Thin Films Technology

Lecture 3:
PVD princples

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Contents

- PVD vs CVD briefly
- Factors affecting thin film quality
- Relation between those factors
- Thin film growth process
- Physical Vapour Deposition (PVD)

Thin film deposition

Covered by Prof. Franssila

PVD

- Solid target
- Line of sight deposition
- Physical
- Low substrate temperature

PVD and CVD (overlap)

- PECVD
- Reactive PVD
- CVD by sublima-tion

CVD

- Liquid or gas precursor
- Global deposition
- Chemical
- High substrate temperature

Source materials

PVD Source

CVD Source

http://sunnygreater.com/products/sputtering_targets

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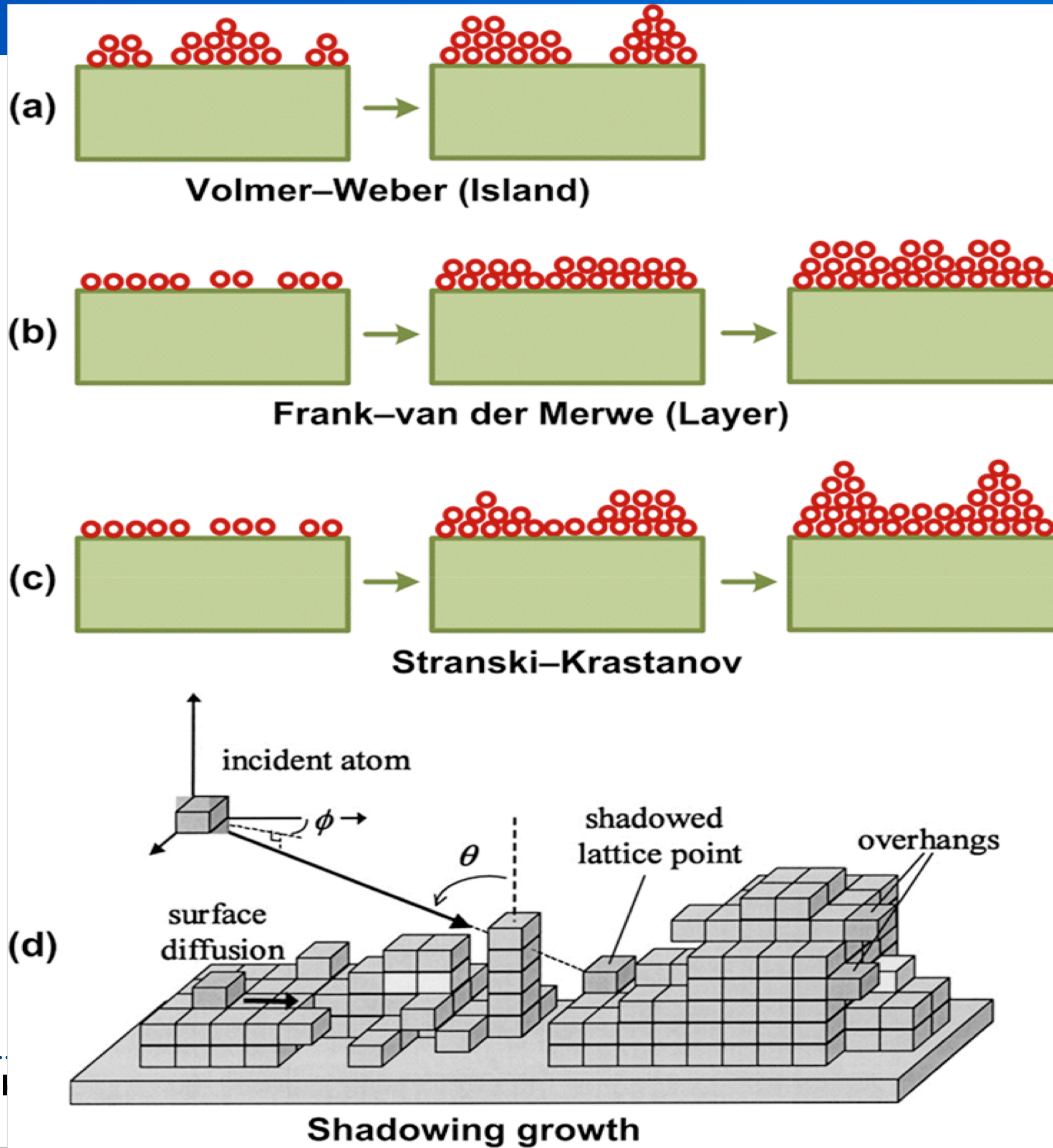
Factors which affect thin film growth and quality

Factor	Effect
Energy	Optimum energy = optimum film growth and quality
Vacuum level	High vacuum - Better film quality - Longer mean free path - Less contamination - Faster growth rate - Note Vacuum relates to Energy also
Substrate	- Substrate type (density, porosity etc.) - Level of cleaning - Topography - Surface chemistry (Wetability, reactions etc.)
Temperature	Optimum Temperature = optimum film quality and growth - Note Temperature related to Energy
Case Specific	Process dependant. Angle of Incidence, Rotation of substrate, process gas used etc.

Relation between factors

- **Energy → Ion/Atom/Molecule energy**
- **Energy → Surface Diffusion**
- **Vacuum Level → Collisions → Ion/Atom/Molecule energy + Spread**
- **Vacuum Level → Contamination**
- **Temperature → Energy → Surface Diffusion**
- **Substrate → Thin film growth type and quality**

Thin Film growth mechanisms



Kitchen physics

Thin Film growth MC simulation

Thin film growth highlighting surface diffusion effect

Weak surface Diffusion
due to insufficient energy:

Film has low density
Film has voids
Film surface is rough

Click to Play

Strong surface Diffusion
due to sufficient energy:

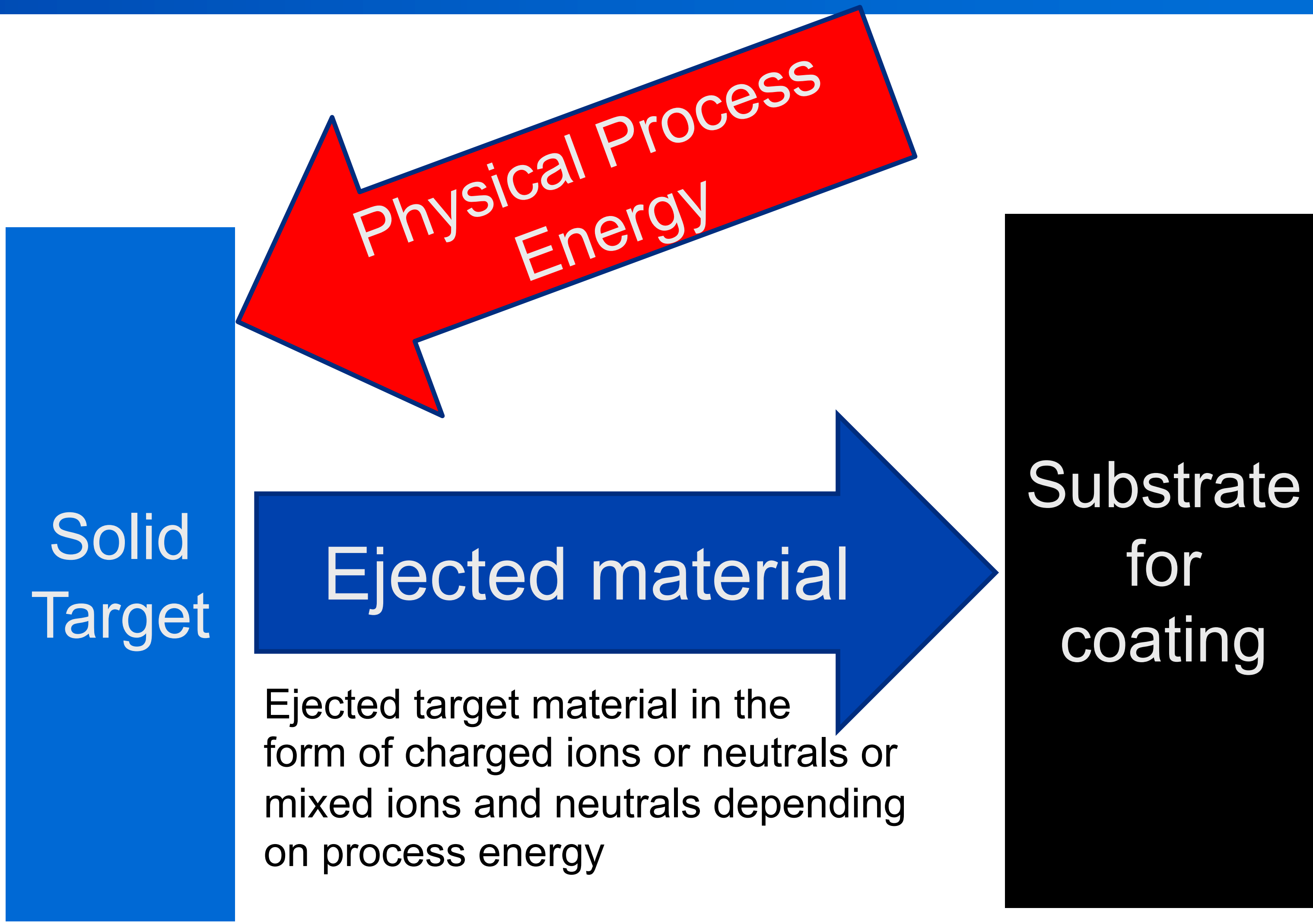
Film has high density
Film has insignificant voids
Film surface is smooth

Physical Vapour Deposition (PVD)

- **Beyond this point we will focus on PVD process exclusively.**

- **Remember the driving force is ENERGY**

Physical Vapour Deposition (PVD) Process



Ejected target material in the form of charged ions or neutrals or mixed ions and neutrals depending on process energy

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Average mean free path (distance between collission) in nitrogen residual gas

REMEMBER ! !

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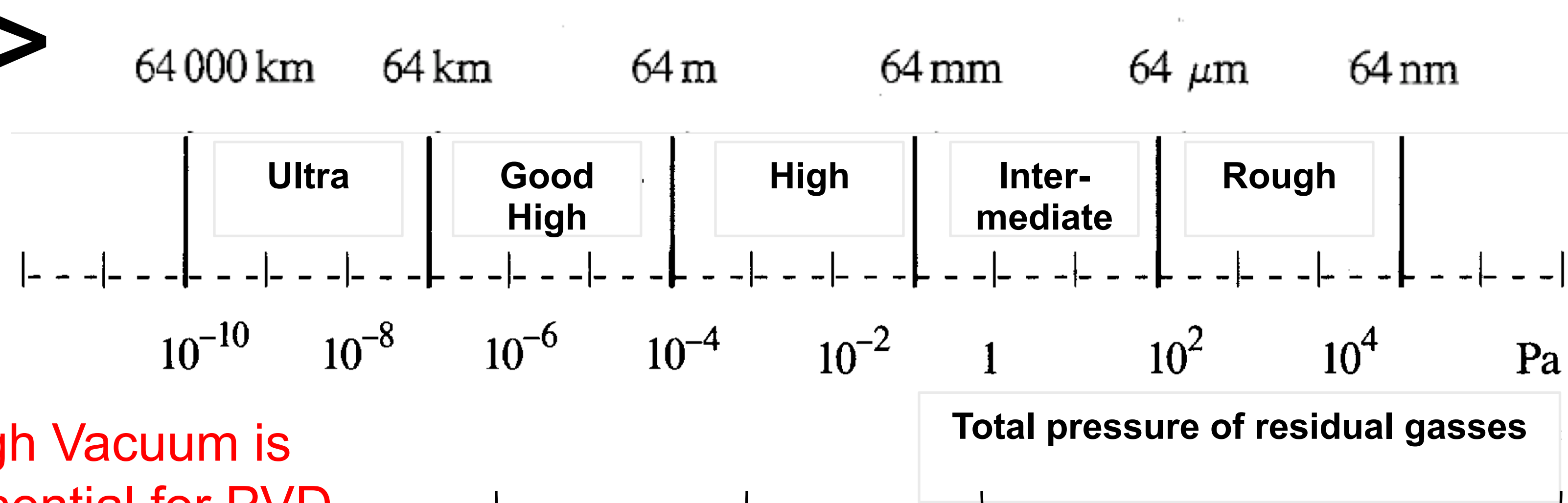
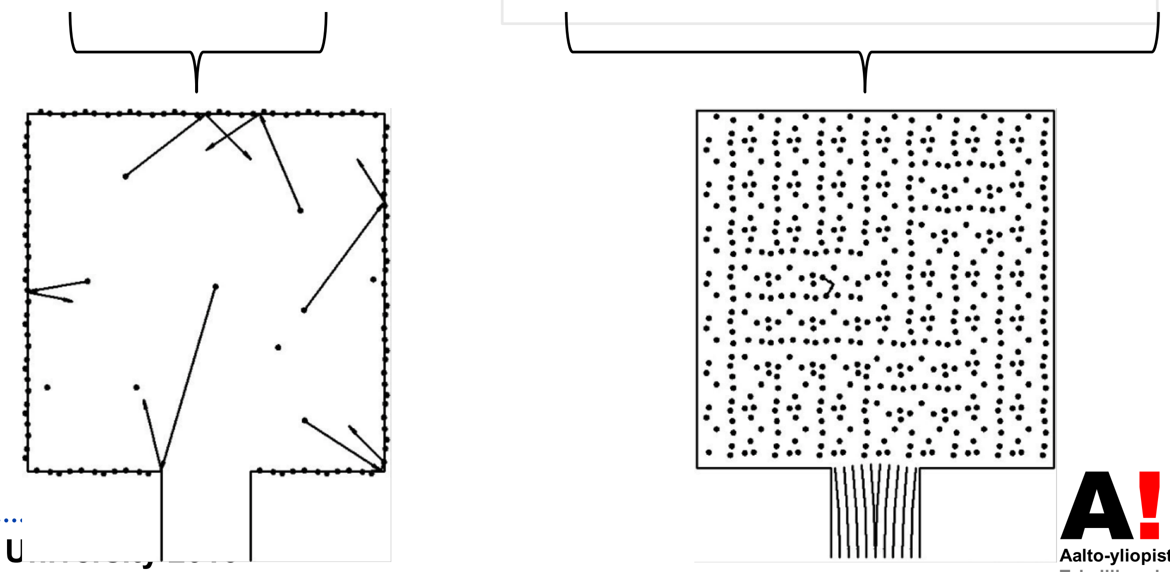


High Vacuum is essential for PVD

Vacuum Level →
Collisions →
Ion/Atom/Molecule energy + Spread



PVD factors and relations

- **Process Energy → Ionization**
- **Process Energy → Ratio ions to neutrals**
- **Process Energy → Ejected species kinetic energy**
- **Ejected species energy → Film growth condition**
- **Temperature → Energy → Surface Diffusion**

PVD process parameters

- **Energy (Ion/Neutral) E_i 10 - 1000 eV**
- **Surface temperature -190° C - 500° C (normally < 200° C)**
- **Incidence angle**
- **Gas pressure**
- **Substrate surface**
  - Chemistry
  - Impurities
  - Topography

PVD process categorized by Energy

Low energy PVD

- **Thermal Evaporation**
  - Electron beam
  - Resistive heating
- **Molecular Beam Epitaxy (MBE)**

High Energy PVD

- **Magnetron Sputtering (MS)**
  - DC or RF
  - Balanced or Unbalanced
- **Pulsed Laser Deposition (PLD)**
- **Cathodic arc**
  - DC or pulsed
  - Filtered or un-filtered
  - With or without substrate bias
- **High power impulse magnetron sputtering (HIPIMS)**

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LOW Energy PVD physical process

Low energy PVD

- Target material is evaporated.
- Evaporated species is neutrals
- Consists of atoms/molecules
- Evaporated species have low energy.

Process :

- Thermal Evaporation
  - Electron beam
  - Resistive heating
- Molecular Beam Epitaxy (MBE)

HIGH Energy PVD physical process

High energy PVD

- **Target material is sputtered or vaporized.**
- **Ejected species consists of ionized atoms and neutrals**
- **Ratio of ionized atoms to neutrals depends on process energy**
- **Ejected species have high energy.**

Process:

- **Magnetron Sputtering (MS)**
  - DC or RF
  - Balanced or Unbalanced
- **Pulsed Laser Deposition (PLD)**
- **Cathodic arc**
  - DC or pulsed
  - Filtered or un-filtered
  - With or without substrate bias
- **High power impulse magnetron sputtering (HIPIMS)**

Comparison of low and high energy PVD process

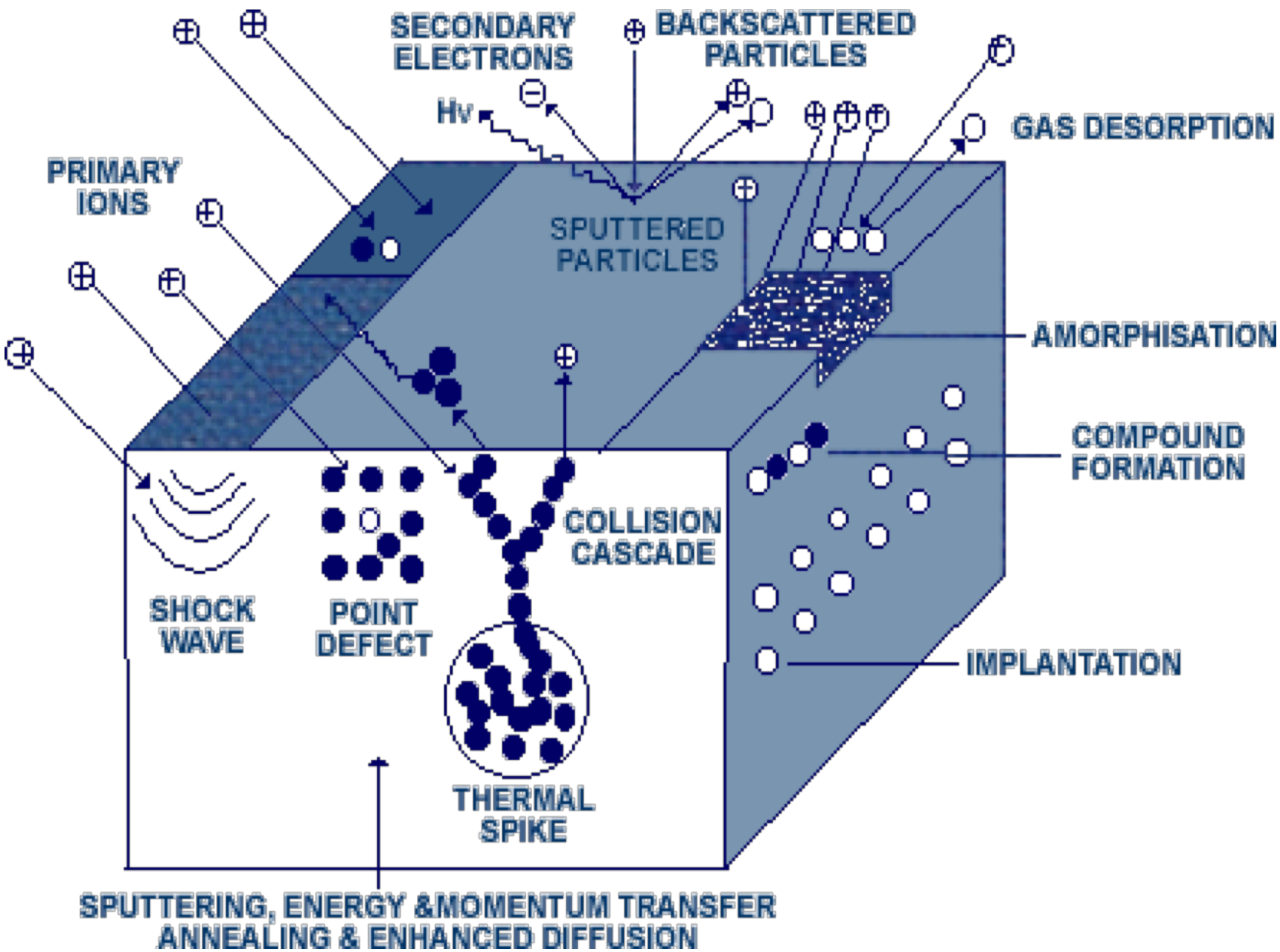
How Low is Low?

- Case: Gold
- Boiling Point (Atm) : 2856 ˚C
- In Vacuum
- 10^{-8} Torr = 807 ˚C
- 10^{-6} Torr = 947 ˚C
- 10^{-4} Torr = 1132 ˚C
- Vacuum needed !
- Typical Au species is atoms
- Typical Au energy is around 5eV

How High is High?

- Case: Gold
- Process : Arc Discharge (10^{-7} Torr)
- Arc power density around 10^{9} W/m2
- Temperature at arc spot around 15000 to 25000 ˚C
- Typical Au ion fraction = 99%
- Typical Au ion charge is +3
- Typical Au ion velocity around 7500 m/s
- Typical Au ion energy around 90eV

What do High Energy Species Do on Substrate?



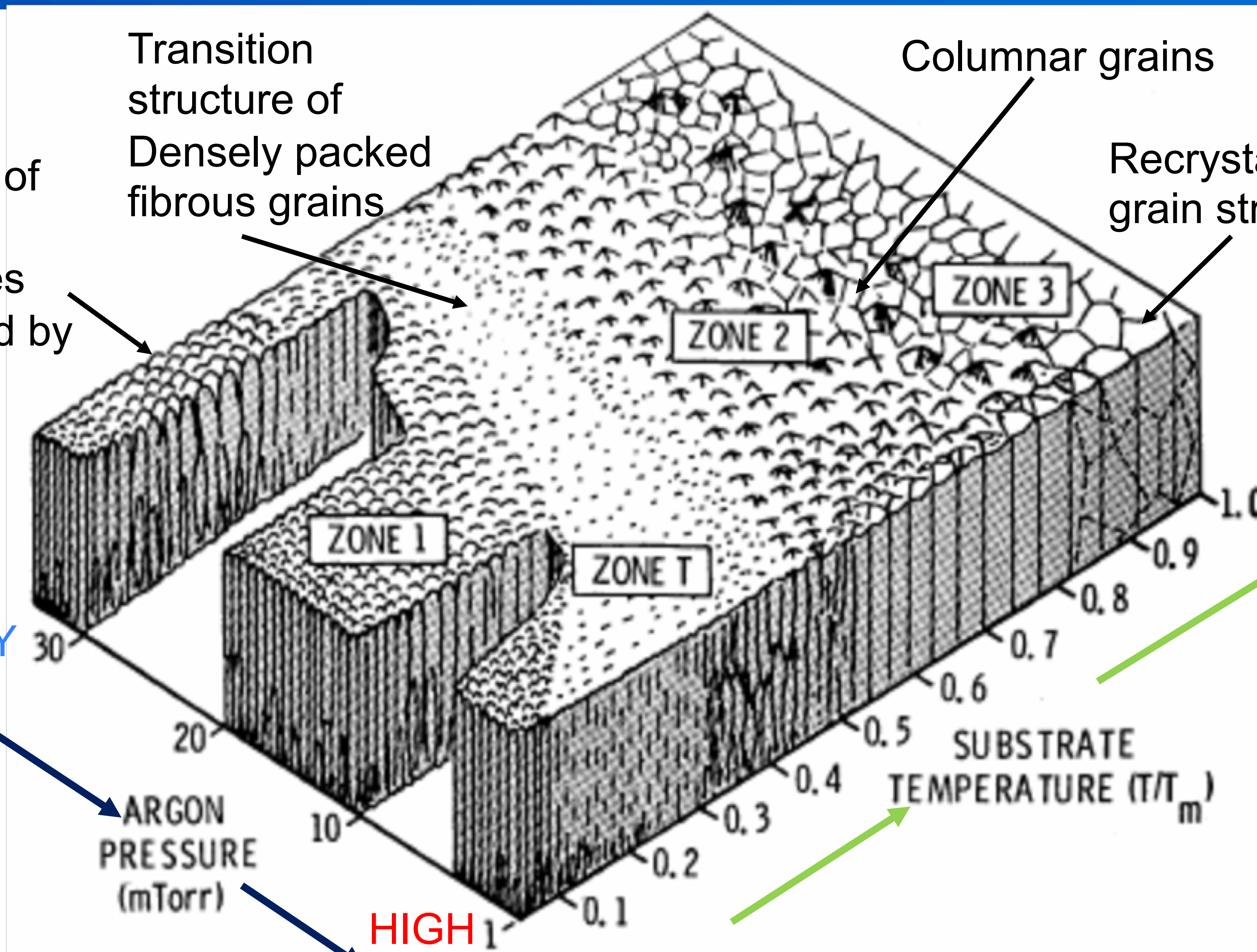
Thin film structure in PVD process

Porous structure of tapered crystallites separated by voids

Transition structure of Densely packed fibrous grains

Columnar grains

Recrystallized grain structure



HOT

LOW ENERGY

HIGH ENERGY

COLD

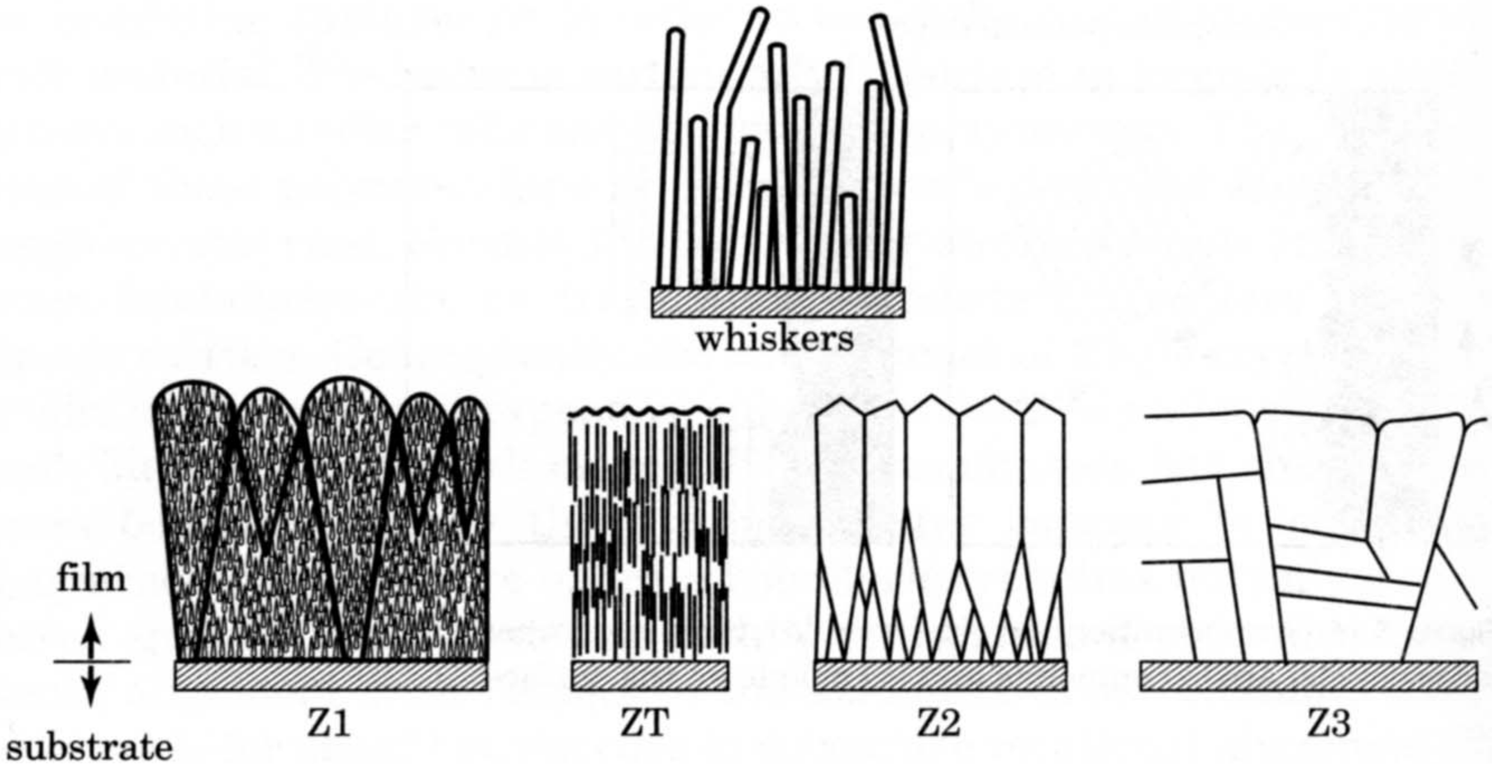
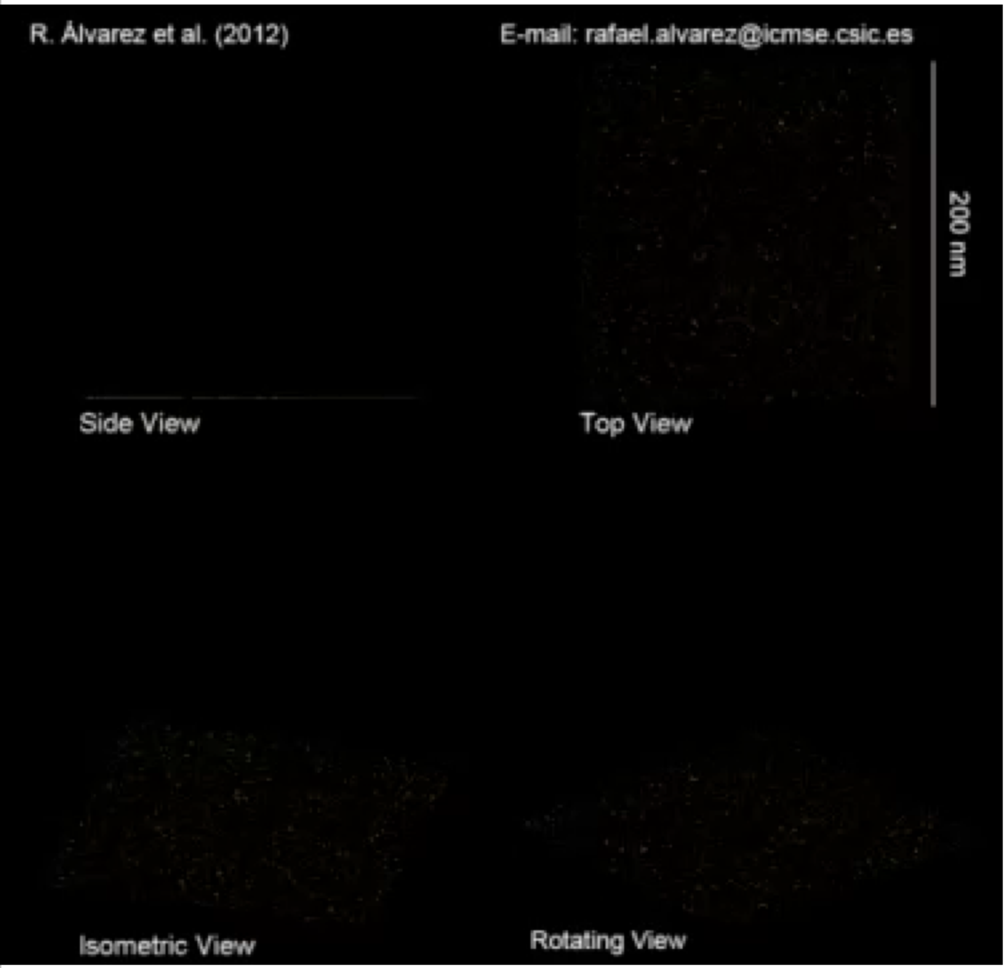
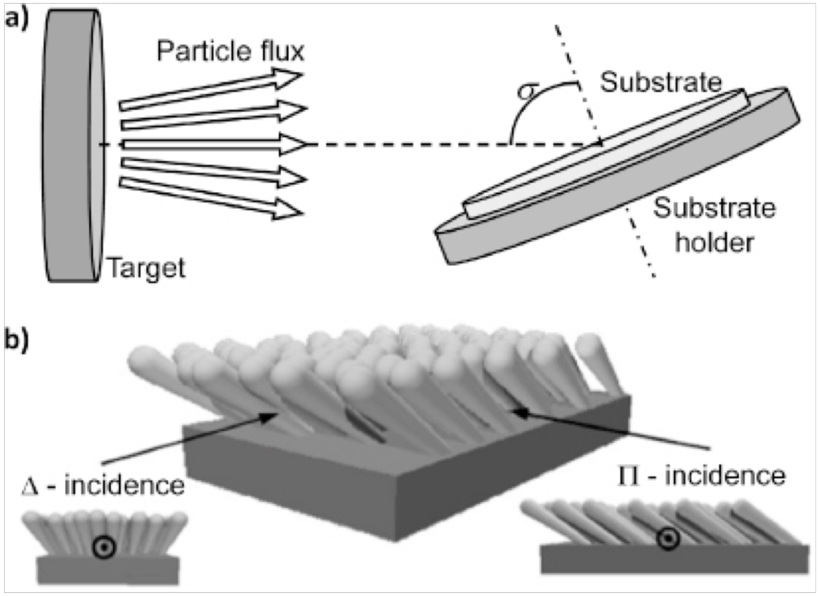


Figure 5.15 Characteristics of the four basic structural zones and of whiskers, in cross section. The ratio of substrate T to film melting T (T_s/T_m) increases in the direction Z1→ZT→Z2→Z3.

Angle of incidence in PVD process





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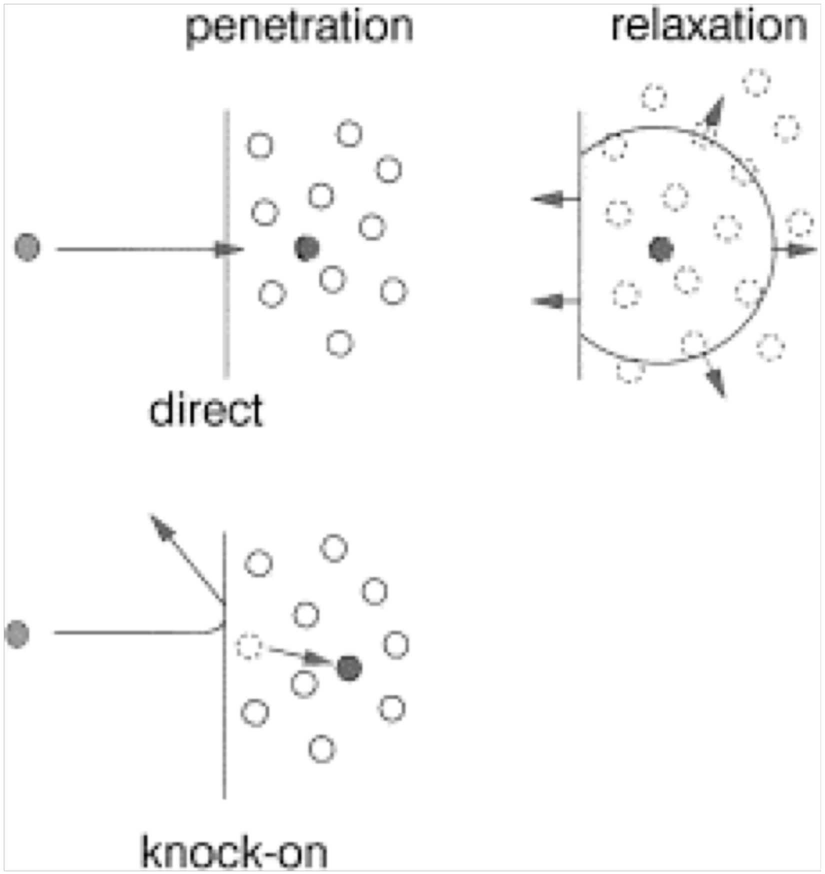
High energy species Subplantation



J. Robertson/Materials Science and Engineering R 37 (2002) 129–281

Subplantation -> Ion peening

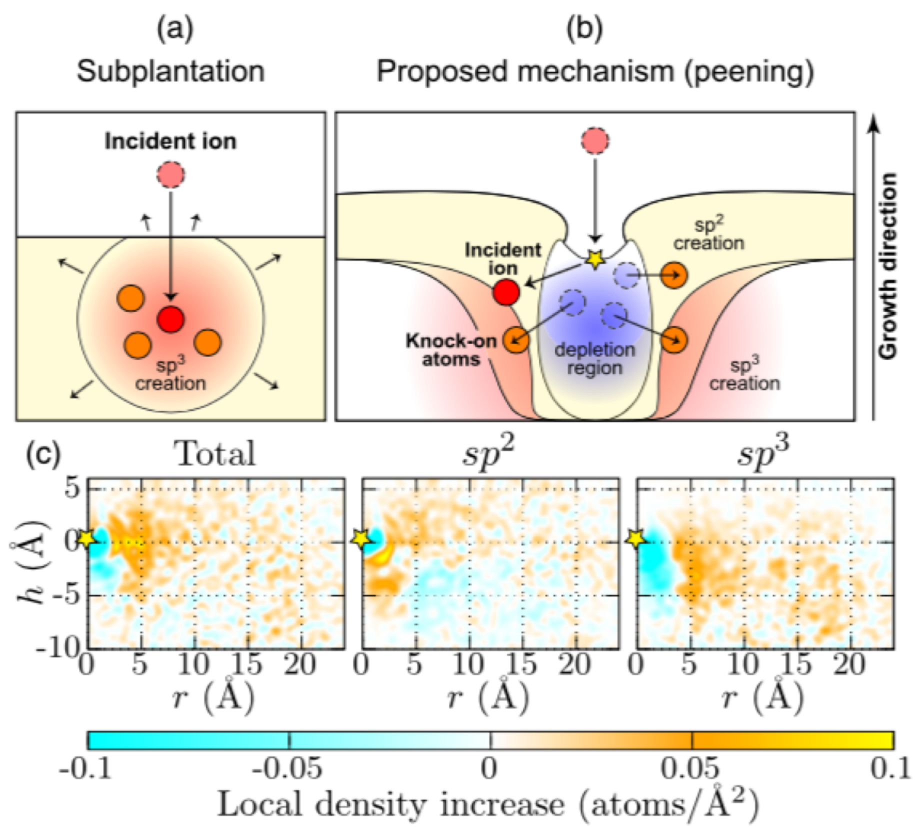
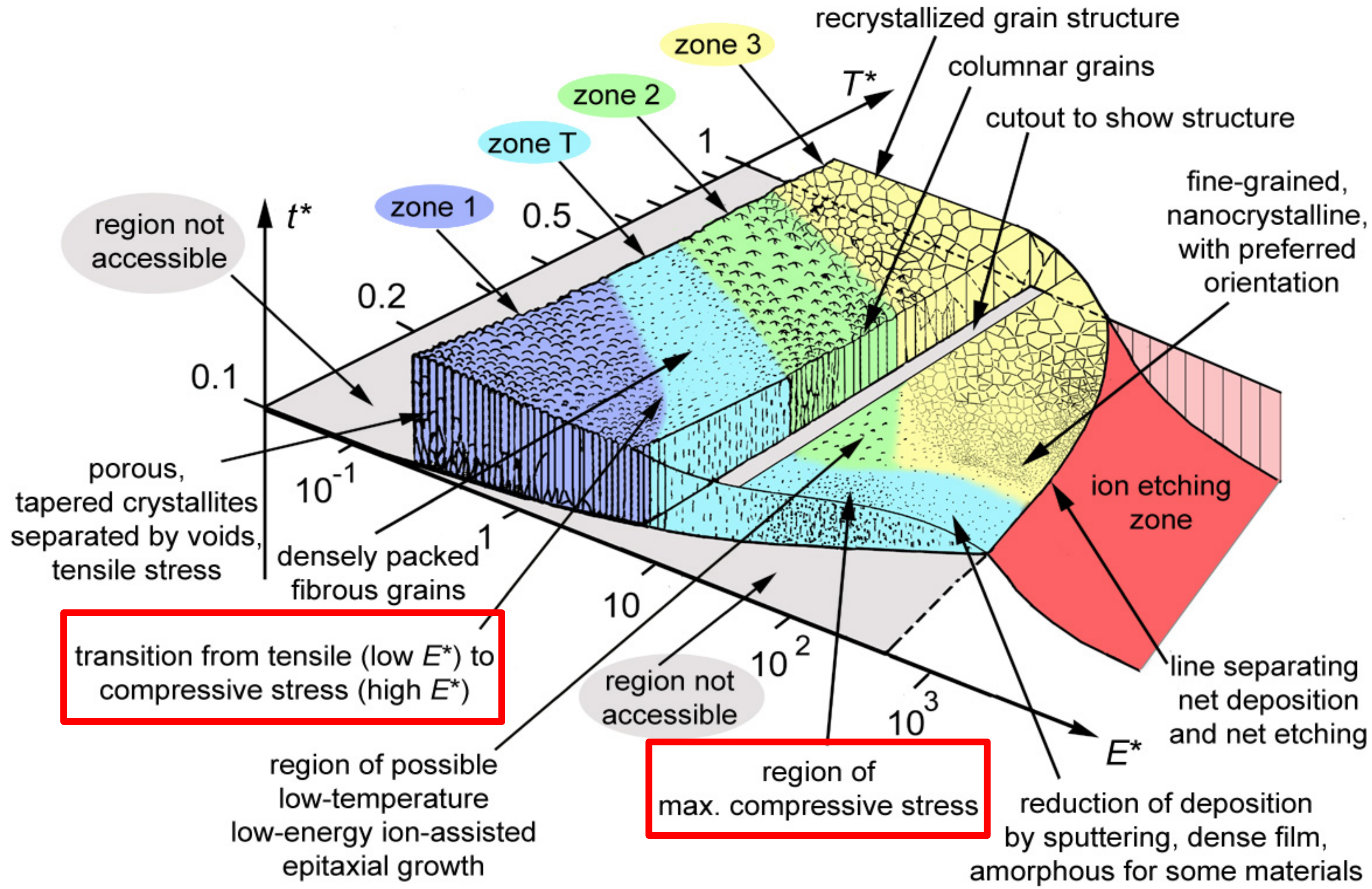


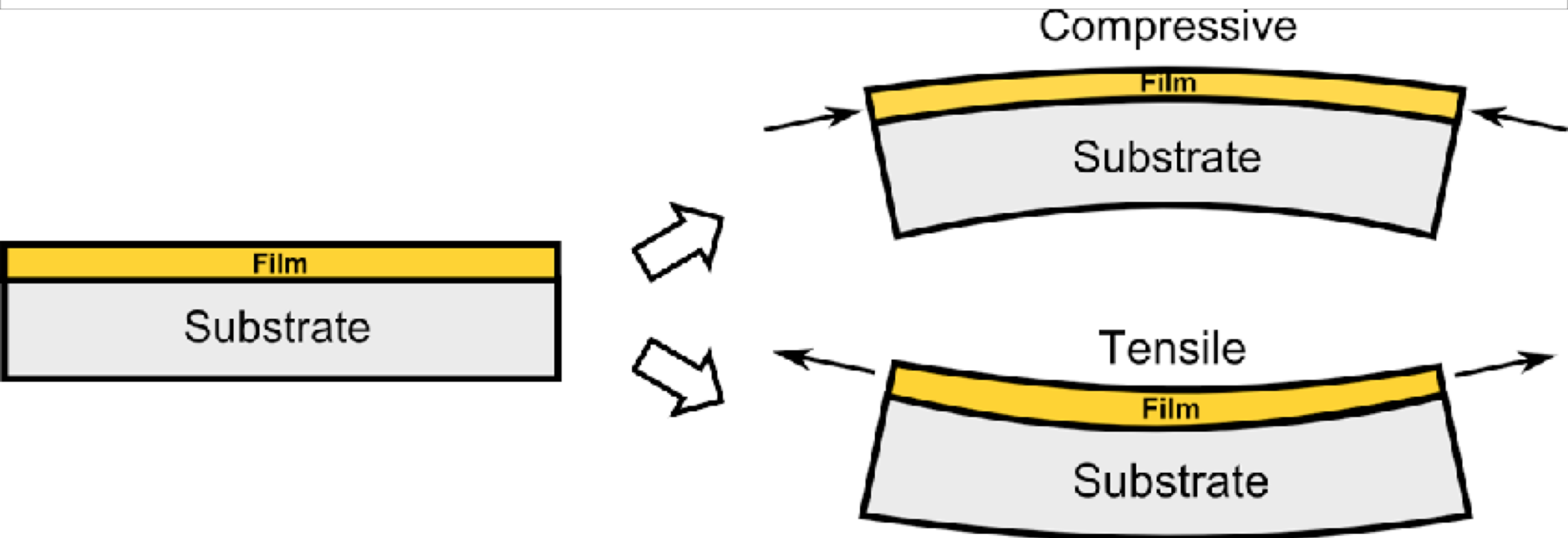
FIG. 4. (a) Previously accepted growth mechanism in ta-C and (b) growth mechanism proposed in this Letter. (c) Average increase in local mass density after ion impact (60 eV deposition; see text for details). The star indicates the impact site.

Miguel A. Caro, Volker L. Deringer, Jari Koskinen, Tomi Laurila, Gábor Csányi, PHYSICAL REVIEW LETTERS 120, 166101 (2018)

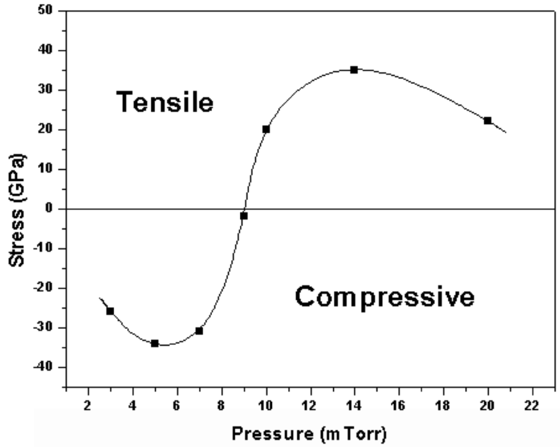
Effect of Subplantation on film growth



Intrinsic stress



Stress Control



Growth and study of magnetostrictive FeSiBC thin films, for device applications, Mannan Ali (1999) 50 *(Online Copy)*

- **Gas pressure /temperature**
- **Tensile stress due to collapsing of voids**
- **Higher temperature annealing of structure – low stress**
- **Compressive stress – subplantation**

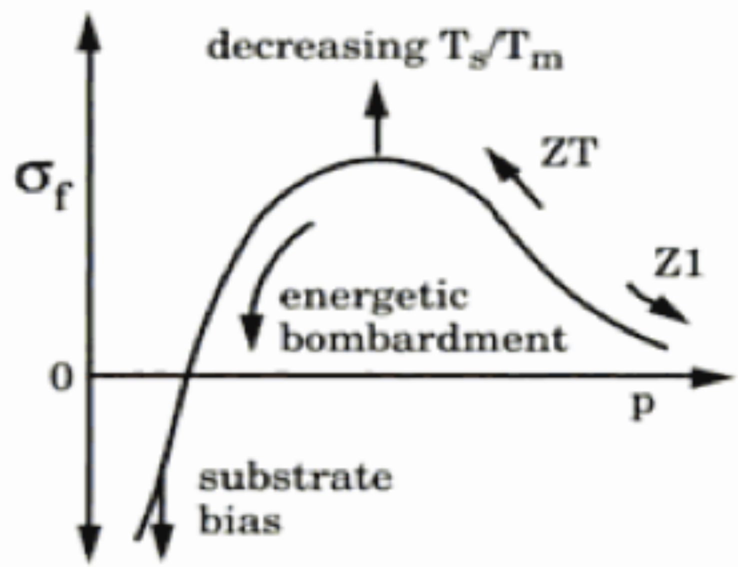


Figure 5.38 Behavior of film stress with sputter-deposition conditions.