

Scaling PVD Techniques for Large Scale Coated Conductor Production

Dr. Werner Prusseit
Georg Sigl, Jörg Handke
THEVA Dünnschichttechnik GmbH

- Economic aspects of CC production
- Technical implications on PVD
- Yield and process control
- Design rules for PVD equipment



Why talking about PVD ?

- PVD consistently produces the best CCs ($I_C \times L$)
- PVD is used in every production route (even in MOD)

PVD will play the major role in CC production

THEVA

- is an engineering company
- is strong in process development (ISD, e-beam evaporation etc.)
- has centered on smart solutions for CCs

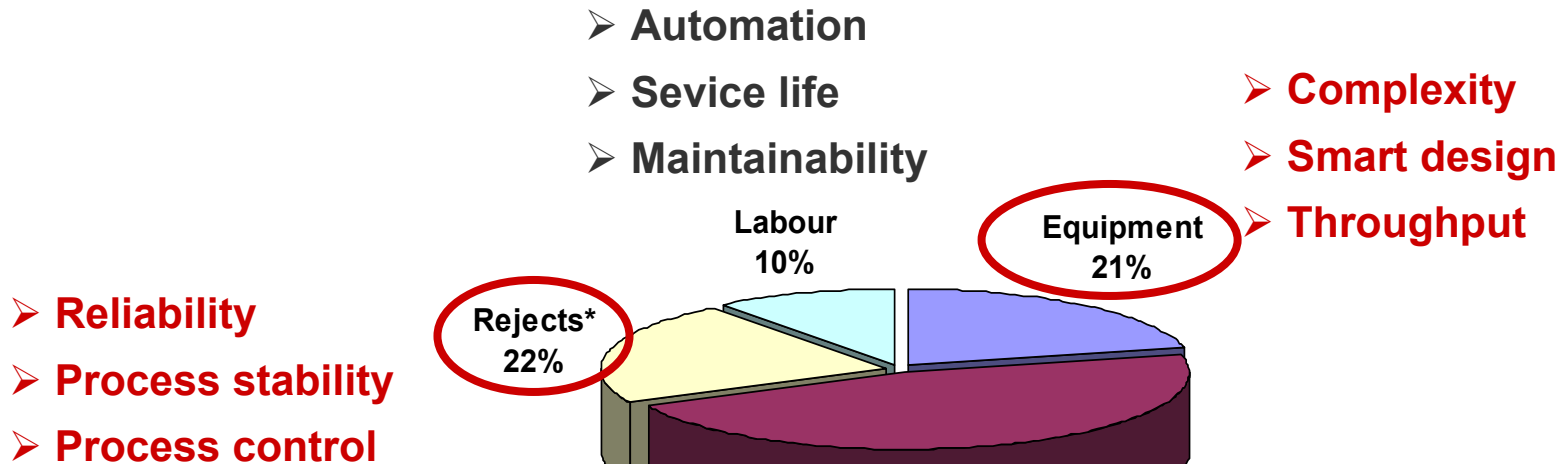
THEVA

creating the future



Technology follows economy

Key factors determining cost

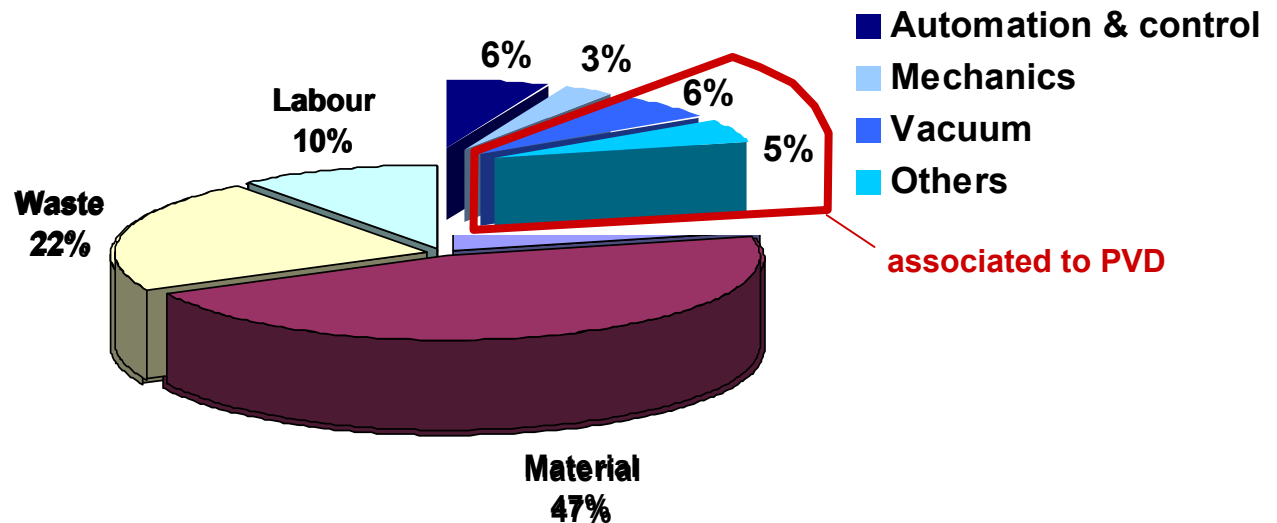


* 95 % yield in each of 9 process steps

- Architecture, film thickness
- material efficiency
- Recycling, storage, waste

Cost structure of CCs – cost of vacuum

What contributes to the equipment costs ?



„Vacuum“ accounts for about 6% of the total cost

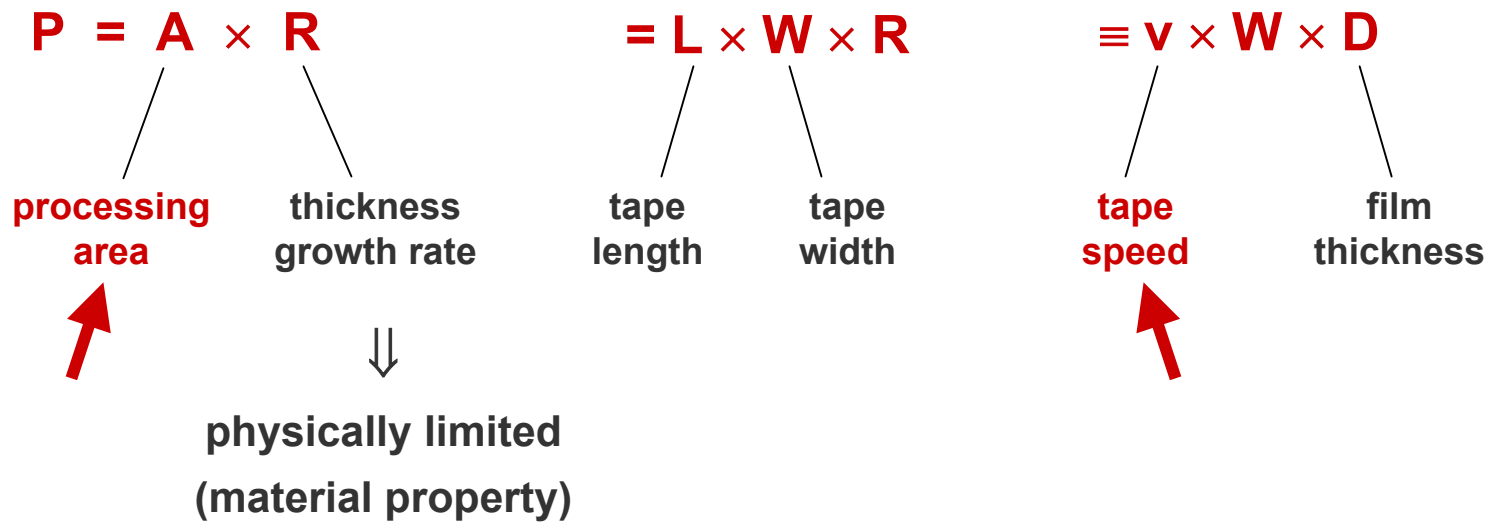
Throughput is the key

Equipment cost share = capital investment / throughput



Key to lowering cost

Throughput \equiv volume production rate



How will future PVD equipment look like ?



Tape winder – extending deposition area

... is a must for

processing narrow tape

covering large deposition area

improving uniformity

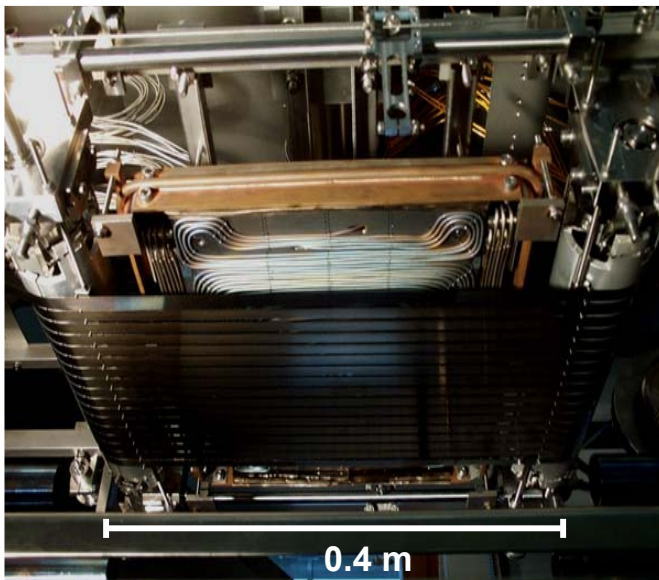



Foto: THEVA 1999

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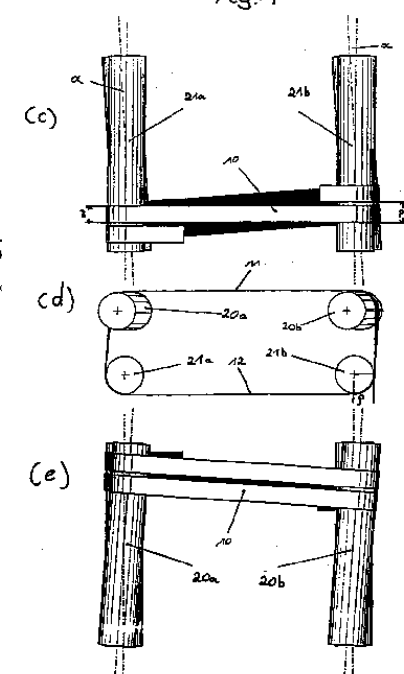
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⑬ Anmelder:
Theva Dünnschichttechnik GmbH, 85386 Eching, DE

⑭ Vertreter:
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Fig. 1

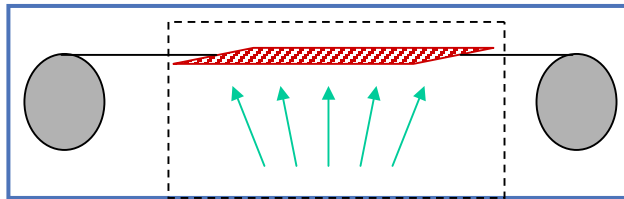


Die folgenden Angaben sind dem vom Anmeldeamt gem. § 44 PatG ist gestellt

⑮ **Vorrichtung und Verfahren zum Verarbeiten eines Bandes**
Abmessungen

⑯ Die vorliegende Erfindung betrifft eine Vorrichtung und ein Verfahren zum Verarbeiten eines Bandes (10) in einem Verarbeitungsbereich mit begrenzten Abmessungen, und insbesondere die Herstellung eines Bandes (10), das mit einem Hochtemperatur-Supraleiter beschichtet ist. Entsprachen sind zu mindest zwei Transportelemente (20, 21) vorzusehen. Das Band (10) wird in einer Vielzahl von Windungen um die zumindest zwei Transportelemente (20, 21) transportiert, so daß das Band (10) in dem Verarbeitungsbereich verarbeitet werden kann. Eine unabsichtliche seitliche Bewegung des Bandes (10), senkrecht zur Transportrichtung der Transportelemente (20a, 20b) wird durch die Schrägstellen der Transportelemente (20, 21) um einen Winkel (α) oder durch das Steuern der Geschwindigkeit der Transportelemente, so daß das Band in gleitendem Kontakt mit den Transportelementen ist oder durch das Aufteilen der Transportelemente in Segmente, die senkrecht zur Transportrichtung beweglich sind, verhindert.

Capacity scaling of PVD equipment

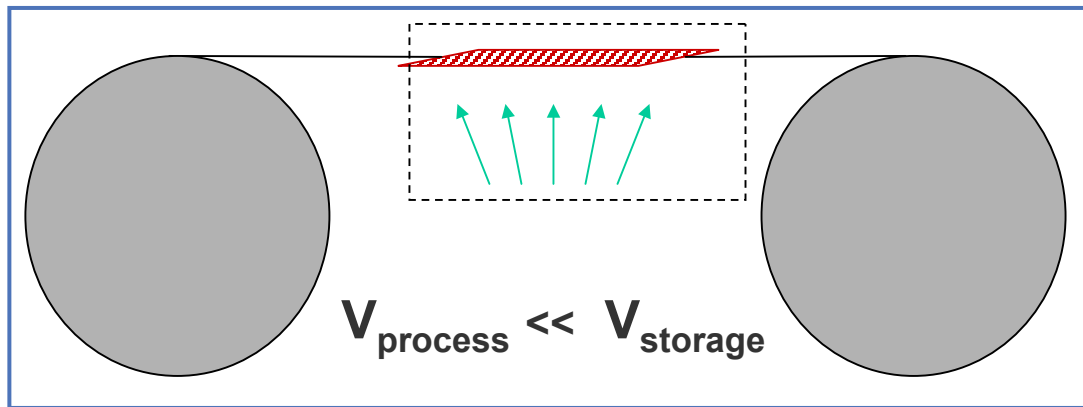


Equivalent in throughput
(same area A)

but

different capacity

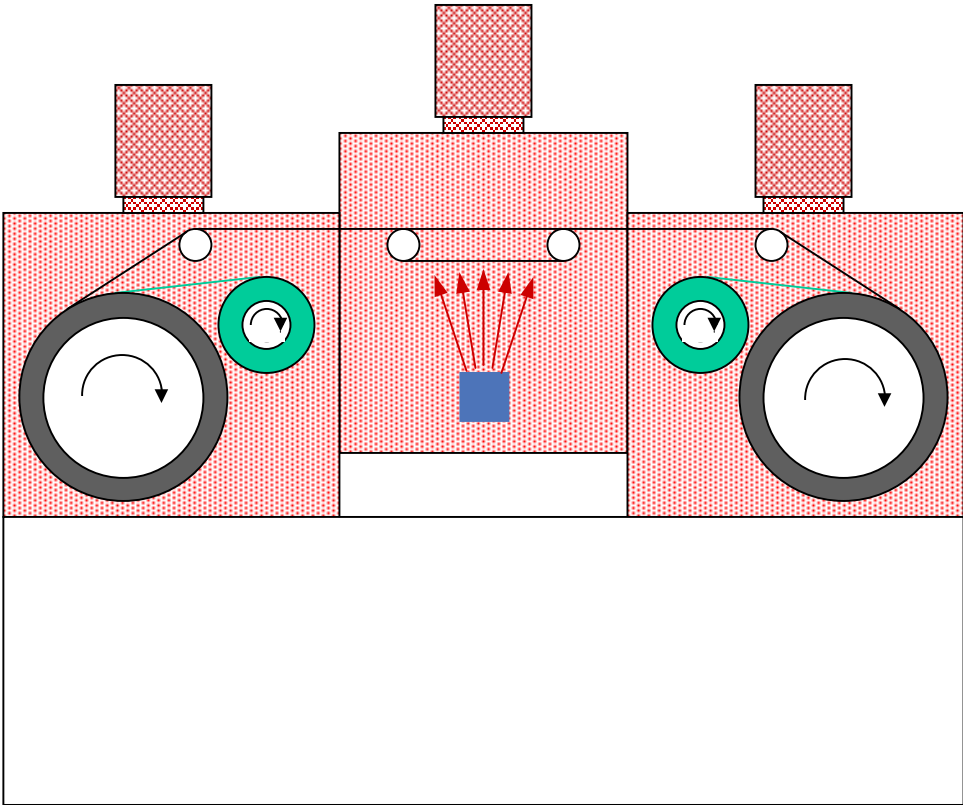
⇒ suboptimal design



Separate storage from vacuum processing !



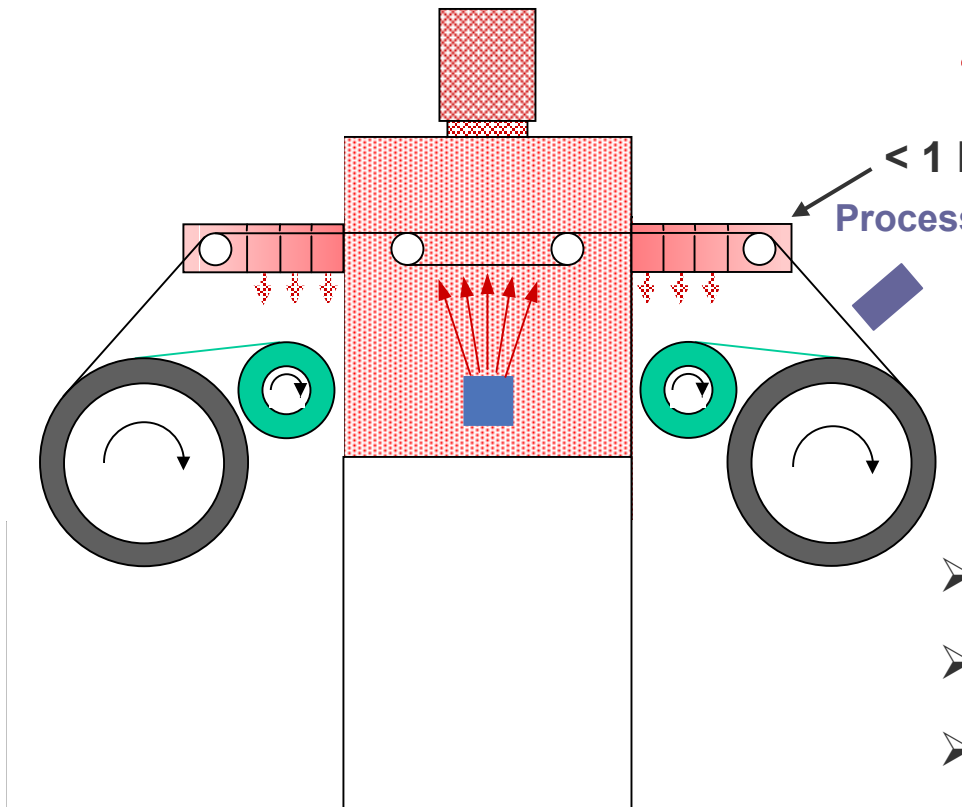
Modular equipment design



PVD tape processing
Standard design

Modular equipment design

Tape geometry ideal for
atm to atm vacuum processing



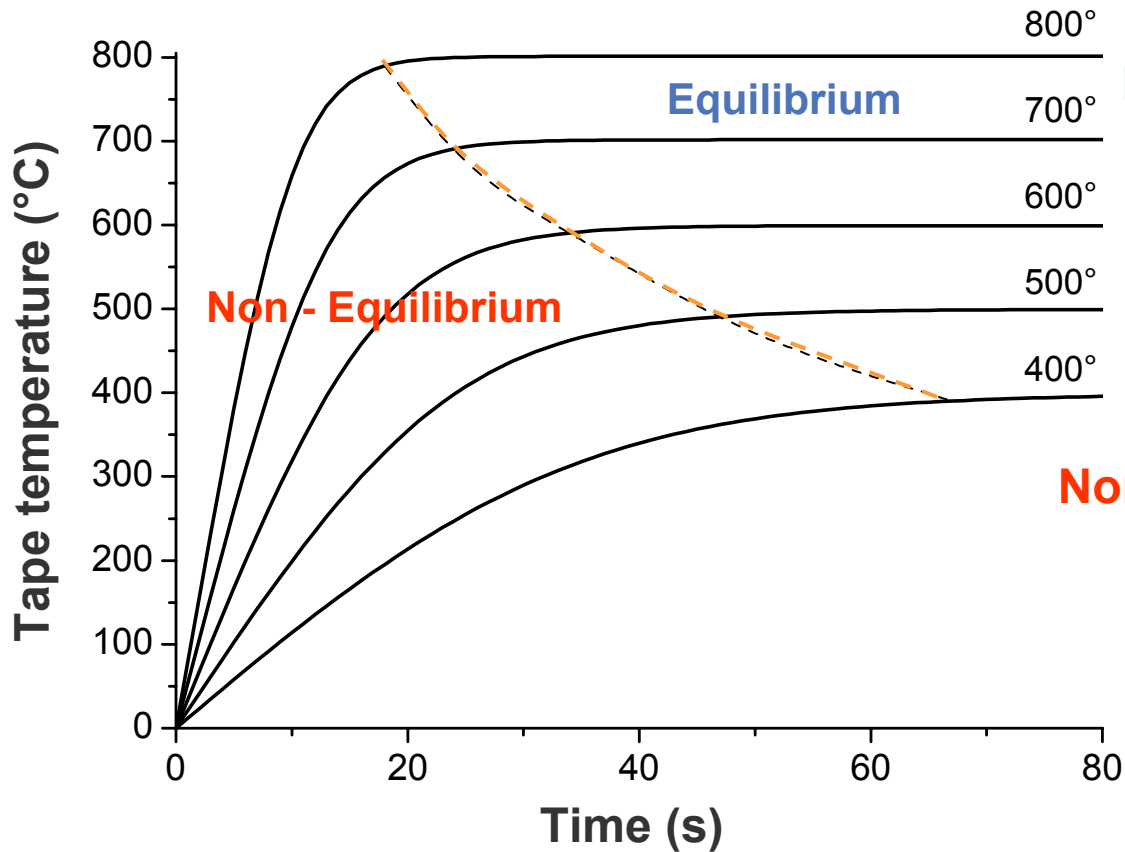
< 1 l/s (W = 12mm)
Process control

Benefits

- permanent accessibility
- high flexibility
- easy service and maintainability
- cheaper non-vacuum components
- more control options

High speed tape heating

Heating curves of steel tape ($10 \times 0.1 \text{ mm}^2$, $\alpha = 0.2$)



Equilibrium heating slow

20 s \equiv 56 cm

@ 100m/h

Non-equilibrium heating risky

- overheating
- thermal inertia
- depends on IR-reflectivity
- depends on tape speed

$$\Delta T_{\text{substrate}} = T_{\text{substrate}} (1 - \Delta v/v)$$



Imagine a beam of energy ...

Goals: rapid tape pre-heating
compact tape winders

E-beam heating

- independent of IR-properties
- high power density $> 50 \text{ W/cm}^2$
- spot size 1 – 2 cm^2
- no inertia & easy to control
- extreme temperatures accessible
- operating pressure $< 10^{-3} \text{ mbar}^*$

*differential pumping available

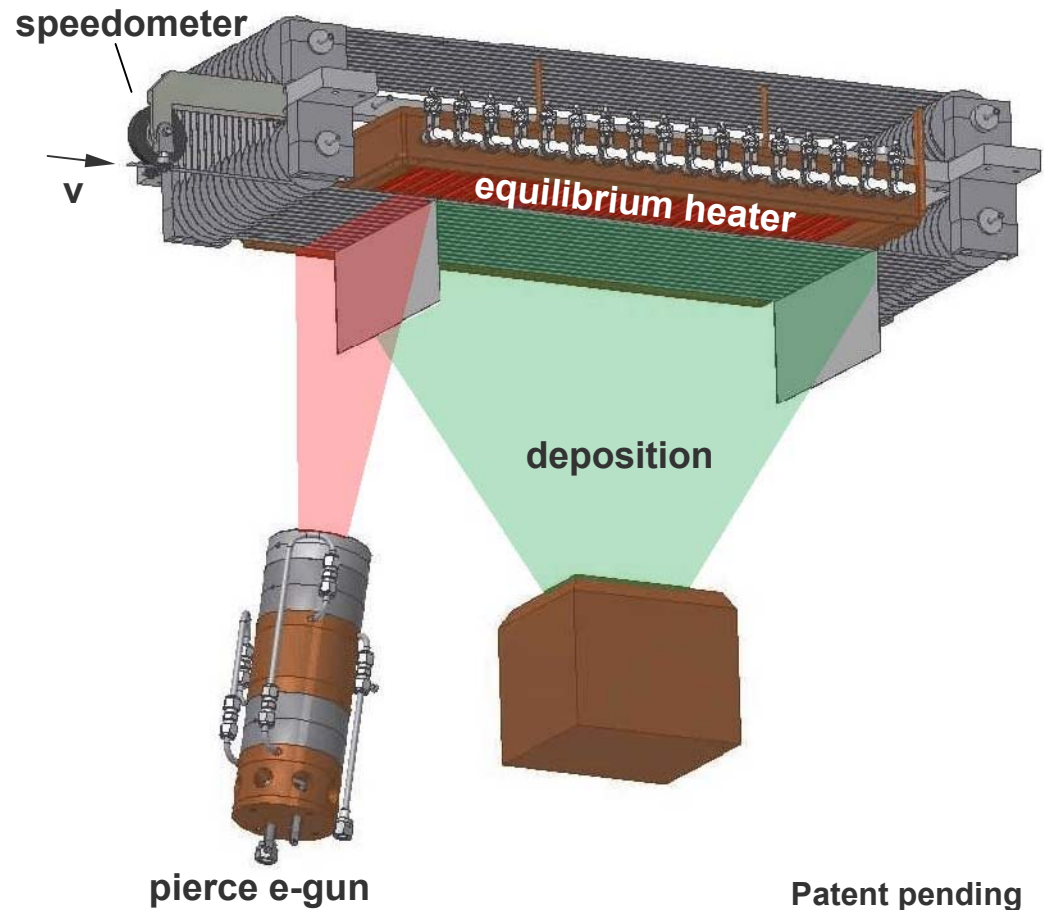


Pierce e- gun

... and what you can do with it

Tape pre-heating

- high power density
short heating zone
 $\frac{\partial T}{\partial t} > 700 \text{ K/s}$
- fast duty cycle
no risk of damage
- high dynamics
feedback $P = P(v)$



Patent pending

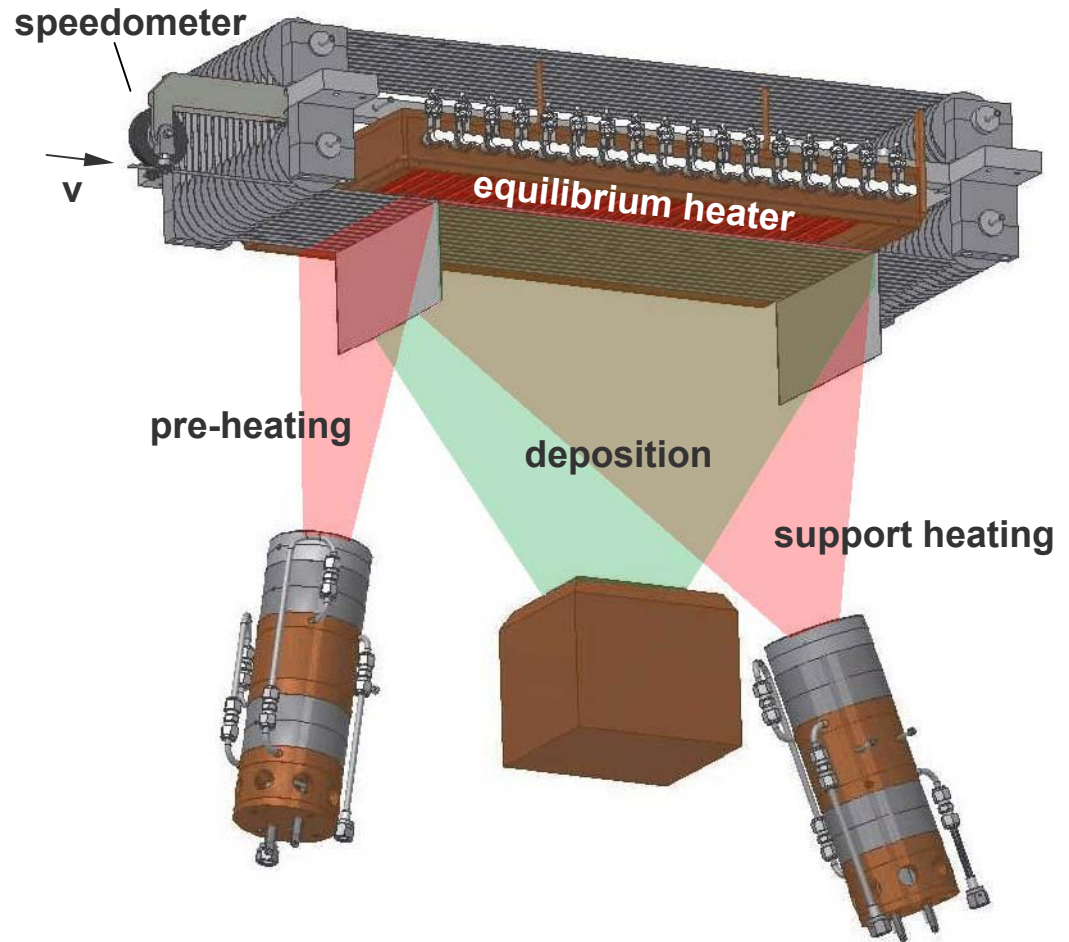
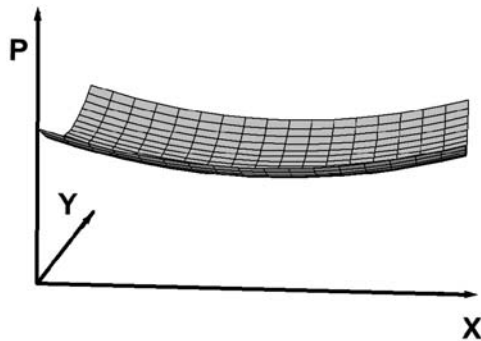
Localized e-beam heating

Support heating

spatial power adjustment
by controlling dwell time

Compensating for

- edge effects
- change of IR - reflectivity

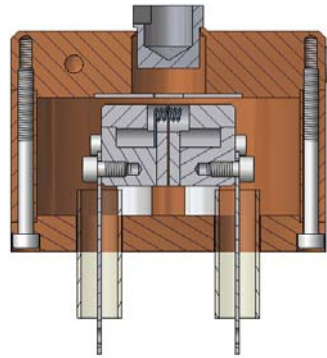


Compact, continuous metal deposition

E-beam heated crucible with wire feeding

small source (1 cm³)

huge capacity (Ag: 10 kg/d)

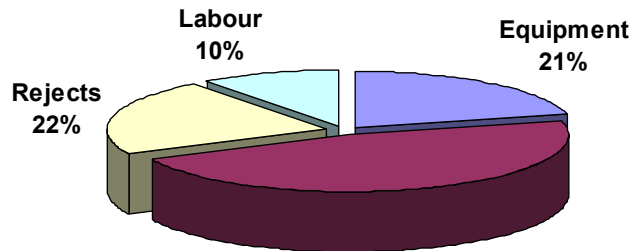


- high deposition rate > 5nm/s
- smooth films – no splashing
- minimum heat radiation
- long filament life

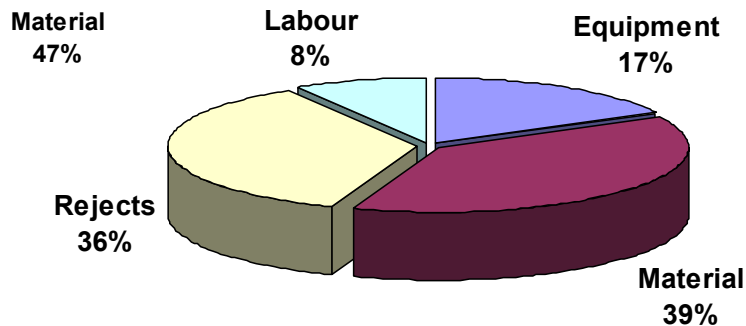


Cost structure of CCs – importance of yield

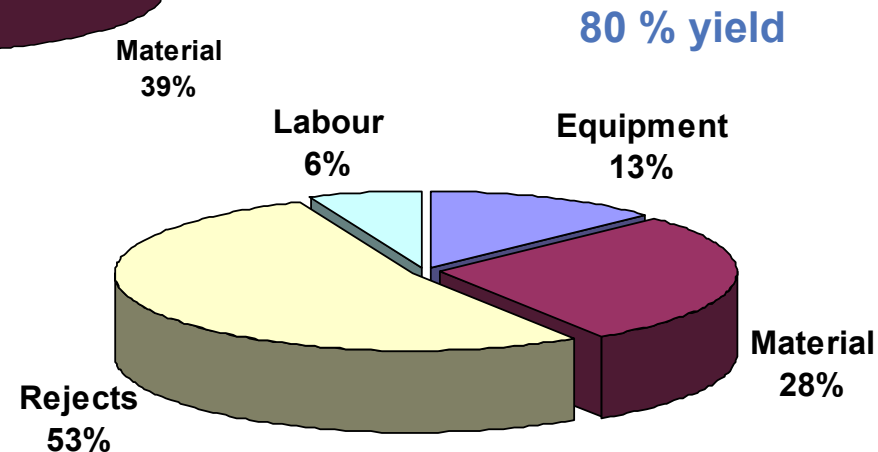
How does yield in every process step⁽⁹⁾ influence cost ?



95 % yield



90 % yield



80 % yield

Yield is a real issue !

Reduction of rejects easily
compensates for higher investment

In-line process control

Monitor whatever is accessible

Vacuum:

pressure and gas flow

Temperature:

pyrometer or IR-imaging

Tape transport:

speed, tension

Deposition parameters:

rate, composition, source operation

Film growth:

crystallinity, thickness, surface, phys. properties

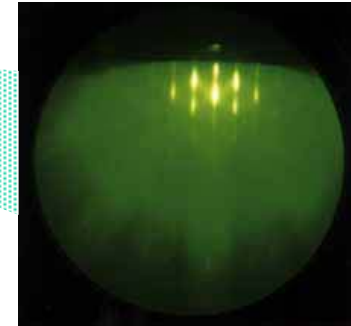
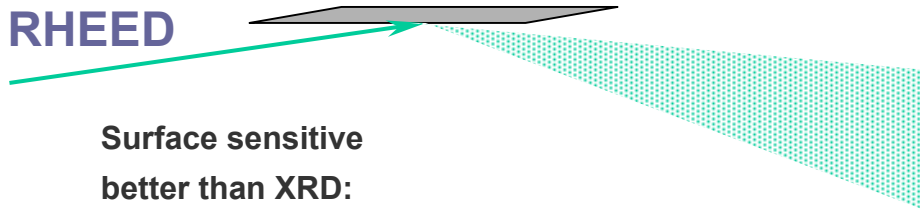
Process accessibility is a priceless advantage of PVD



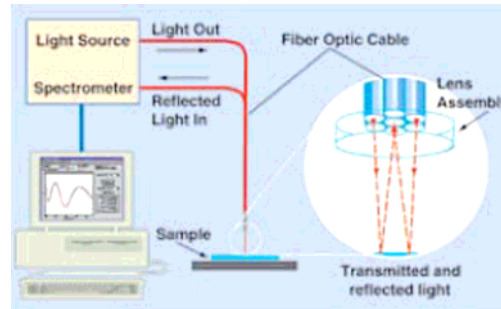
Film crystallinity and quality

➤ Crystallinity: RHEED

Surface sensitive
better than XRD:
much faster
more information



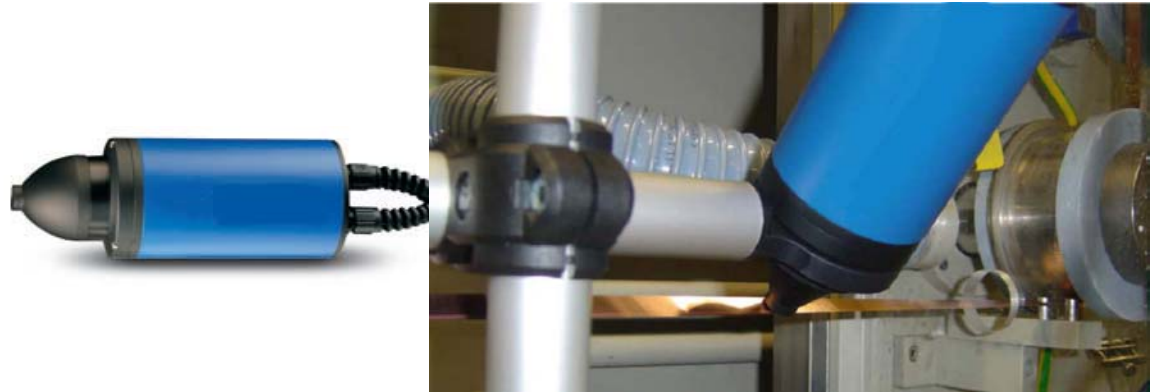
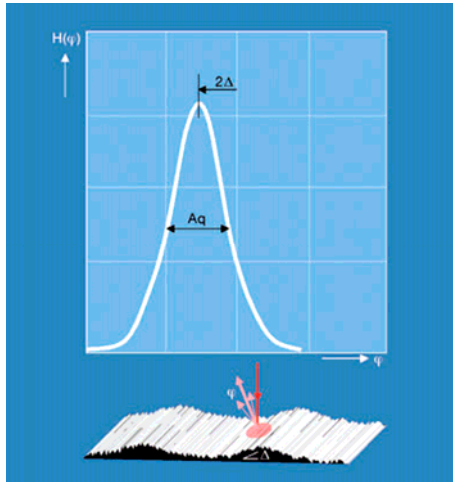
➤ Film thickness: spectral reflection analysis



Spot size: 20 μ m – 1.5mm
Thickness range: 150nm – 50 μ m
Sampling time: < 1sec
Accuracy: 0.4%

Surface roughness analysis

➤ Surface light scattering



Continuous tape surface analysis

Many malfunctions lead to enhanced surface roughness

Light scattering is extremely sensitive to roughness

Spot size: 0.9 mm – scanning possible

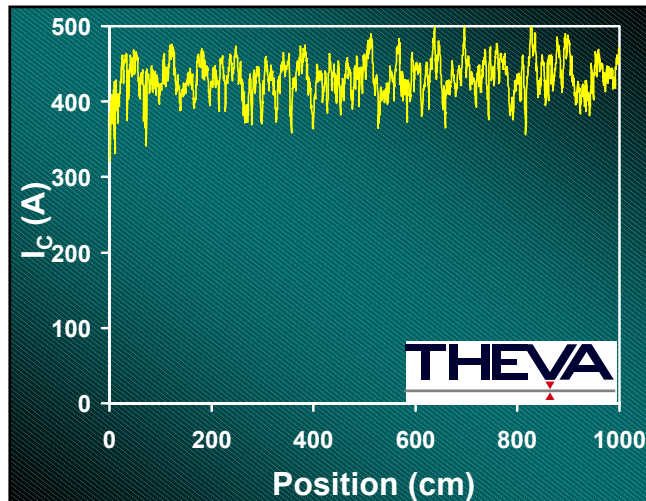
Sampling time: 0.5 ms



Critical current assessment

➤ TapeStar: rapid, high resolution I_C -measurement

Scanning speed: 50 – 200 m/h
Resolution: 0.5 mm
Capacity: > 1000 m



Golden design rules of PVD processing

- **Maximize deposition area & rate**
- **Design modular**
 - put only in vacuum what needs vacuum
 - separate functions
(deposition, process control, drive, storage)
- **Don't save on reliability and process control**

... or simply ask THEVA 

