Some Interfacial Thermodynamics Issues Involved In Water Erosion Project

A Presentation For MECH 6661 Course

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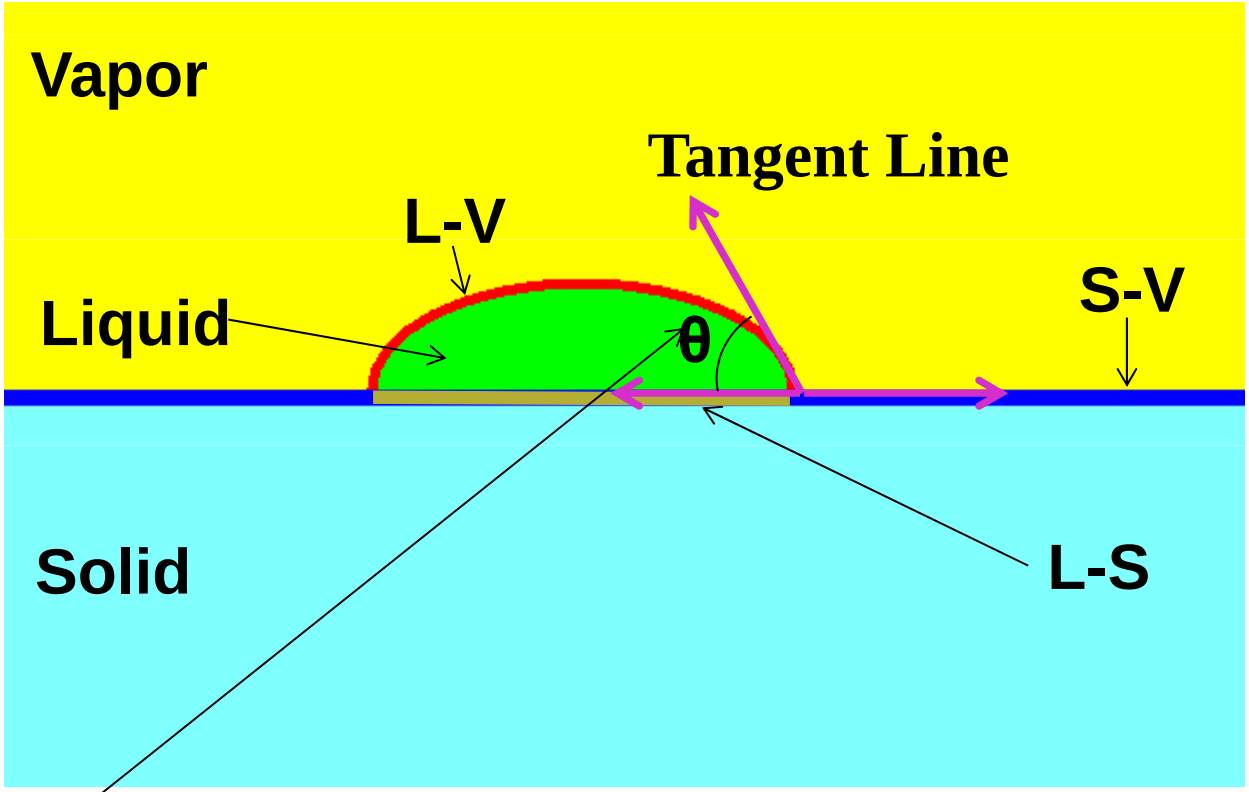
05/12/2011

OUTLINE

1. Interfacial Thermodynamics Fundamentals
2. Hydrophobicity
3. Wetting in Laser Cladding

1 Interfacial Thermodynamics Fundamentals

Wetting Angles



θ ---- Contact Angle

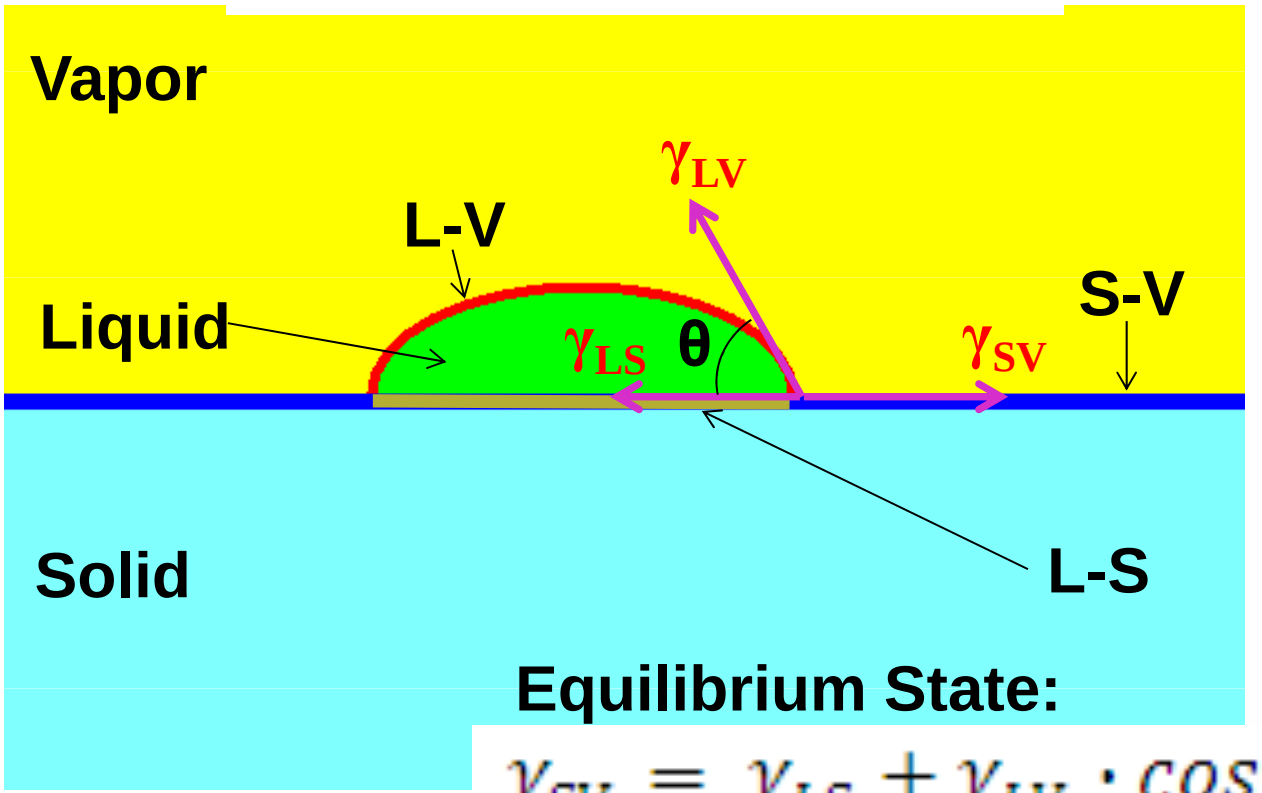
- θ = 0° Complete Wetting
- θ > 90° Hydrophobic (water)

Surface Energy

$$Surface\ Energy = A \cdot \gamma_j$$

A ------ Surface Area

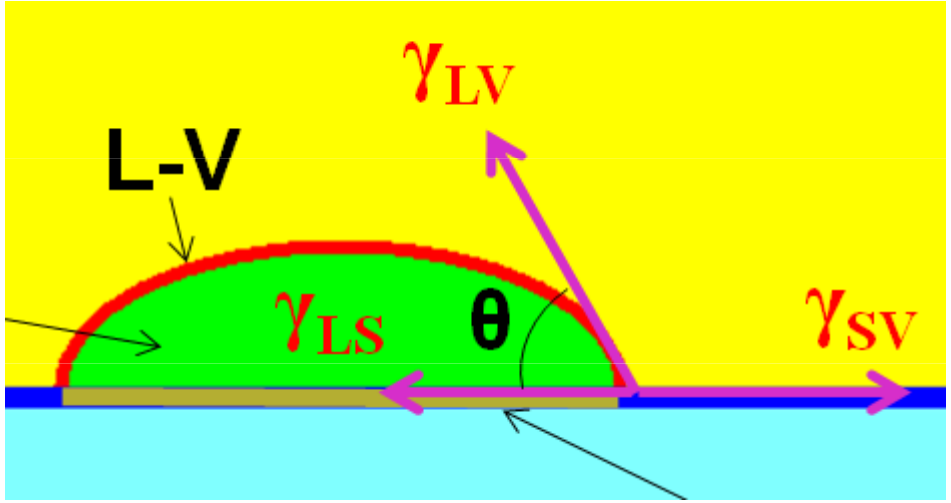
γ_j ------ Specific Surface Energy



Equilibrium State:

$$\gamma_{SV} = \gamma_{LS} + \gamma_{LV} \cdot \cos\theta$$

Simplifications



Equilibrium State:

$$\gamma_{SV} = \gamma_{LS} + \gamma_{LV} \cdot \cos\theta$$

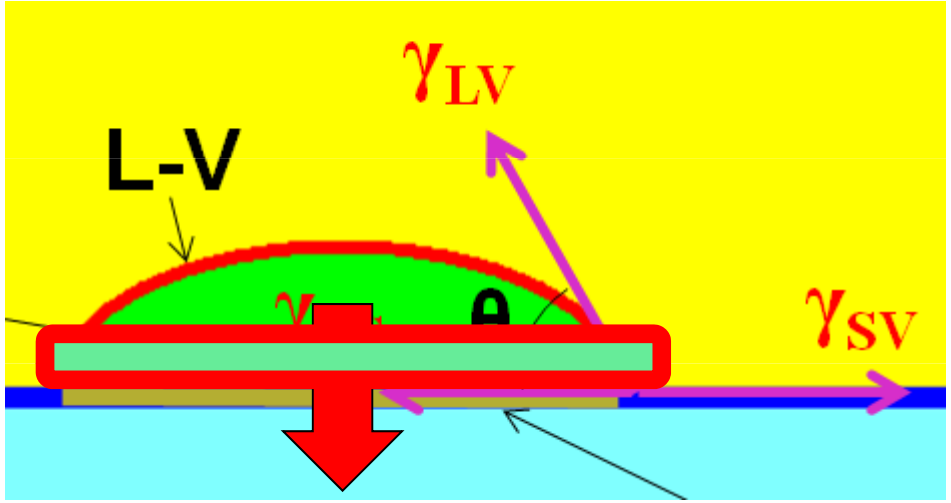
Simplifications: [For Wetting @ lower θ value]

$\theta \rightarrow 0, \quad \cos\theta \rightarrow 1$

$Neglect \ \gamma_{LS}$

$$\gamma_{SV} = \gamma_{LS} + \gamma_{LV} \cdot \cos\theta$$

Simplifications



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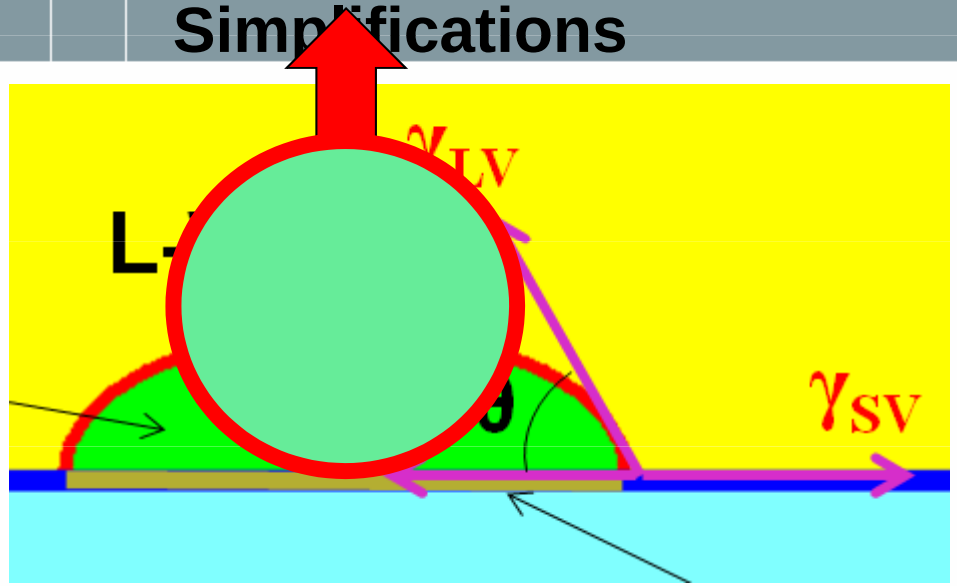
$$\gamma_{SV} > \gamma_{LV}$$

Complete Wetting

Simplifications



Equilibrium State:

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Simplifications: [For Wetting @ lower θ value]

$\theta \to 0, \quad \cos\theta \to 1$

$Neglect \ \gamma_{LS}$

$$\gamma_{SV} = \gamma_{LS} + \gamma_{LV} \cdot \cos\theta$$

$\gamma_{SV} > \gamma_{LV}$ → **Complete Wetting**

$\gamma_{SV} < \gamma_{LV}$ → **Non-wetting (Hydrophobic)**

2 Hydrophobicity

Hydrophobicity [For water]

Droplet

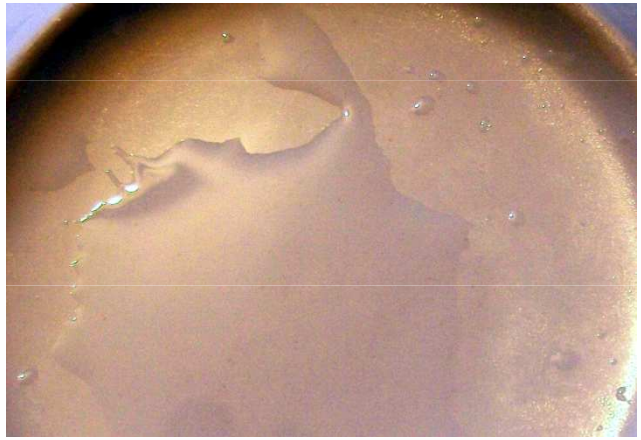
Teflon

γ = 18 dyne/cm

Ceramic

γ = 500-5000 dyne/cm

Water Film



Water

γ = 73 dyne/cm

Water

Glass

γ = 500 dyne/cm

Metal

γ = 500-5000 dyne/cm

Water Film

Fundamentals: Surface Area

$$Surface\ Energy = A \cdot \gamma_j$$

A ------ Surface Area

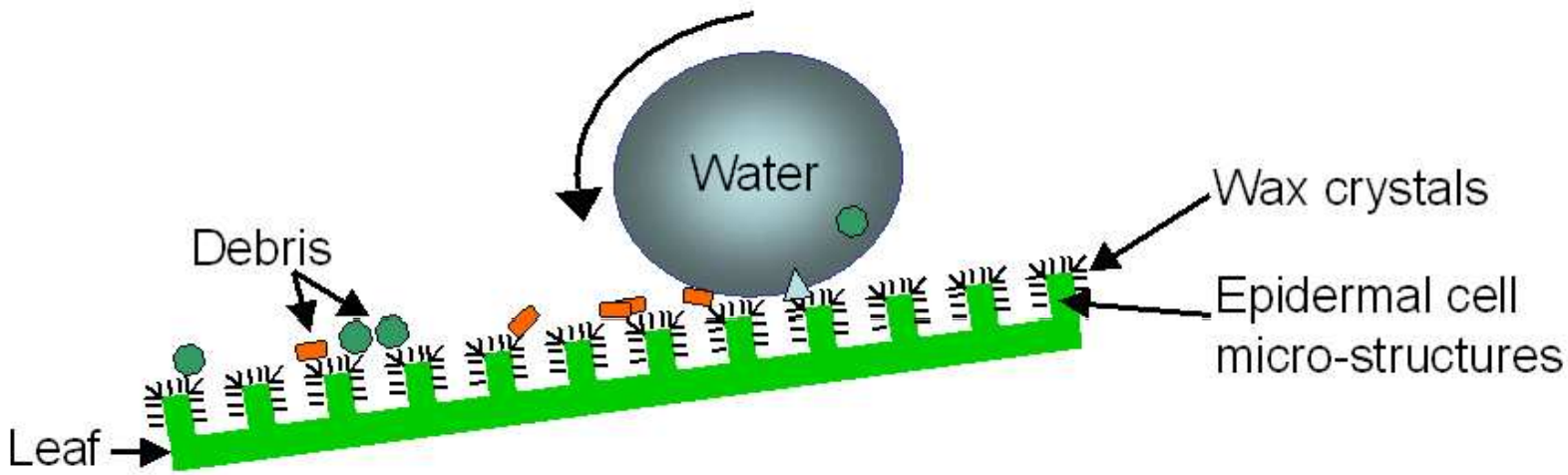
γ_j ------ Specific Surface Energy

?

Lotus Effect & Bio-mimic Material

Photo Source: http://en.wikipedia.org/wiki/File:Lotus3.jpg

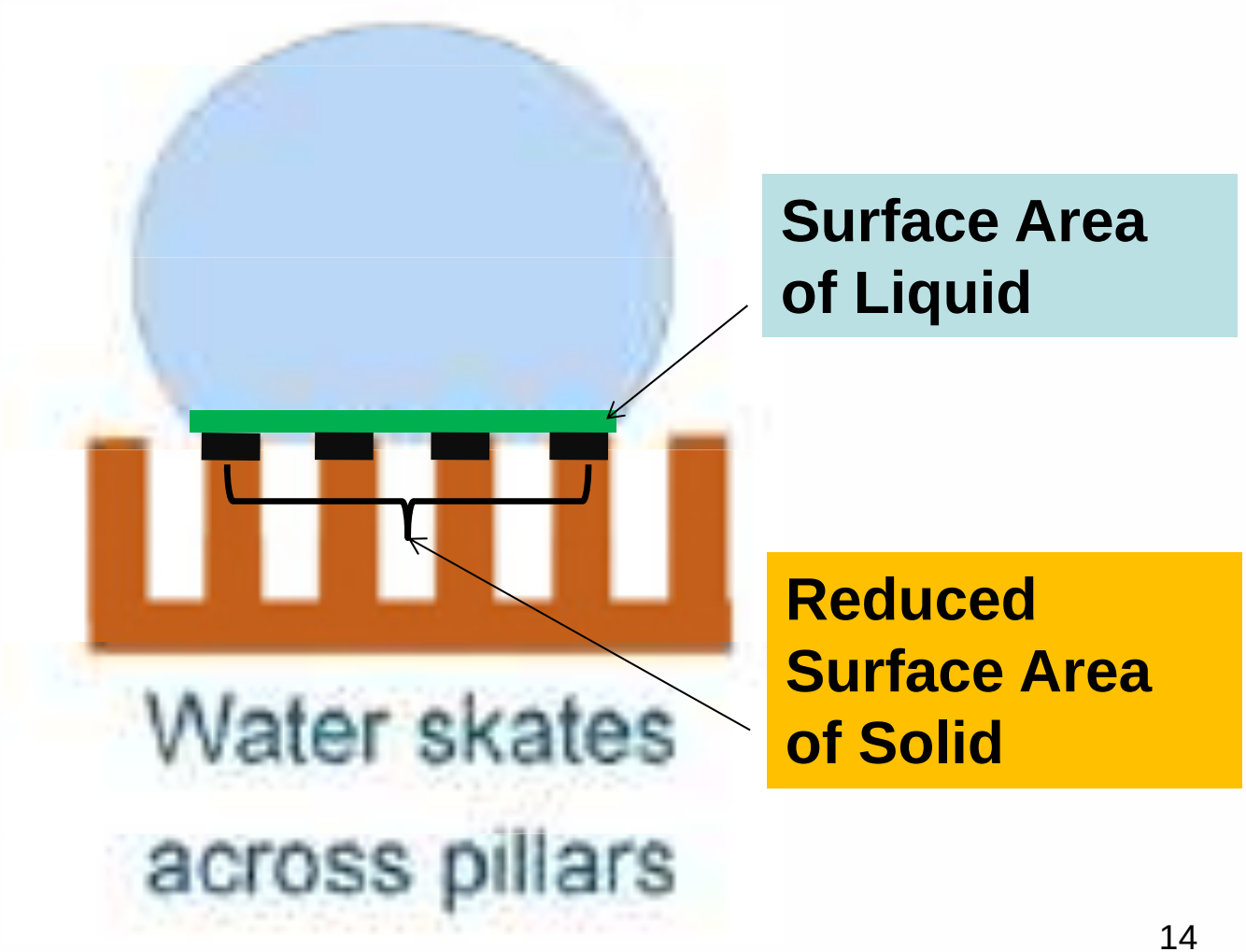
Lotus Effect & Bio-mimic Material



Lotus Effect

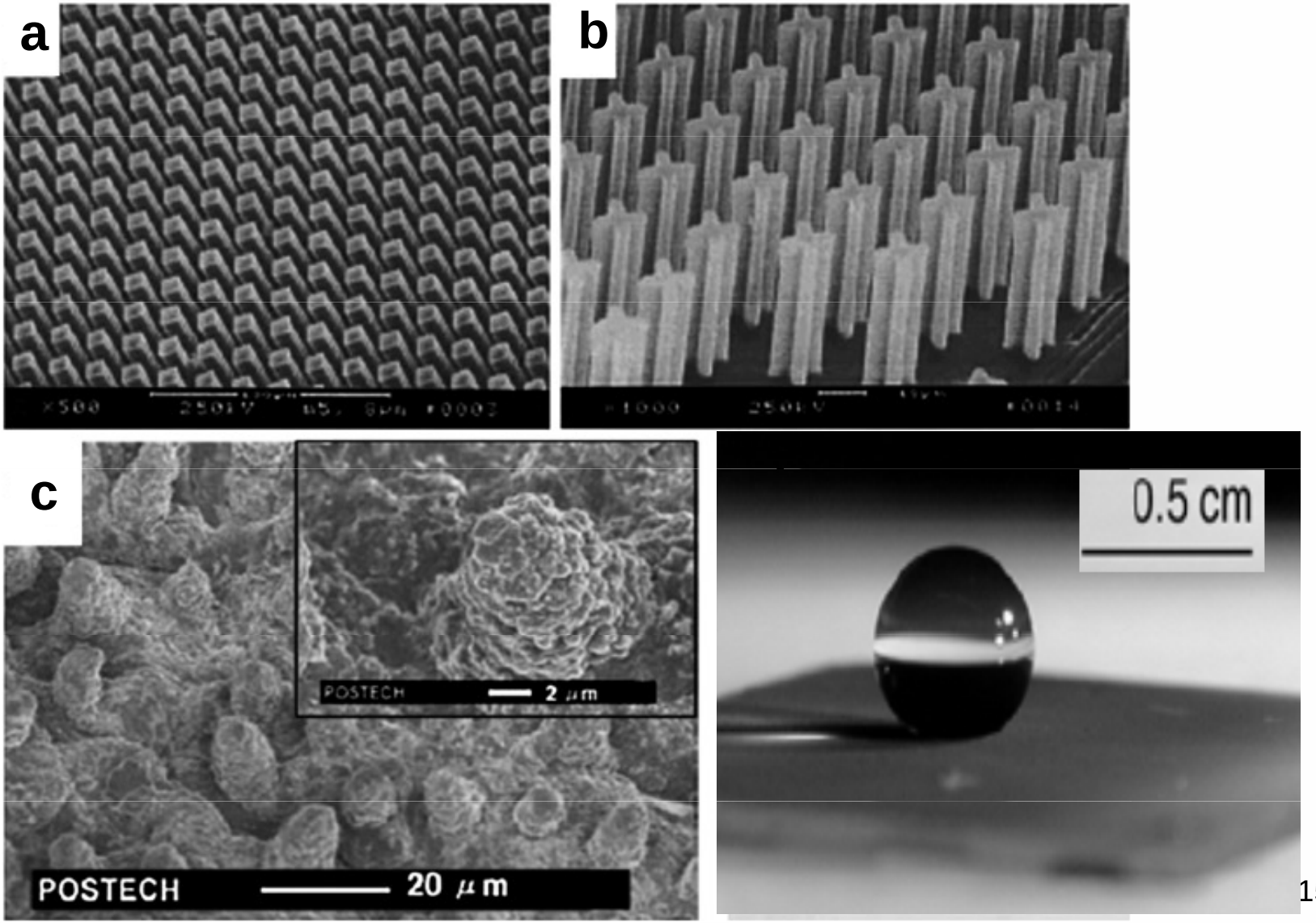
Photo Resource: http://www.thenakedscientists.com/HTML/uploads/tx_naksciimages/lotus_leaf_jpg.jpg

2 Hydrophobicity



Ref: Shirtcliffe, 2010

Printing or Etching: → Hydrophobic, even metal surfaces



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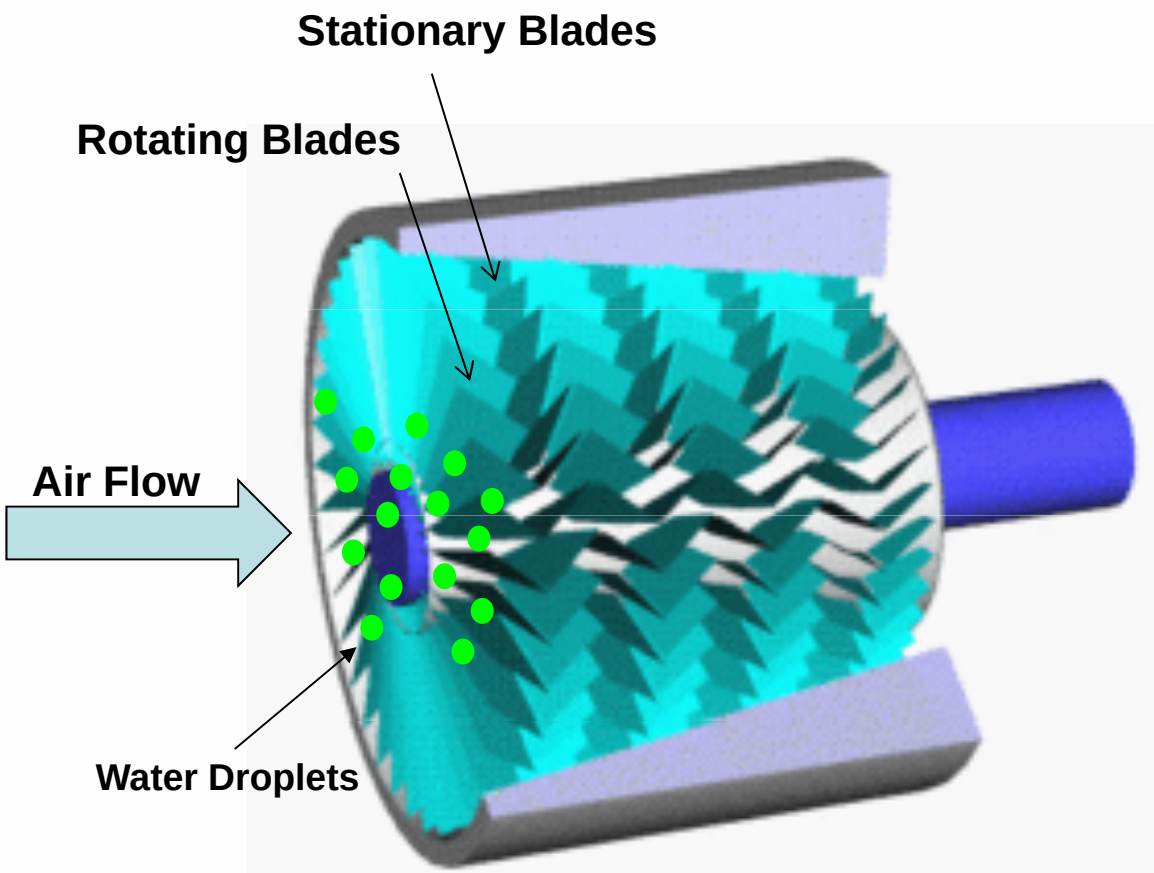
Turbine Inlet Cooling-–-– Why there is water?

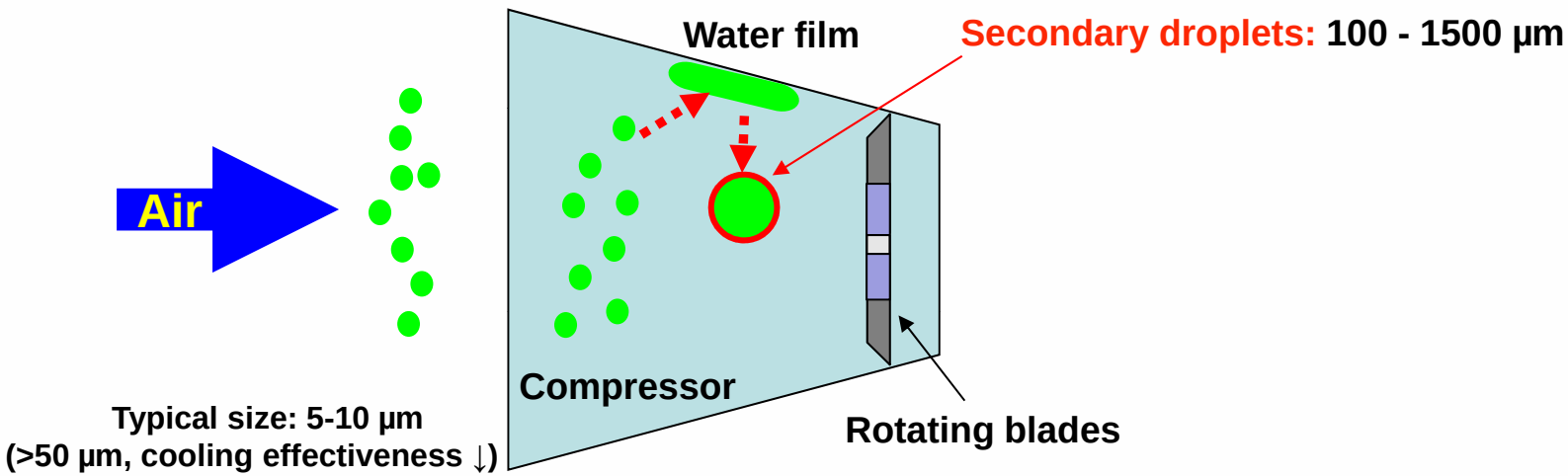


Gas Turbine Compressor

Photo Source: http://www.wikipedia.org/turbojet

Droplet Erosion Issues --- droplet size

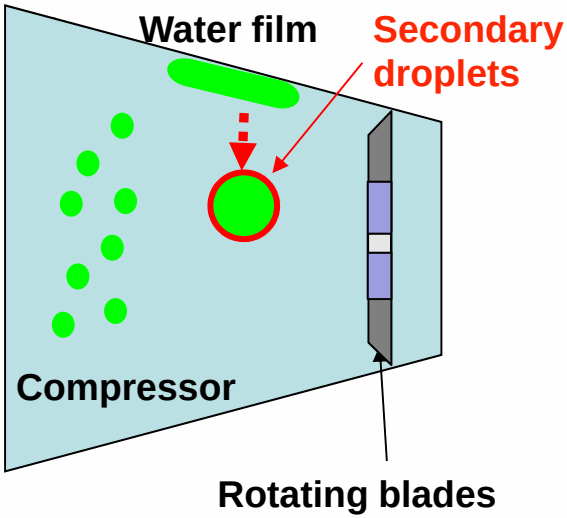
Secondary Droplets



Data Source: Khan. 2009.

Why & Why Not?

Why Hydrophobic? → **Water repellence.**
Prevent water film.
Reduce secondary droplets.



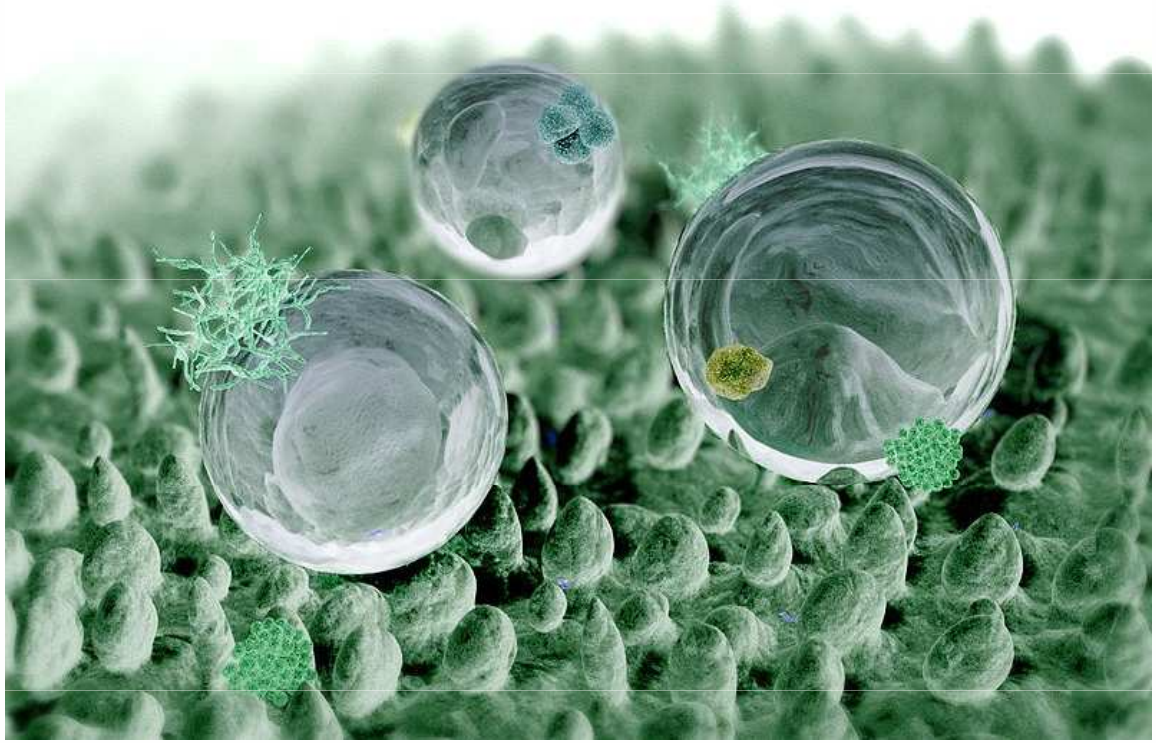


Photo Source: http://en.wikipedia.org/wiki/File:Lotus3.jpg

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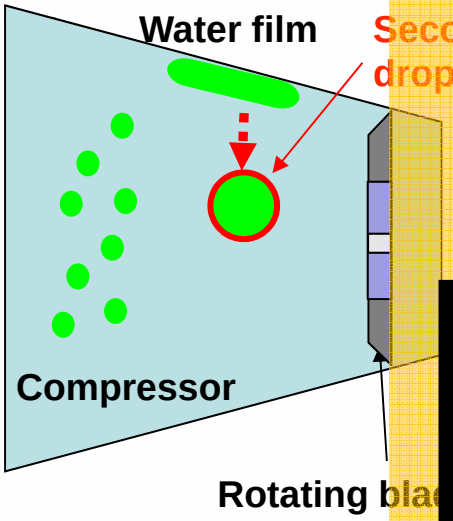


Why Not?

Photo Source: http://en.wikipedia.org/wiki/File:Lotus3.jpg

Dominant Factor: Dynamic Load, Momentum

Static Load

Photo Source: http://images.google.com

Dominant Factor: Dynamic Load, Momentum

Photo Source: http://images.google.com

Static Load

Dominant Factor: Dynamic Load, Momentum

speed

Dynamic Load

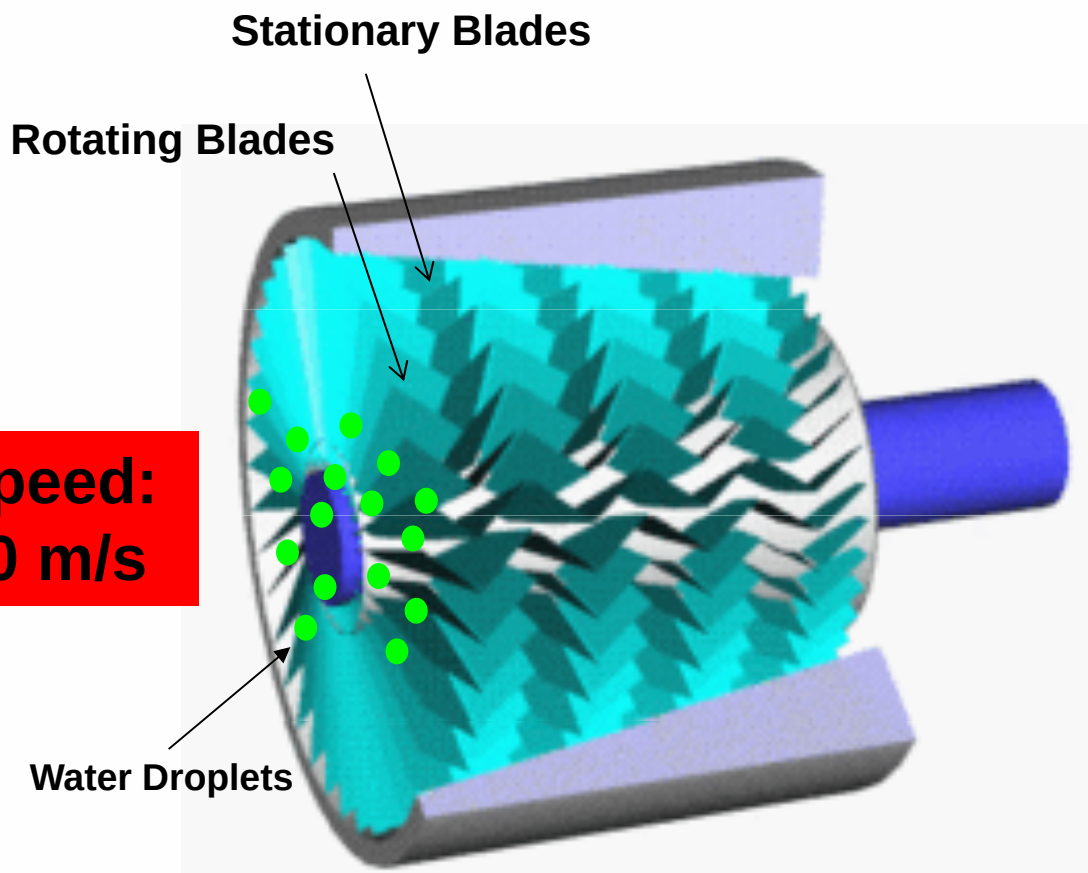
Momentum

Overwhelms

Surface Tension

Photo Source: http://images.google.com

Turbine Inlet Cooling-–-– Why there is water?



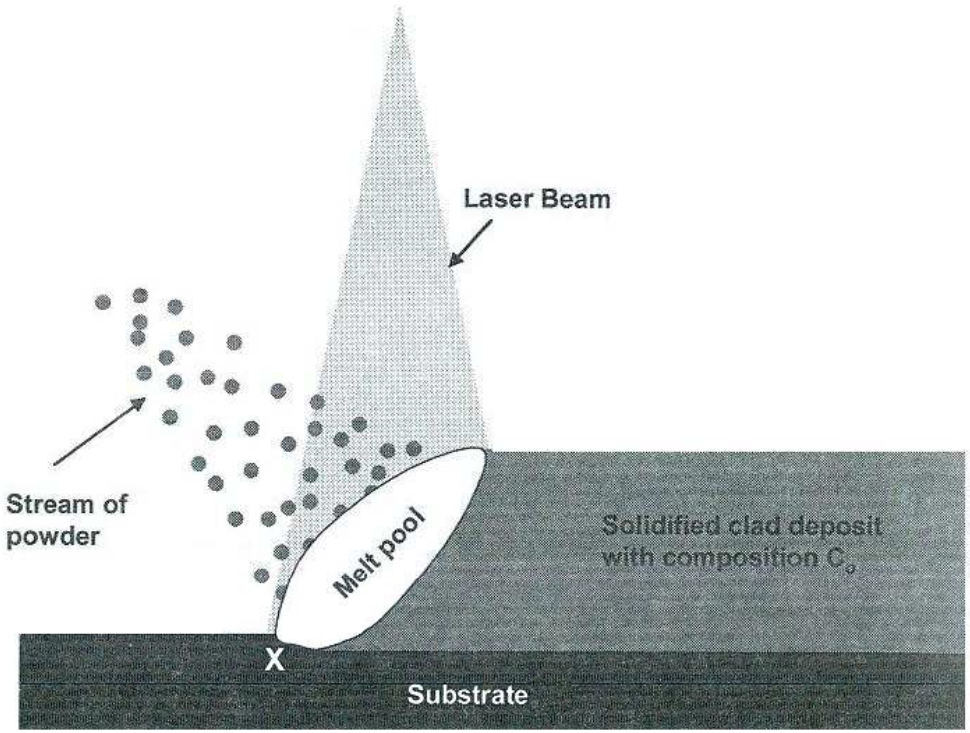
Impact Speed: Up to 500 m/s

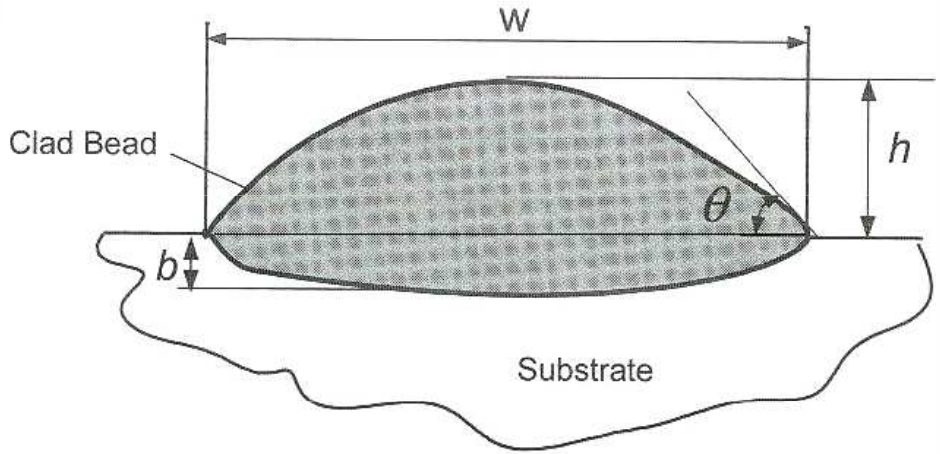
Gas Turbine Compressor

Photo Source: http://www.wikipedia.org/turbojet

3 Wetting in Laser Cladding

Non-equilibrium State @ Laser Cladding





$$dilution = \frac{b}{h+b} = \frac{1}{\frac{h}{b}+1}$$

Dilution ∝ Laser Power

h/b ∝ 1/ power

Ref: Toyserkani, 2005

Non-equilibrium State @ Laser Cladding

Spreading Factor: $S = \gamma_{SV} - \gamma_{LV} - \gamma_{LS}$

Laser Power ↑ ⇒ Temperature ↑ ⇒ γ_{LV} ↓

⇒ S ↑ θ↓ (wetting ↑)

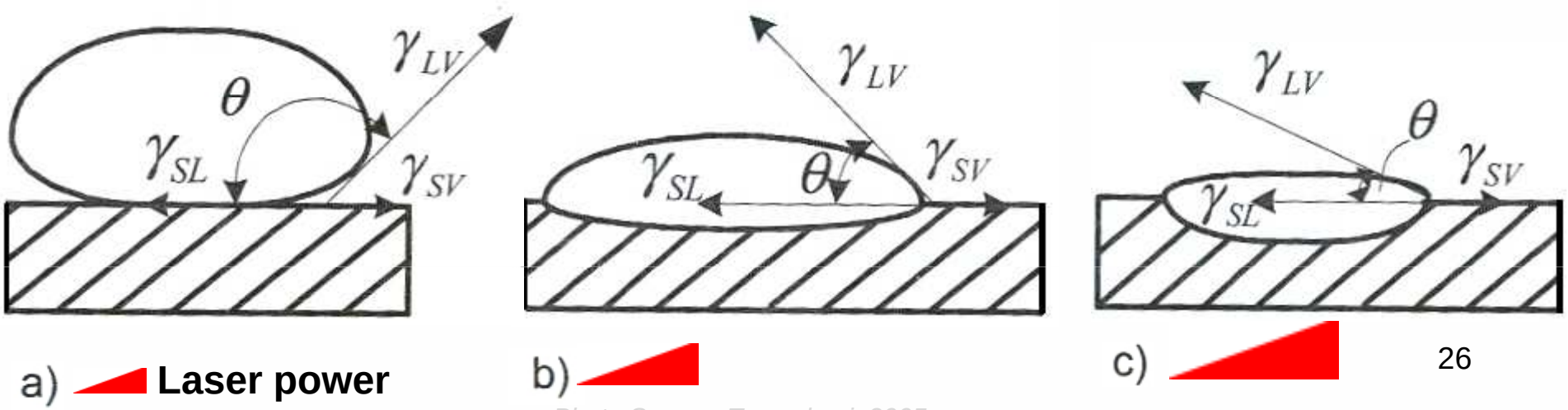


Photo Source: Toyserkani, 2005

Effect of oxidation

Spreading Factor: $S = \gamma_{SV} - \gamma_{LV} - \gamma_{LS}$

γ (Al)= 1674-1923 dyne/cm

γ (Al_2O_3)= 580 dyne/cm

Oxidation

Raw Material

- Grinding
- (Deoiling)

Laser Heating

- Inert gas
- Reduce laser power ?

Data Source: Bondi, 1952

Thank you!