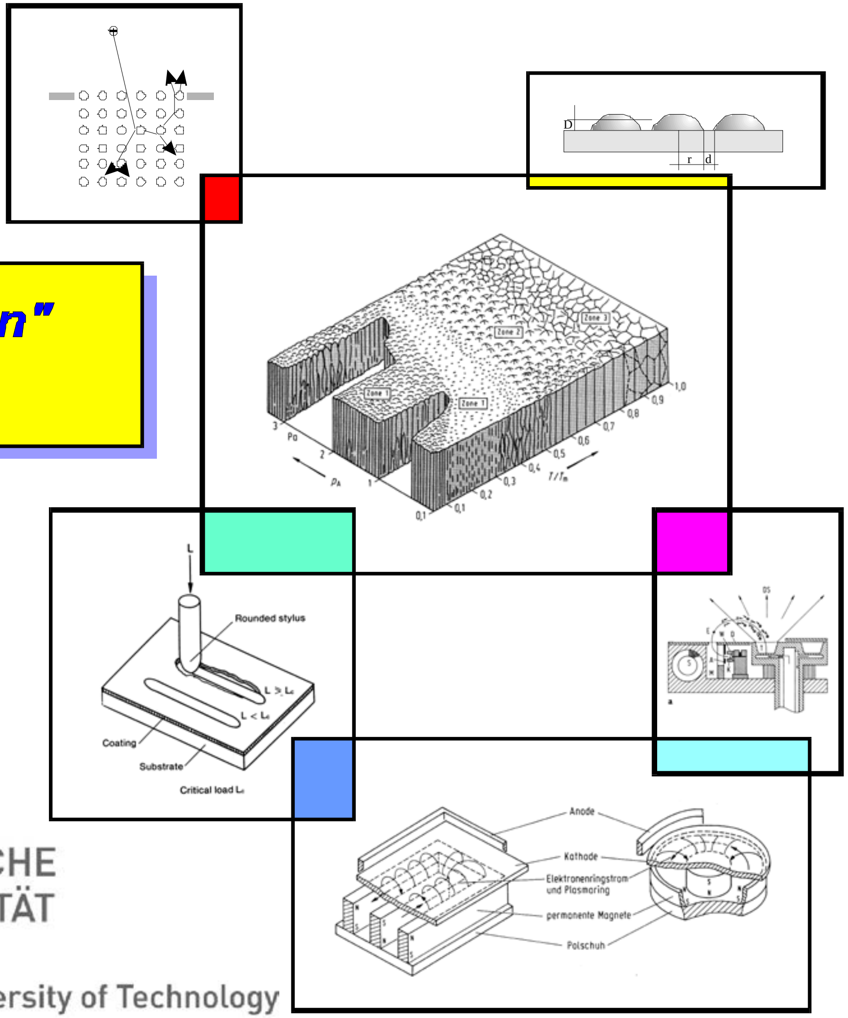
Introduction

"Physik Dünner Schichten"

Dr. C. Eisenmenger-Sittner

LVA Nr.: 138.032



TECHNISCHE UNIVERSITÄT WIEN
Vienna University of Technology

The Lecture: Details

LVA Nr. 138 032,
"PHYSIK DÜNNER SCHICHTEN"
Catalogs: Master TPH, Catalogs: C, D, Master EMT, Catalogs : B
Master Materials Science, Module Struktur- und Funktionswerkstoffe
Christoph Eisenmenger-Sittner

Location: **Seminarraum DB gelb 07, 7.OG, Yellow Region**
Time: **11:00-13:00**

CONTENT

1. ***Introduction: History, Termini***
2. ***Physical Fundamentals of Vacuum based Depisition Techniques***
3. ***Physics of Film Formation***
4. ***Thin Film Physics***
5. ***Fundamentals of Physical Analysis Techniques***

Cross-Links I

LVA Nr. 138 030,
"TECHNOLOGIE DÜNNER SCHICHTEN"

Catalogs: Ba TPH Ma TPH (D), Ma MW

Christoph Eisenmenger-Sittner

Location: **Seminarraum DB gelb 07, 7.OG, Yellow Region**
Time: **11:00-13:00**

CONTENT

1. ***Introduction: History, Termini***
2. ***Deposition Methods: PVD, CVD, Electrochemistry, …***
3. ***Film Growth: Empirical Models***
4. ***Thin Film Properties and Characterization: Mechanical, Electrical and Optical Properties and their Measurement***

Cross-Links II

LVA Nr. 138 035,
"PHYSIK DÜNNER SCHICHTEN - UE"

Kataloge: Ma TPH (C, D), Ma EMT (B)

Christoph Eisenmenger-Sittner

Location: Institute of Solid State Physics, 7.OG, Yellow Region
Time: To be announced
Duration: 2.5 days

CONTENTS

1. ***Practical Fundamentals of Vacuum based Processes***
2. ***Autonomous Work with Deposition Plants***
3. ***Characterization of Thin Film Properties: Thickness, Morphology, Optical Properties***

Thin Films on the Web

https://static.ifp.tuwien.ac.at/homepages/Personen/duenne_schichten/

search terms: thin film group vienna
→ 1st Hit

WHAT YOU FIND:

- ***Lecture Notes***
- ***Information on Current Projects***
- ***General News***

Ad-hoc information concerning the lecture and the practical short course (shifts in lecture dates, final time for the short course) will be communicated via TISS to the persons subscribed to the lecture.

Historical I

~1650: Observation and interpretation of interference patterns (e. g. oil on water) by R.Boyle, R.Hooke, I.Newton.

~1850: Development of first deposition techniques (M.Faraday; W.Grove; T.A.Edison) and of methods of thickness determination (Arago, Fizeau; Wernicke; Wiener) Commercial introduction of electrochemistry (Galvanics) for gold plating of uniform-accessoires.

~1940: Industrial manufacturing of coatings for optical, electronical and mechanical applications (mostly military).

~1965: Thin film technology develops to an integral part of the mass manufacturing processes in semiconductor and optical industry.

~1990: Thin films of High Tc-Superconductors.

~1995: Thin film processing allows for the tailoring of microstructures of atomic and mesoscopic dimensions („Quantum-Dots“ by PVD, „Cu-technology“ by electrochemistry applied to integrated circuits).

Historical II

~2000: Manufacturing of nanocrystalline materials with defined composition and structure for applications as protective coatings and in tribology. Deposition of highly ordered two and three dimensional objects with sizes in the nm range.

~2004: Upscaling of complex reactive coating processes for industrial applications (coatings on glass, thermal management). Combinatorial investigation of ternery and quartenery material systems.

~2006: Investigation of organic coatings leads to the emergence of organic electronics (OLED, printable circuits).

~2009: Controlled growth of nanotubes, nanowires and nanoscaled heterostructures. Deposition of large scaled graphene layers.

Definition of a Thin Film

- ***One linear dimension is significantly smaller than the other two***
- ***Properties are significantly different from thoes of the bulk material***
- ***Properties can be influenced by film thickness and microstructure***
- ***Different film thicknesses can define different fields of application for the same material***

Example: ***Indium oxide, In_2O_3:***
d = 300 nm: ***Infrared reflector***
d = 2 nm: ***Josephson - junction***

Applications of Thin Films, I

Engineering/Processing

... Tribological Applications: Protective coatings to reduce wear, corrosion and erosion, low lriction coatings
... Hard coatings for cutting tools
... Surface passivation
... Protection afainst high temperature corrosion
... Self-supporting coatings of refractory metals for rocket nozzles, crucibles, pipes
... Decorative coatings
... Catalysing coatings

Optics

... Antireflex coatings ("Multicoated Optics")
... Highly reflecting coatings (laser mirrors)
... Interference filters
... Beam splitter and thin film polarizers
... Integrated optics

Optoelectronics

... Photodetectors
... Image transmission
... Optical memories
... LCD/TFT

Applications of Thin Films, II

Electronics
... Passive thin film elements (Resistors, Condensers, Interconnects)
... Active thin film elements (Transistors, Diodes)
... Integrierted Circuits (VLSI, Very Large Scale Integrated Circuit)
... CCD (Charge Coupled Device)

Cryotechnics
... Superconducting thin films, switches, memories
... SQUIDS (Superconducting Quantum Interference Devices)

New Materials
... Superhard carbon ("Diamond")
... Amorphous silicon
... Metastable phases: Metallic glasses
... Ultrafine powders (diameter < 10nm)
... Spheroidization of high melting point materials (diameter 1-500µm)
... High purity smiconductors (GaAs)

(Altrnative) Energies
... Solar collectors and solar cells
... Thermal management of erchitectural glasses and foils
... Thermal insulation (metal coated foils)

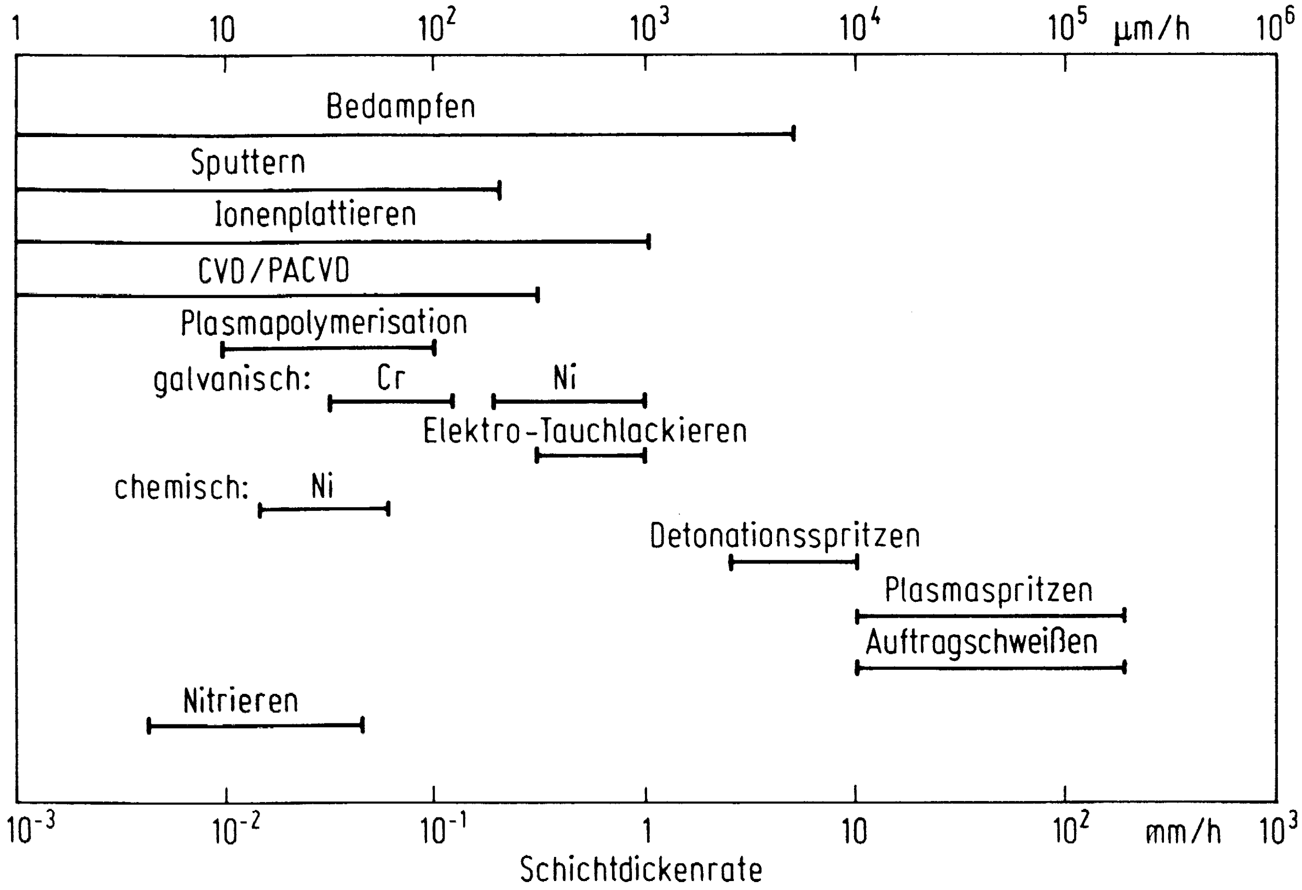
Applications of Thin Films, III

Magnetic Applicaions
... Audio, video and computer memories
... Magnetic read/write heads

Sensorics
... Data acquisition in argessive environments and media
... Telemetry
... Biological Sensorics

Biomedicine
... Biocompatible implant coatings
... Neurological sensors
... Claddings for depot pharmaca

Possible Deposition Rates



Physical Deposition Methods

Important Characteristics:

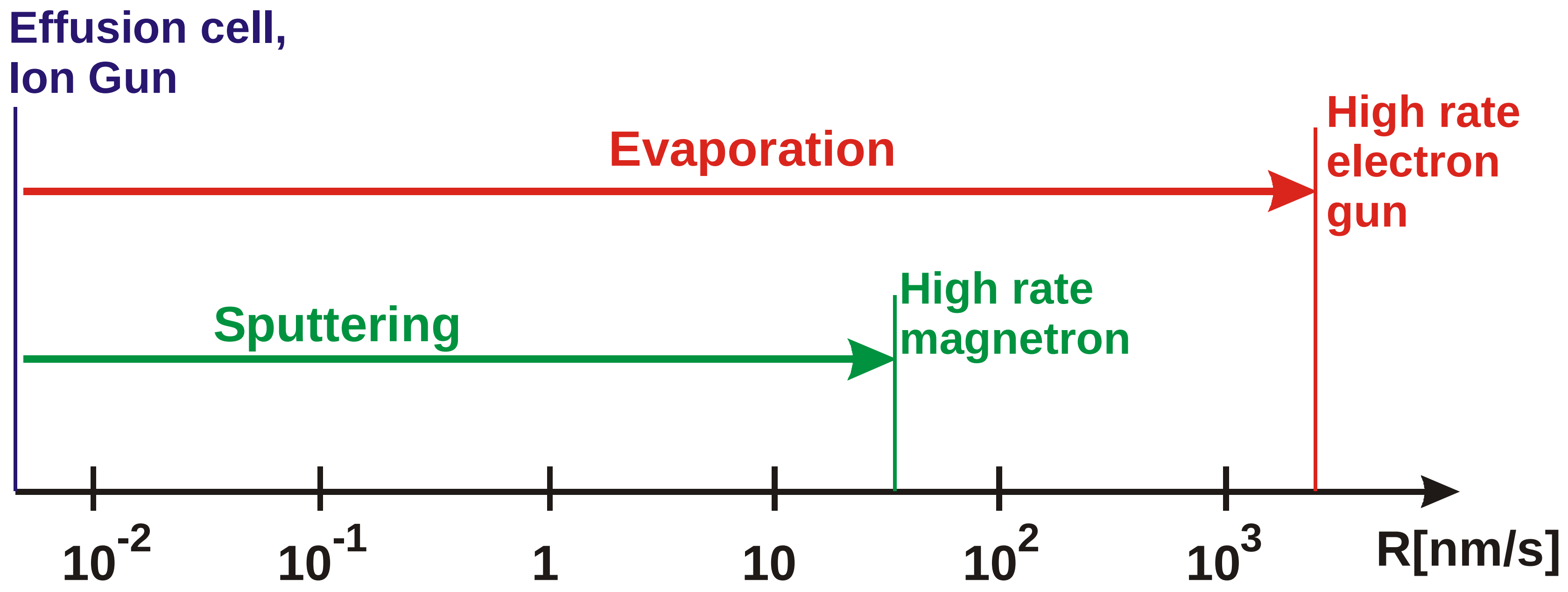
- **Defined separation of source, transport and deposition.**
- **Film formation atom by atom.**
- **Process takes place under vacuum conditions.**

Physical Deposition Processes – Overview

PVD (Physical Vapour Deposition)

- Evaporation
- Sputtering
  - Diode-system
  - Triode-system
  - Magnetron-system ("balanced/unbalanced")
  - Ion beam-system
- Ionplating
  - DC-glow-discharge
  - RF-glow-discharge
  - Magnetron- discharge
  - Arc-discharge
  - Ion-Cluster-beam
- Reactive versions of the above processes

Achievable Deposition Rates - PVD



Definitions PVD

- Substrate: Object, on which the film is deposited. The substrate can be plane or complexly shaped (glass slide or cog wheel). It may be single crystalline (Si-Wafer), poly crystalline (metal) oder amorphous (glass) sein.

- Monolayer: a densly packed atom- or molecular layer on the substrate. For an atomic diameter of approx. 0.3 nm this corresponds to 10^{15} atoms/cm^2 in a simple quadratic arrangement. For molecules other diameters and geometric arrangements have to be chosen.

Fundamental Thermodynamcs of PVD I

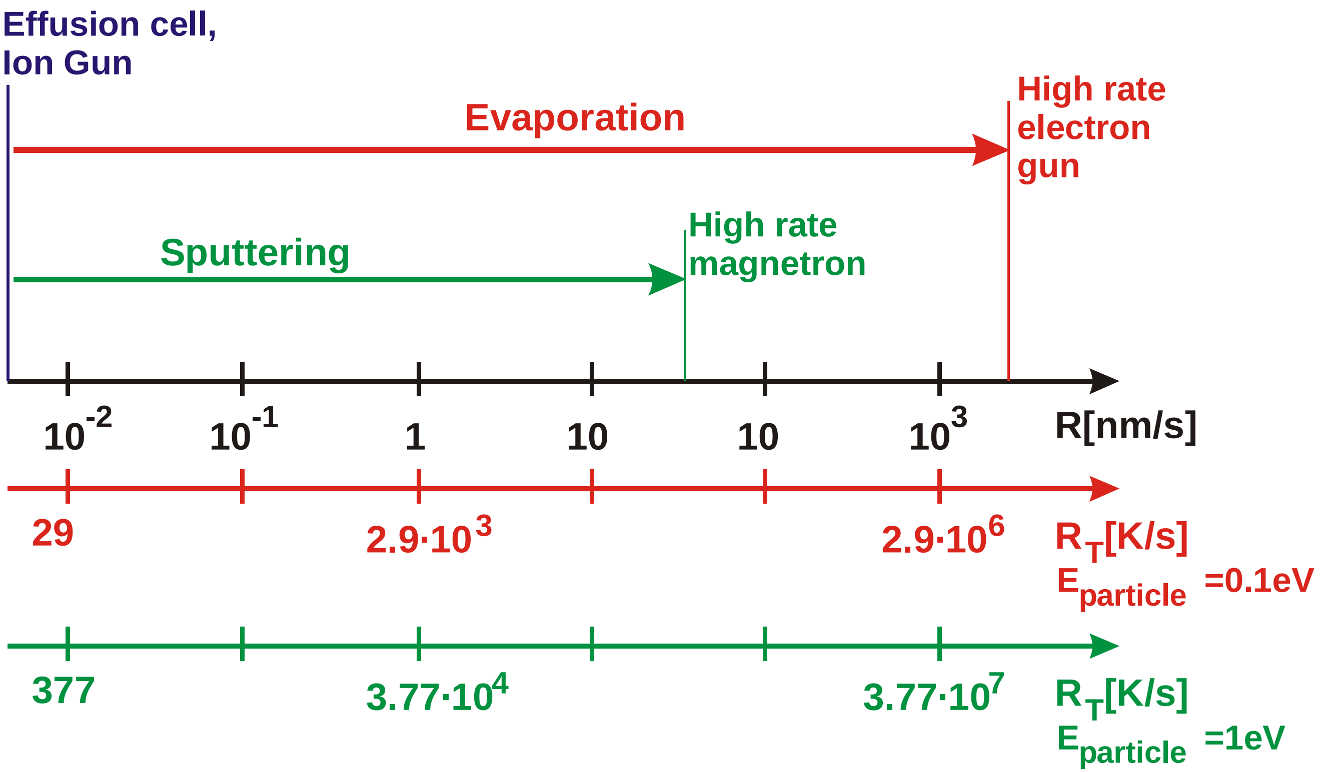
- **Assumption 1:** **Until the formation of a full monolayer an atom has time to reach a thermodynamically favorable position.**
- **Assumption 2:** **Particles impinging on the substrate have an energy E of approx. 1 eV. This corresponst to a temprerature T of approx.**

$$\boxed{\mathrm{T} \cong \frac{\mathrm{E}}{\mathrm{k_B}} = \frac{1.602 \cdot 10^{-19}[\mathrm{J}]}{1.38 \cdot 10^{-23}[\mathrm{J/K}]} = 11600\ \mathrm{K}}$$

Fundamental Thermodynamcs of PVD II

Cooling rate: **the previous assumptions allow for the assessment of a cooling rate R_T:**

$$\boxed{R_T[K/s] = \frac{\left(E_{particle}[J] - E_{substrate}[J]\right) \cdot R[nm/s]}{k_B[J/K] \cdot 0.3[nm]}}$$



Effusion cell,
Ion Gun

Evaporation

High rate
electron
gun

Sputtering

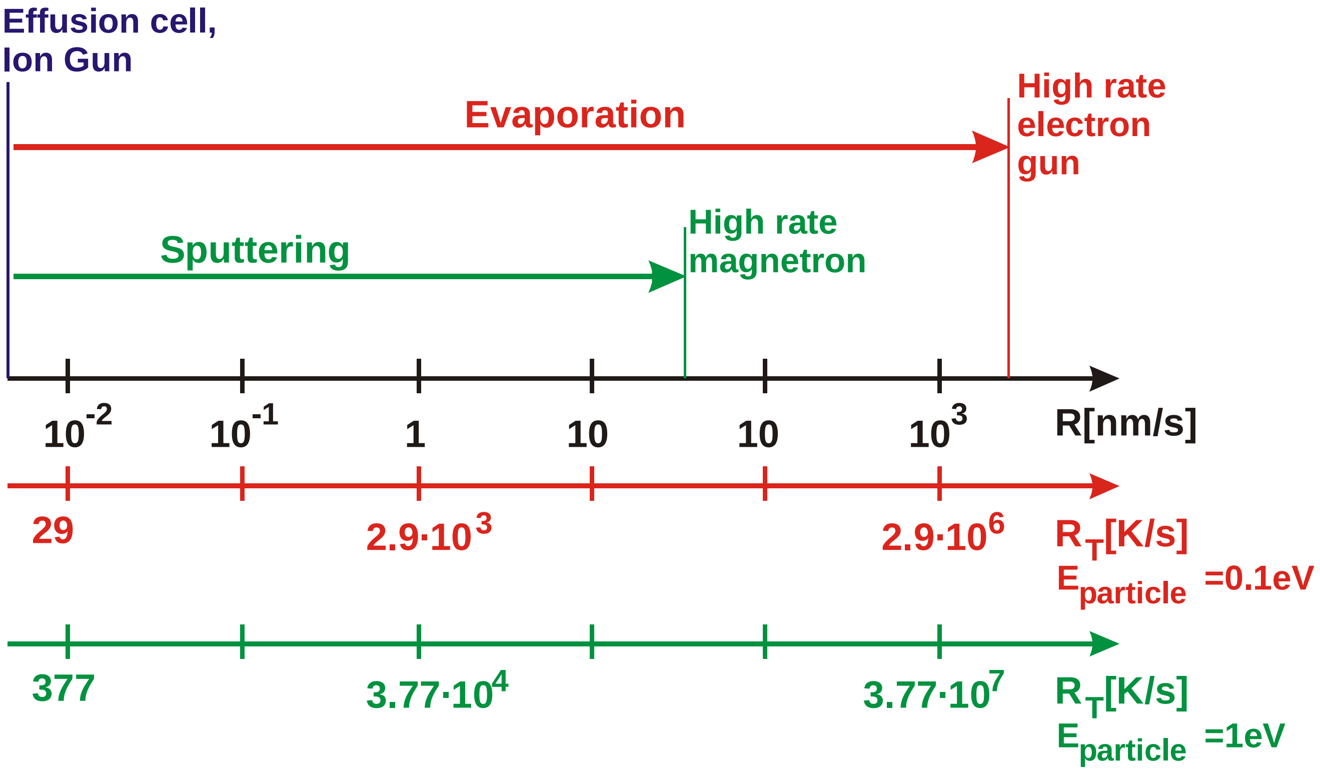
High rate
magnetron

10^{-2} 10^{-1} 1 10 10 10^{3} R[nm/s]

29 $2.9 \cdot 10^{3}$ $2.9 \cdot 10^{6}$ R_T[K/s] $E_{particle}$ =0.1eV

377 $3.77 \cdot 10^{4}$ $3.77 \cdot 10^{7}$ R_T[K/s] $E_{particle}$ =1eV

Fundamental Thermodynamcs of PVD III



These extremely high achievable cooling rates show, that PVD processes (apart from being a direct transition from vapor → solid state) often can be considered as non equilibrium processes.

Cooling Rates in Comparison

Amorphous metals may be obtained at: 10^4 K/s

Lead casting: 600K → 300K: 10^3 - 10^4 K/s

Melt Spinning: 10^6 K/s

Splat Cooling: 10^8 K/s

PVD: 10^1 - 10^7 K/s

Using PVD not only very high cooling rates can be achieved, but the choice of the deposition rete R allows for a very broad range of cooling rates.