Tailoring Materials for Solar Energy Conversion Applications

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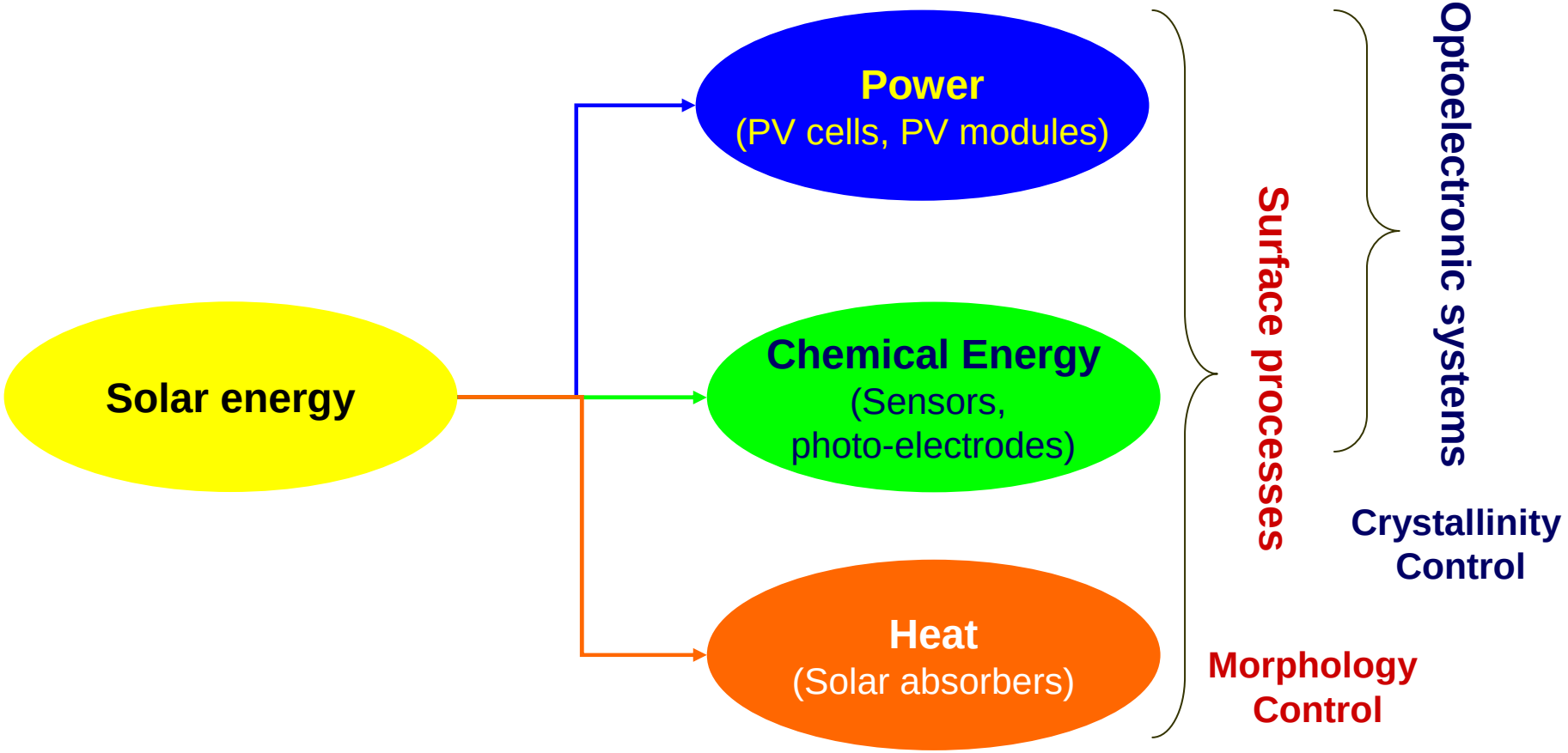
Materials for solar energy conversion devices

Metal Oxide Semiconductors



Up-scalable technique

Department: Renewable Energy Systems and Recycling

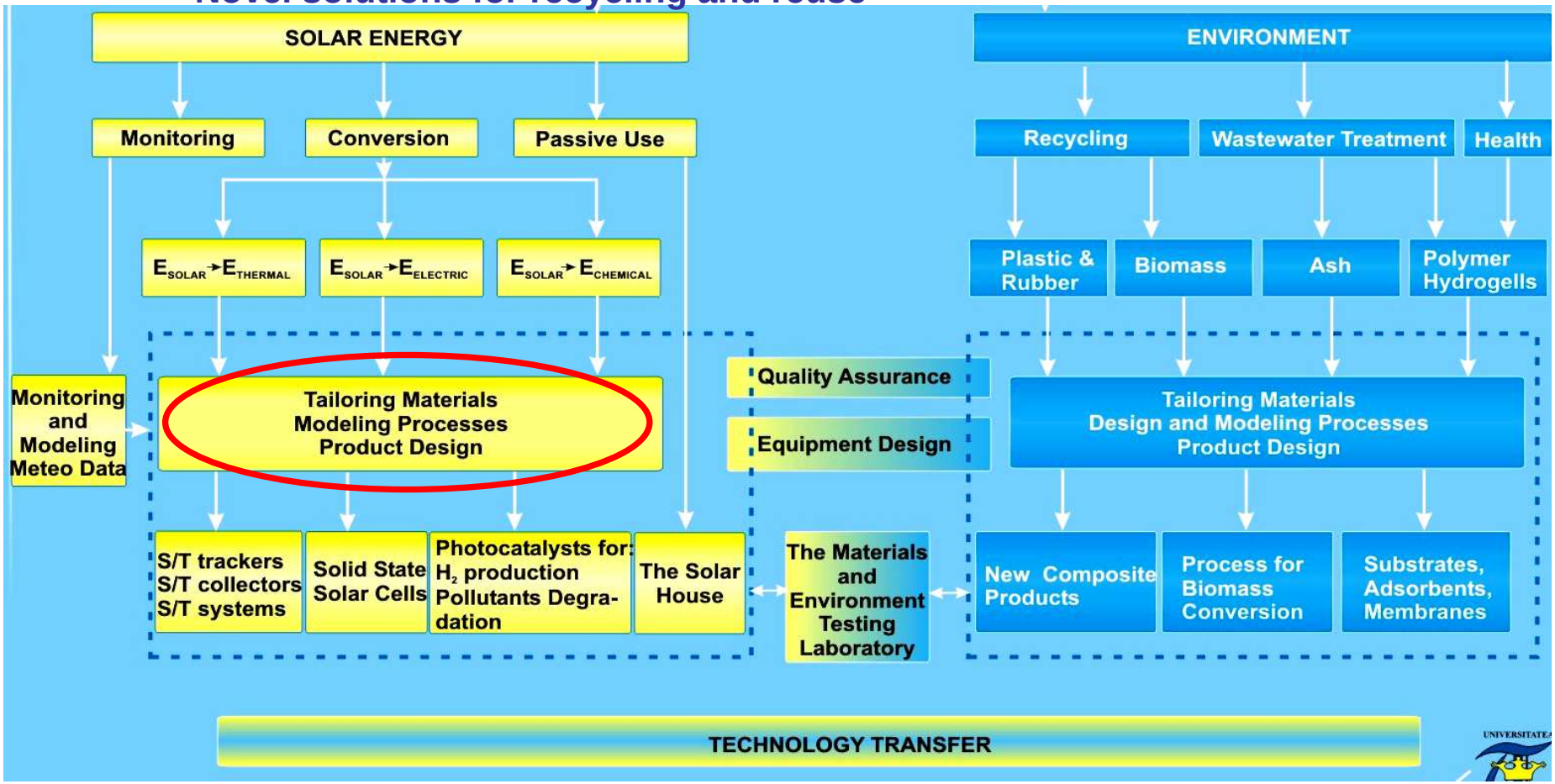
Our approach: Integrated Product Design

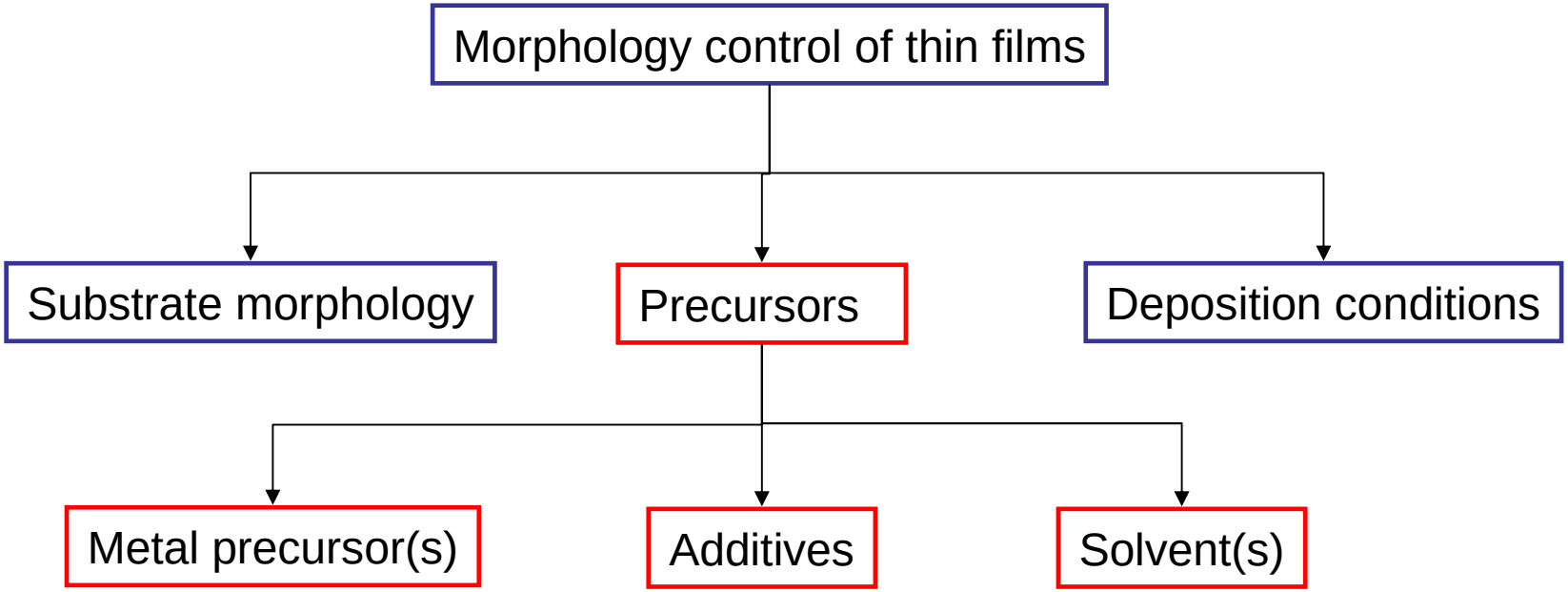
➔ Developing materials for targeted applications

Research areas:

Increasing the efficiency of solar energy conversion

Novel solutions for recycling and reuse

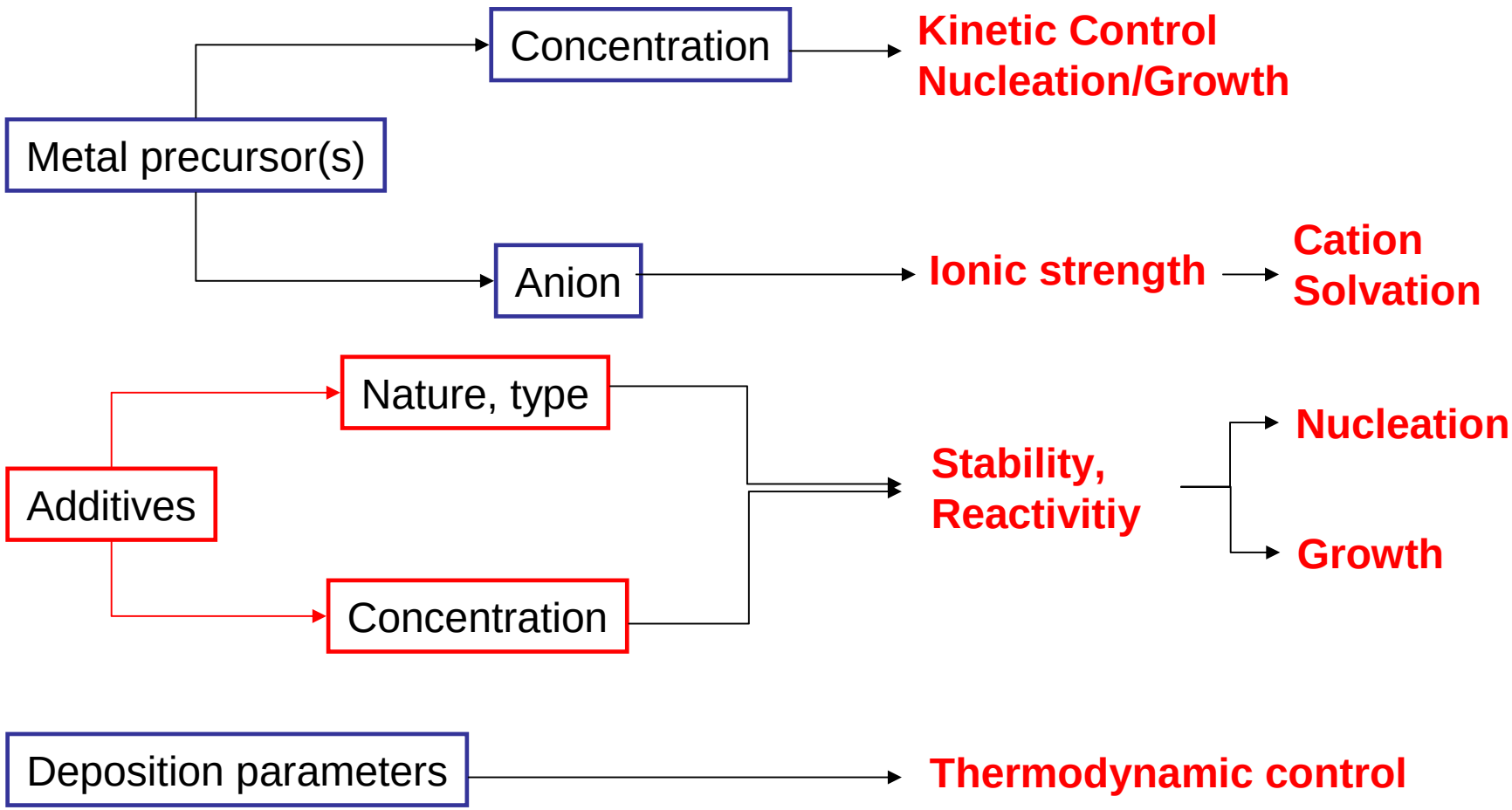




Deposition techniques: up-scalable, suitable for large surface areas

Spray Pyrolisys Deposition (SPD)

Mechanisms of morphology control in thin films of metal oxide semiconductors



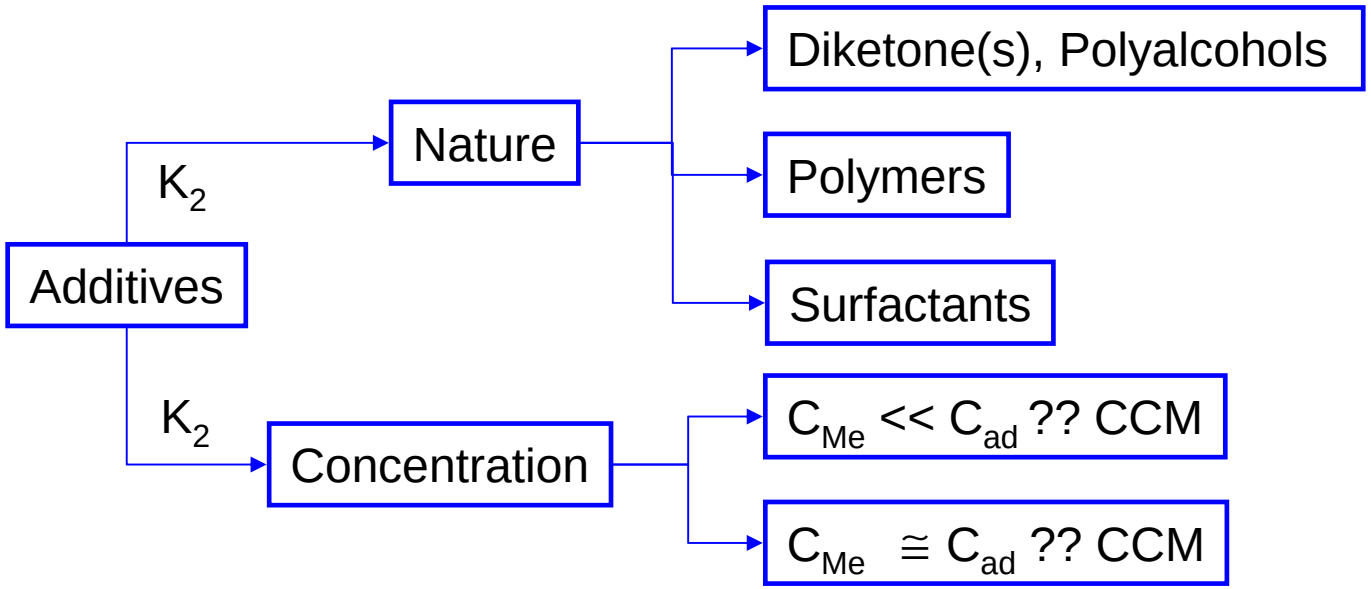
Mechanisms of morphology control in thin films of metal oxide semiconductors\
Aditives: interaction with the precursor metal cation

$[Me(Solvent)_n]^{z+} + x\ Ad \rightarrow [Me(Solvent)_{n-x}Ad_x]^{z+} + x\ Solvent, \quad x = 1 \ldots n$

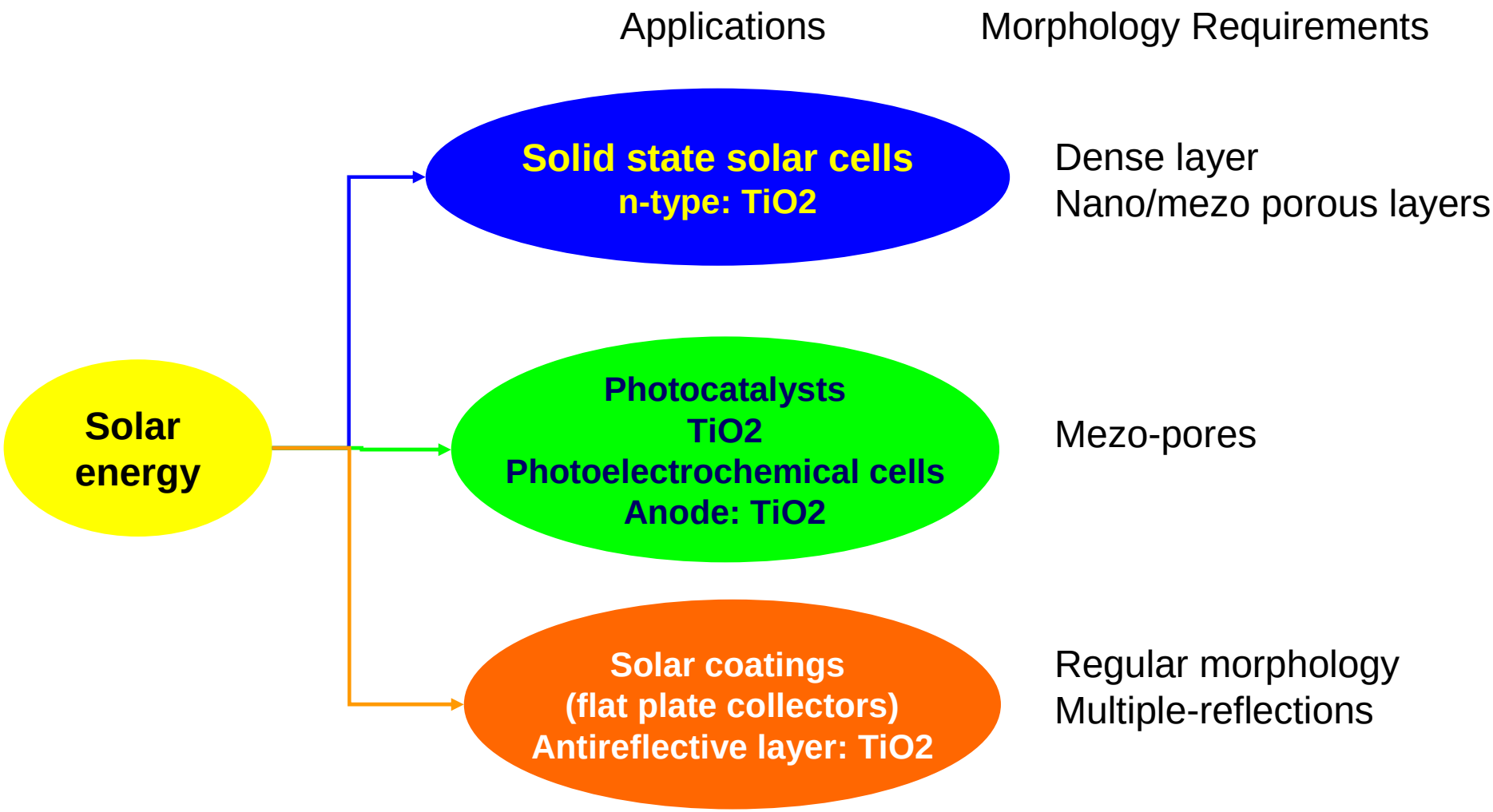
K_1 $\qquad$ K_2

$Me^{z+} + n\ Solvent \qquad Me^{z+} + (n-x)\ Solvent + x\ Ad$

Observation: K_1 is fixed; K_2 can be modified/controlled (by changing x)

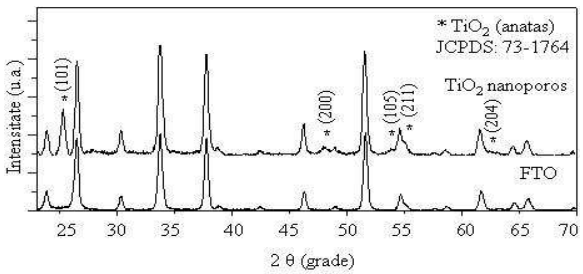


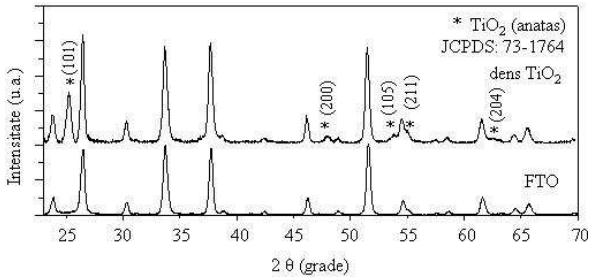
Case study: TiO_2 (anatase)



Thermodynamic control in SPD
Deposition T, P

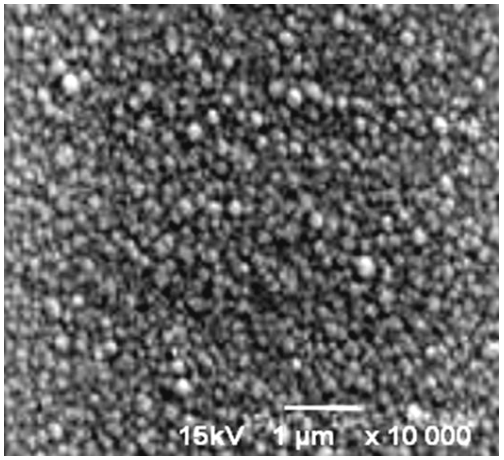
Homogeneous growth (dense films, small grains):
excess of **complexing** aditiv (AcAc)



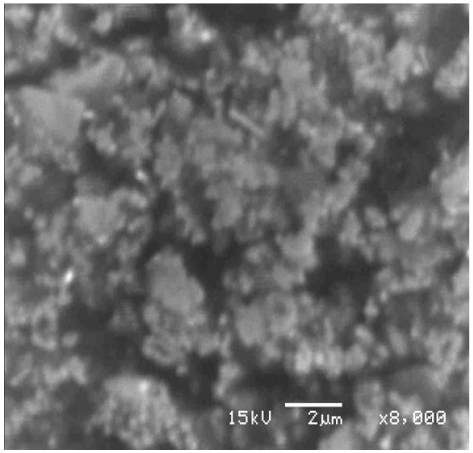


Precursor: TTIP
Additive: Acetylacetone (AcAc)
Solvent: Ethanol (EtOH)

Morphology control:
Composition
Temperature

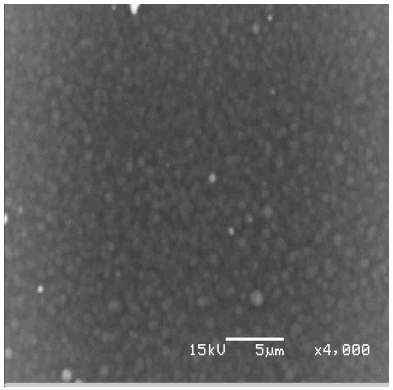


Dense thin film:
TTIP: AcAc: EtOH =1: 1.5: 22.5
T = 350ºC

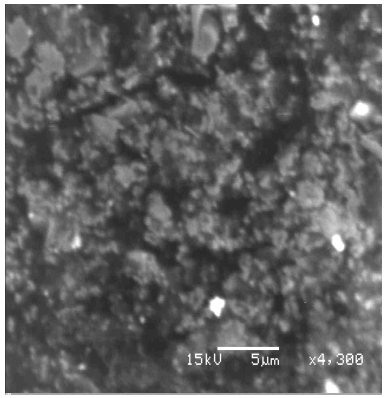


Nano/mezo porous thin film:
TTIP: AcAc: EtOH =1.3: 1: 20.8
T = 400ºC

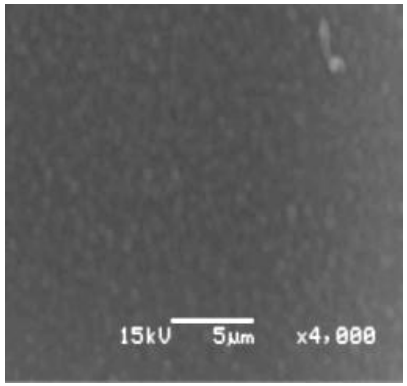
Thermodynamic control in SPD
Deposition T, P



P = 0.8 bar



P = 1.2 bar



P = 1.4 bar

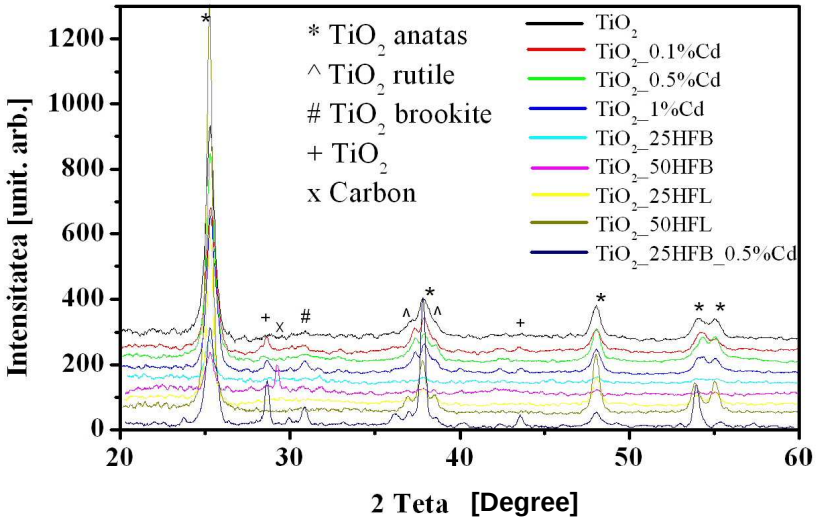
Precursor: TTIP
Additive: Acetylacetone (AcAc)
Solvent: Ethanol (EtOH)

Morphology control:
Composition
Pressure

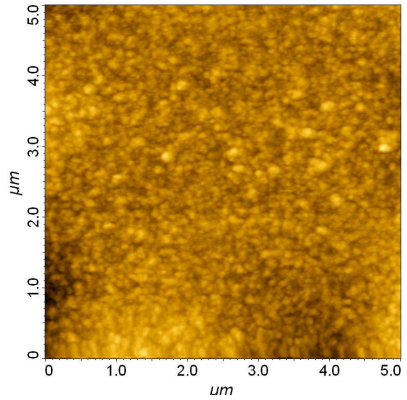
TTIP: AcAc: EtOH: 1.3: 1: 20.8
T = 400ºC

Kinetic control in SPD
Additives: Polymeric additives

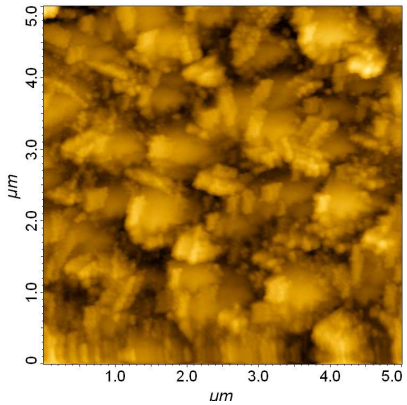
Homogeneous growth, various aspect ratio:
Very low amount of **tailored** additives
(weak interactions)



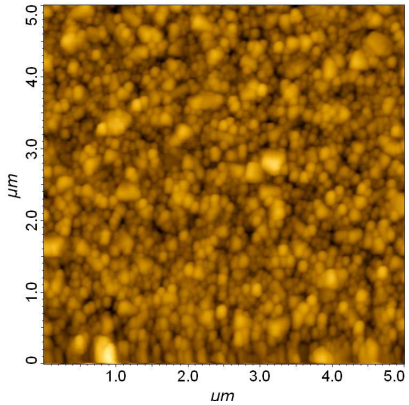
Precursor: $TiCl_4$
Additives:
Hydrophobic polymer, HFB
Hydrophilic polymer, HFL
Solvent: Ethanol
Morphology control:
Aditive type
Doping



a)



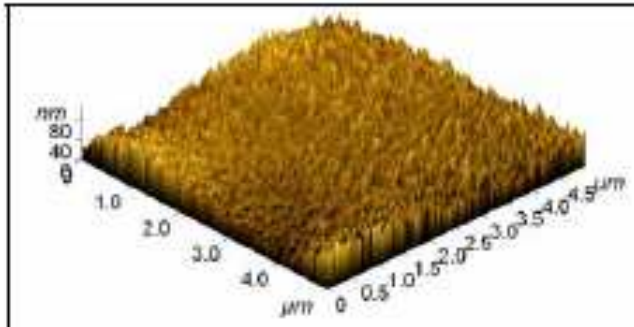
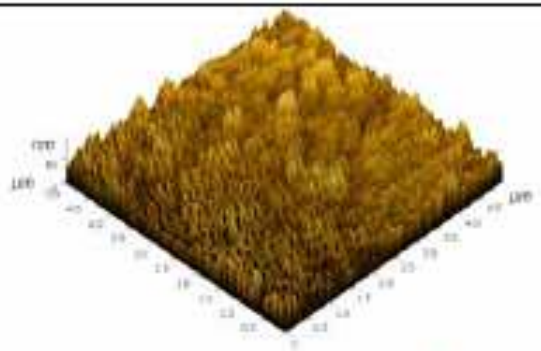
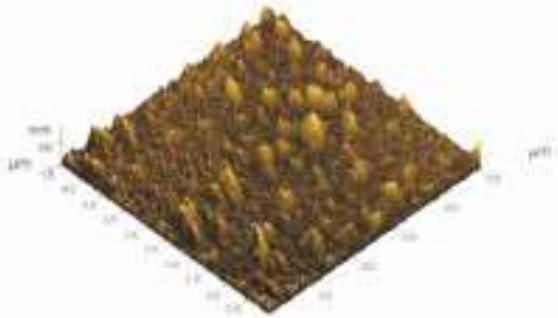
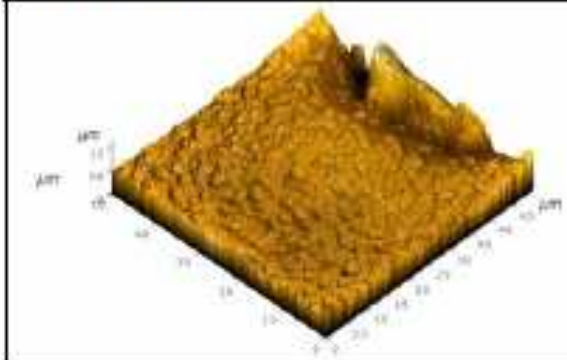
b)



c)

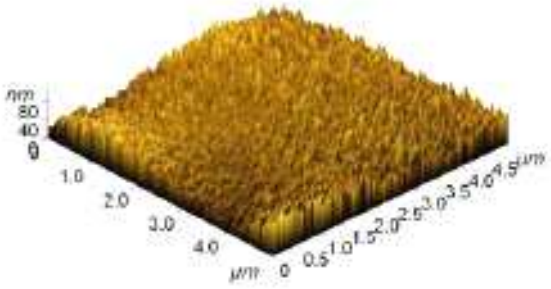
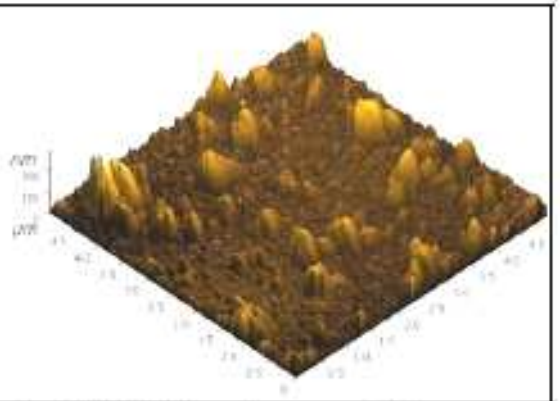
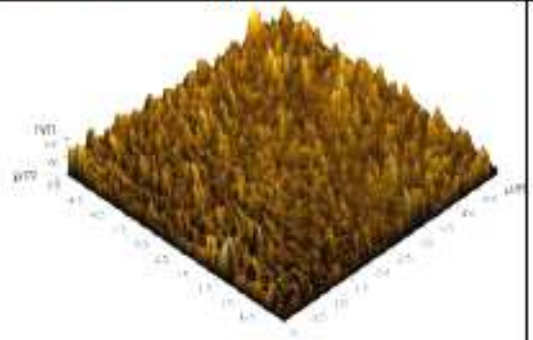
a) $TiCl_4$ (in Ethanol) 0.05M, 400ºC
b) $TiCl_4$ (EtOH), 0.05M, 25ppm HFL, 400ºC
c) $TiCl_4$ (EtOH), 0.05M, 25ppm HFB, 0.5%Cd, 400ºC

Kinetic control in SPD
Additives: Nonionic surfactants (Decanol, Hexadecanol)

		
d = 194 Å; Roughness = 8.9 nm Surfactant: 0	d = 81 Å; Roughness = 12.8 nm Surfactant: decanol, 50ppm	d = 100 Å; Roughness = 29 nm Surfactant: decanol, 400 ppm
		
d = 211 Å; Roughness = 71 nm Surfactant: hexadecanol, 25ppm	d = 196 Å; Roughness = 17.2 nm Surfactant: hexadecanol, 50ppm	d = 184 Å; Roughness = 18 nm Surfactant: hexadecanol, 400 ppm

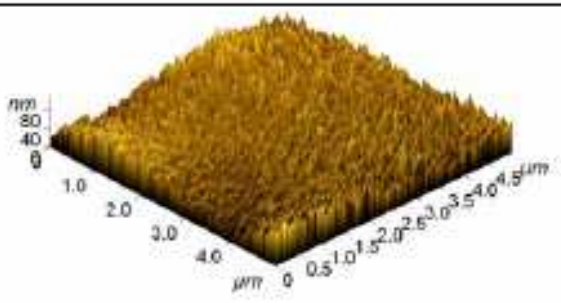
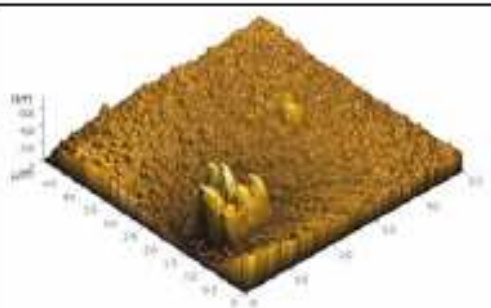
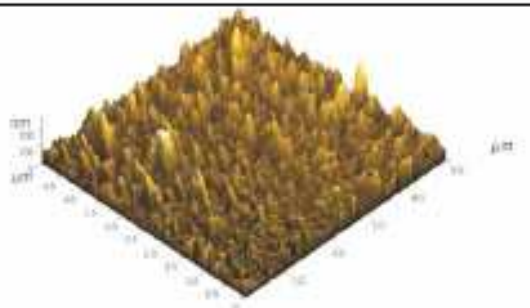
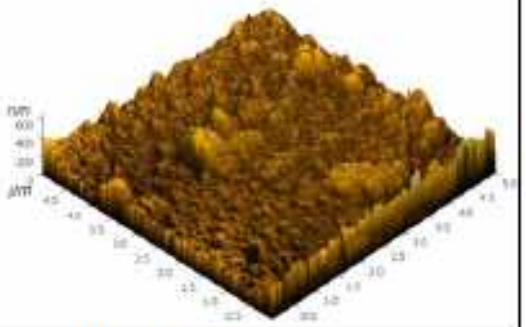
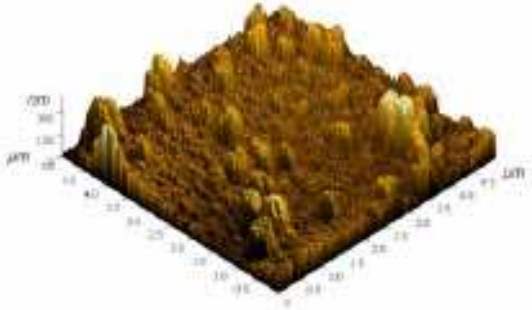
Precursor: $TiCl_4$ (in Ethanol) 0.05M
Temperature: 400ºC

Kinetic control in SPD
Additives: Cationic surfactant (hexadecyl-trimethyl-ammonium bromide)

		
d = 194 Å; Roughness = 8.9 nm Surfactant: 0	d = 171 Å; Roughness = 11.7 nm Surfactant: 25 ppm	d = 100 Å; Roughness = 33 nm Surfactant: 50 ppm
		
d = 384 Å; Roughness = 73 nm Surfactant: 100 ppm	d = 240 Å; Roughness = 14.8 nm Surfactant: 200 ppm	d = 290 Å; Roughness = 45 nm Surfactant: 400 ppm

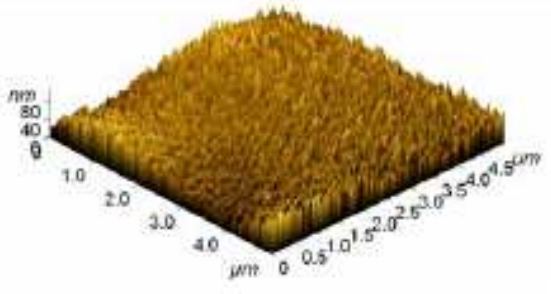
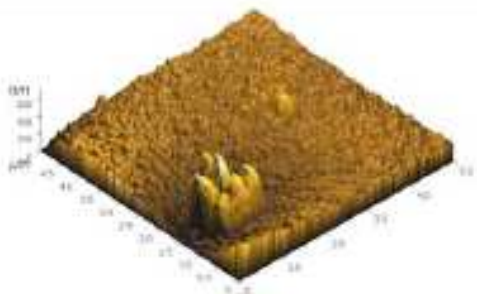
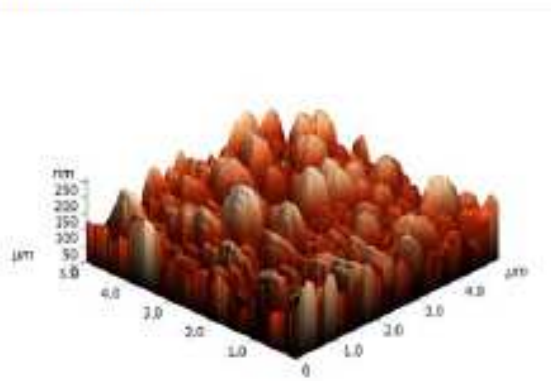
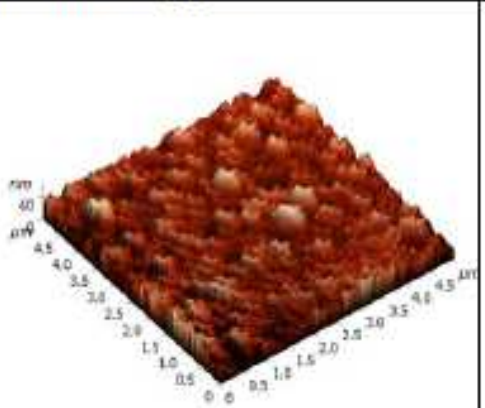
Precursor: $TiCl_4$ (in Ethanol) 0.05M
Temperature: 400ºC

Kinetic control in SPD
Additives: Anionic (sodium-dodecyl-sulfate)

		
d = 194 Å; Roughness = 8.9 nm Surfactant: 0	d = 274 Å; Roughness = 42 nm Surfactant: 25 ppm	d = 88 Å; Roughness = 29 nm Surfactant: 50 ppm
		
d = 479 Å; Roughness = 21 nm Surfactant: 100 ppm	d = 149 Å; Roughness = 45 nm Surfactant: 200 ppm	d = 189 Å; Roughness = 41 nm Surfactant: 400 ppm

Precursor: $TiCl_4$ (in Ethanol) 0.05M
Temperature: 400ºC

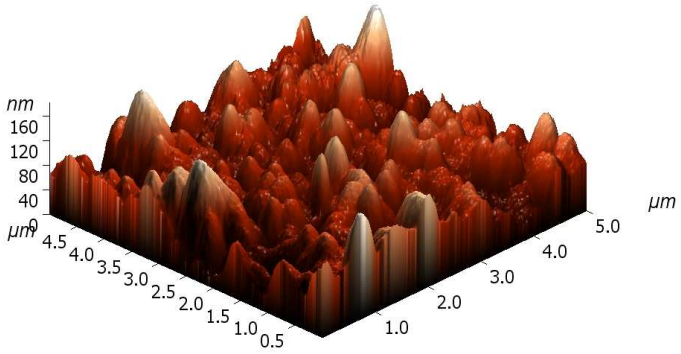
Kinetic control in SPD
Additives: Anionic (sodium-dodecyl-sulfate)

		
Precursor: TiC14 Surfactant: 0	Precursor: TiC14 Surfactant: 25 ppm	Precursor: TiC14 Surfactant: 100 ppm
		
Precursor: TTIP Surfactant: 0	Precursor: TTIP Surfactant: 25 ppm	d = 189 Å; Roughness = 41 nm Surfactant: 400 ppm

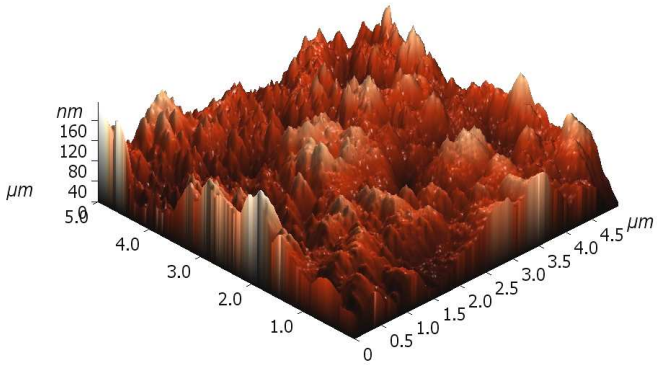
Temperature: 400°C

Similar results for p-type semiconductor CuInS2 (CIS)

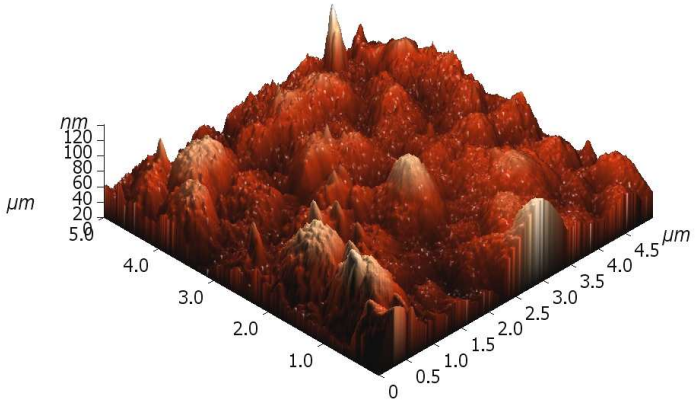
Surfactant: sodium-dodecyl-sulfate



Surfactant: 0 ppm



Surfactant: 50 ppm



Surfactant: 70 ppm

Conclusion:

There’s plenty of room at the bottom!

Richard Feynman, 1960