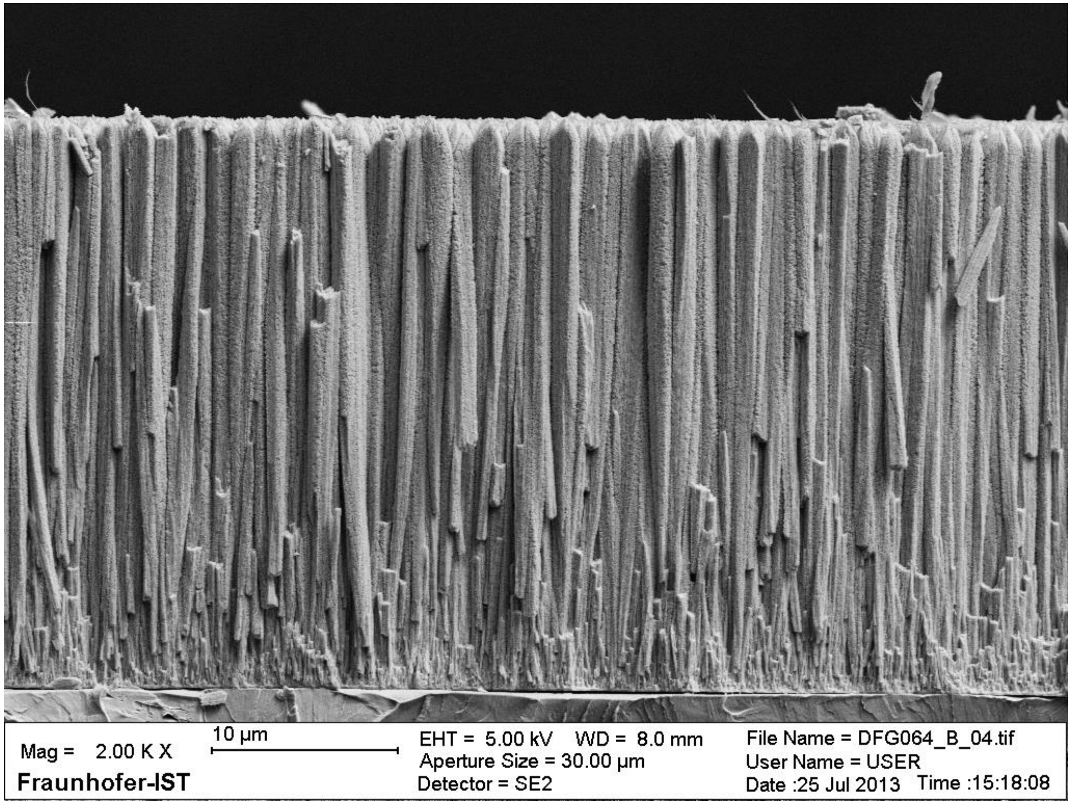
Deposition by Thermal Spraying → porous structure



Deposition by Electron Beam Evaporation (EBPVD) → columnar structure

Source: Nicholls et al., Surf. Coat. Technol 151 (2002), 383

Deposition of thermal barrier coatings by GFS



Outline

- Introduction
- HIPIMS – ready for industry?
- Sputter technology for optical coatings
- Hollow cathode based sputter processes
- What comes next?
- Summary

Main R+D efforts in magnetron sputtering during the past 35 years

- Improvement of target material utilization
- Stabilization of the reactive process in the transition regime
- Long term stable high rate deposition of dielectric films
- Improved film properties through HIPIMS
- Higher deposition rates

Magnetron sputtering through five decades

- The 1980s: The decade of **reactive DC sputtering**
- The 1990s: The decade of **pulsed sputtering** and **higher target utilization**
- The 2000s: The decade of **higher ionization**
- The 2010s: The deacade of **higher ionization** and **higher precision**

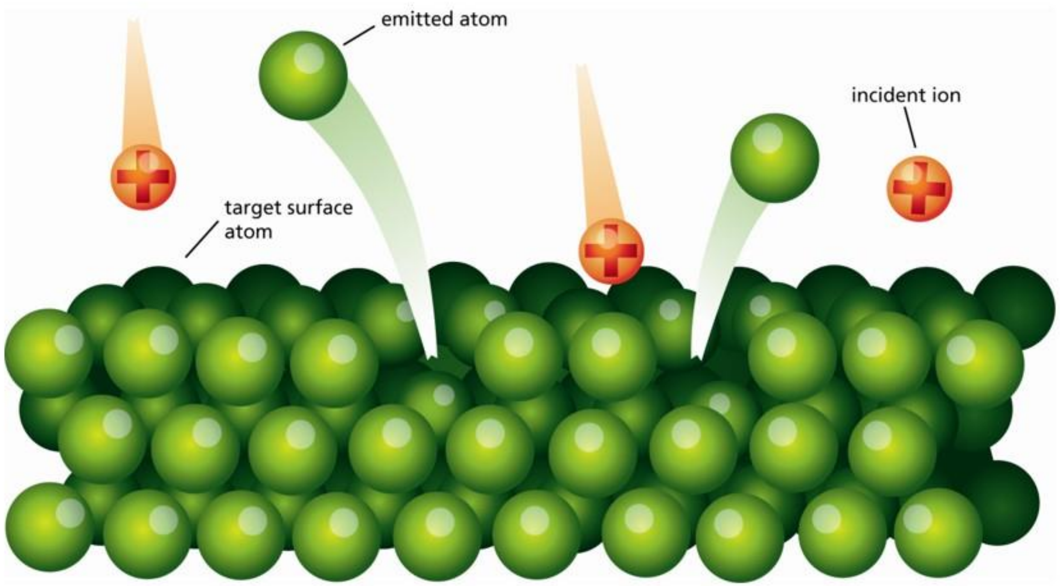
What comes next?

- The 2020s: The decade of **higher efficiency?**

Fraunhofer
IST

The sputter yield

$$\text{Sputter Yield } Y = \frac{\text{number of emitted target atoms}}{\text{number of incident ions}}$$

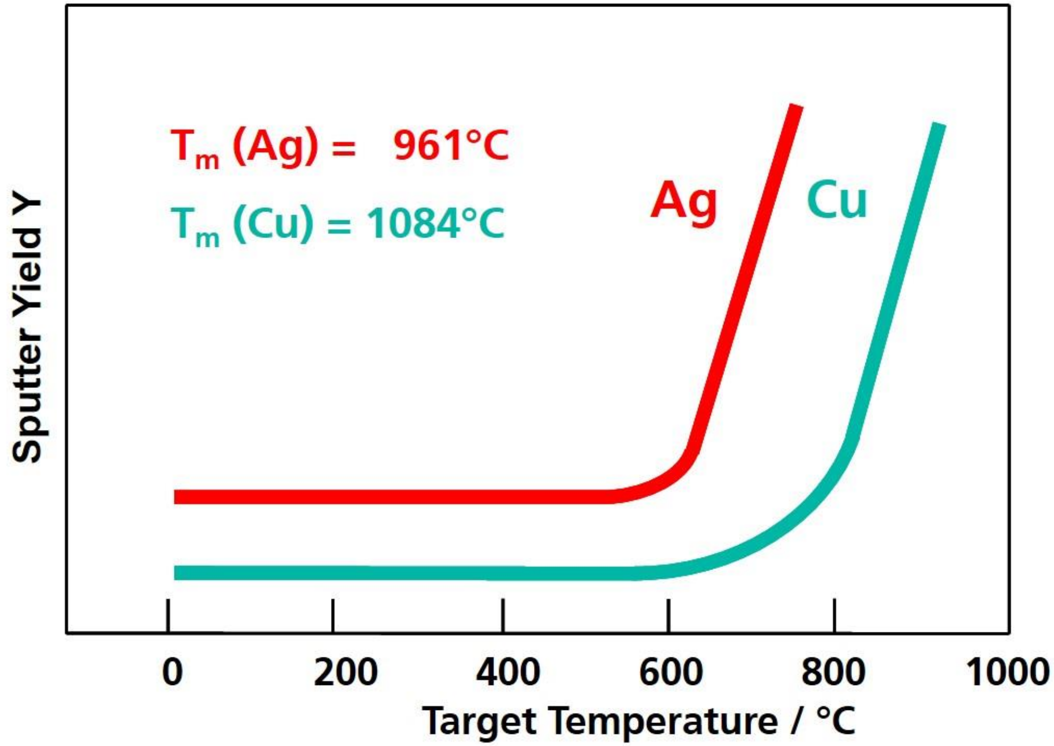


Yield depends on:

- E_0 ion energy
- M_1 ion mass
- M_2 mass of target atom
- U_0 surface binding energy of target atom
- Θ angle of ion incidence
- T target temperature

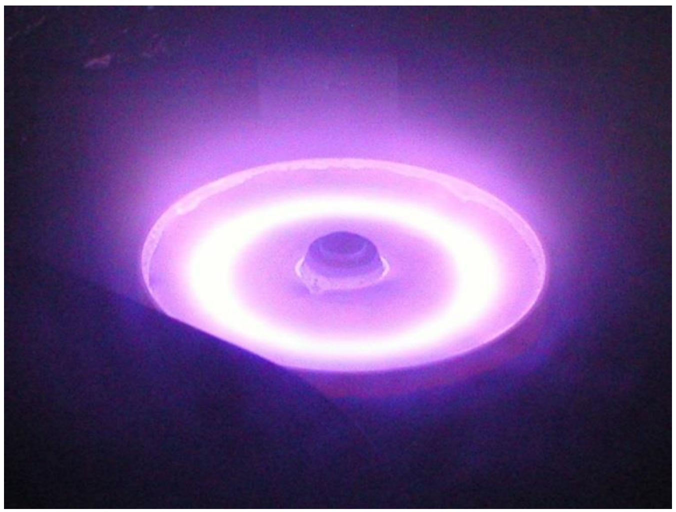
The temperature dependence of the sputter yield

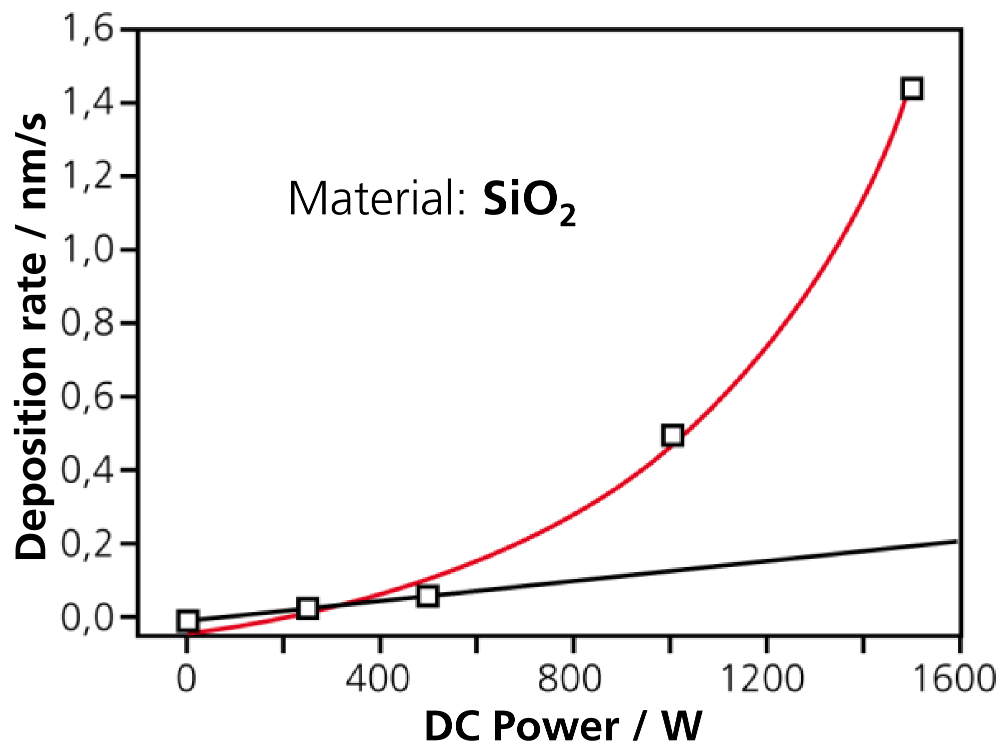
At $T \sim 0.8\ T_m$
(T_m = melting point)
Y increases substantially due to the formation of „thermal spikes“.



R. A. Haefer: *Oberflächen- und Dünnschichttechnologie (Teil 1: Beschichtungen von Oberflächen)*, Springer Verlag, 1987

Sputtering from hot targets (HTS)





Outline

- Introduction
- HIPIMS – ready for industry?
- Sputter technology for optical coatings
- Hollow cathode based sputter processes
- What comes next?
- Summary

Summary

The manufacturers of hard coatings count on HIPIMS, but there is still a lot of work to establish the technology for glass coating.

Magnetron sputtering has entered the world of precision optics. In the near future large area optical coatings should be available at reasonable cost.

Hollow cathode based sputter processes have found niche markets, in particular when very thick coatings are required.

With η ~ 2% the efficiency of the sputter process is still much lower than the efficiency of a solar cell.

THANK YOU FOR YOUR ATTENTION!