

# Large-scale chemical and physical texturing of surfaces for engineering and biomedical applications

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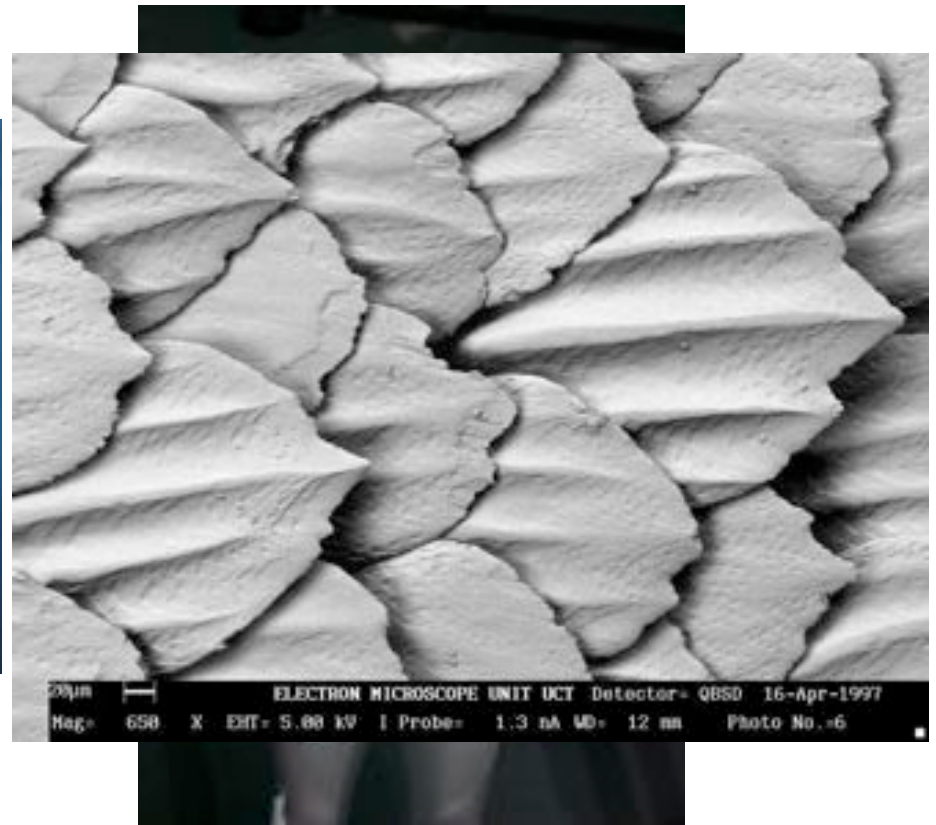
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Department of Mechanical Engineering

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# What surface texture?

- Natural and artificial
- Macro and micro

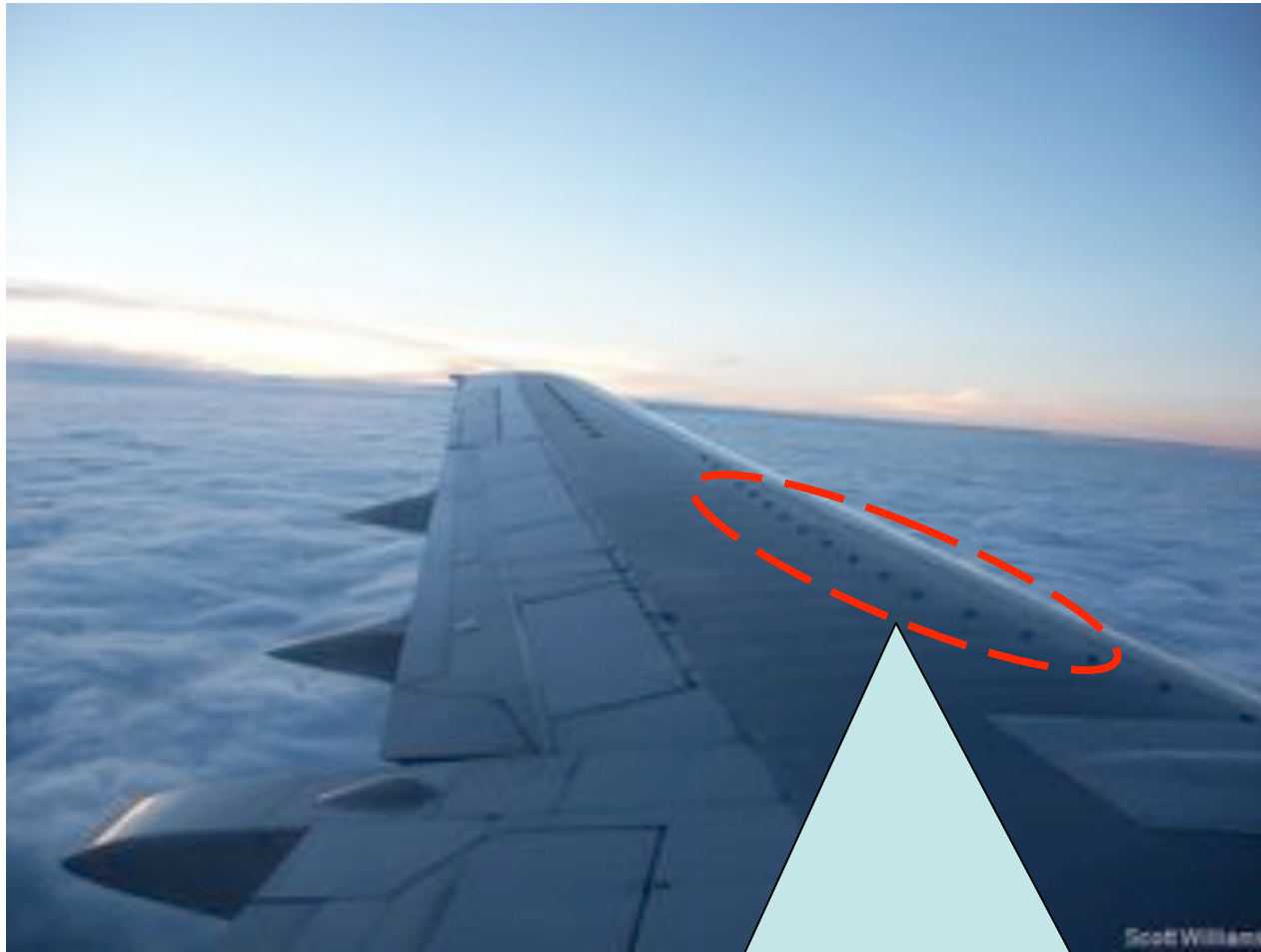


# What's old is new again

Surface texturing to improve performance is an old hat



# Roughening airplanes

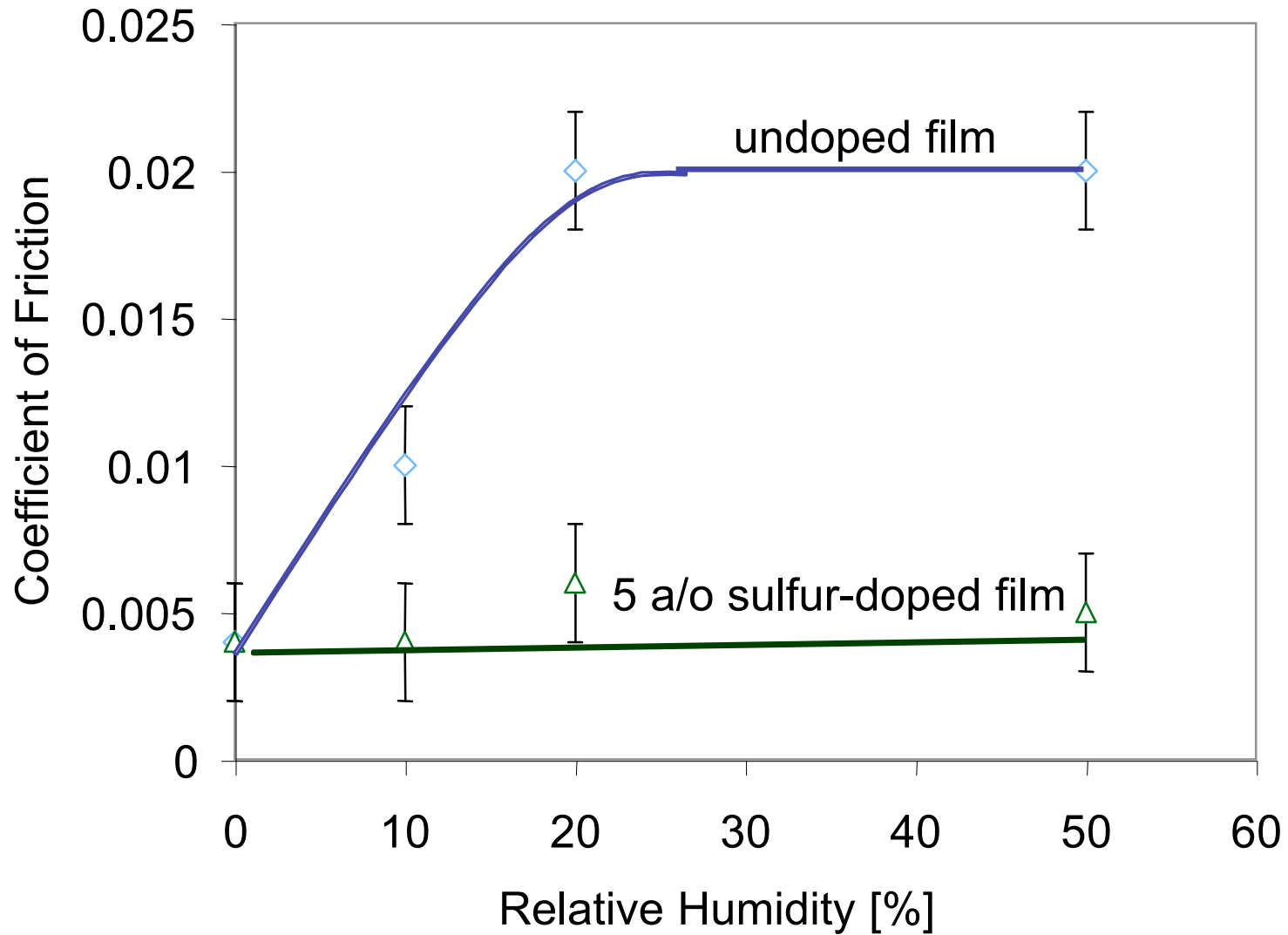


737 wings textured with vortex generators to reduce drag and increase lift, especially at low air speeds

# Other applications of surface texturing

- Increase optical absorption
- Control hydrophobicity
- Reduce friction and wear
- Manipulate growth of algae/bacteria/cells
- .....

# Coatings (chemical texturing)



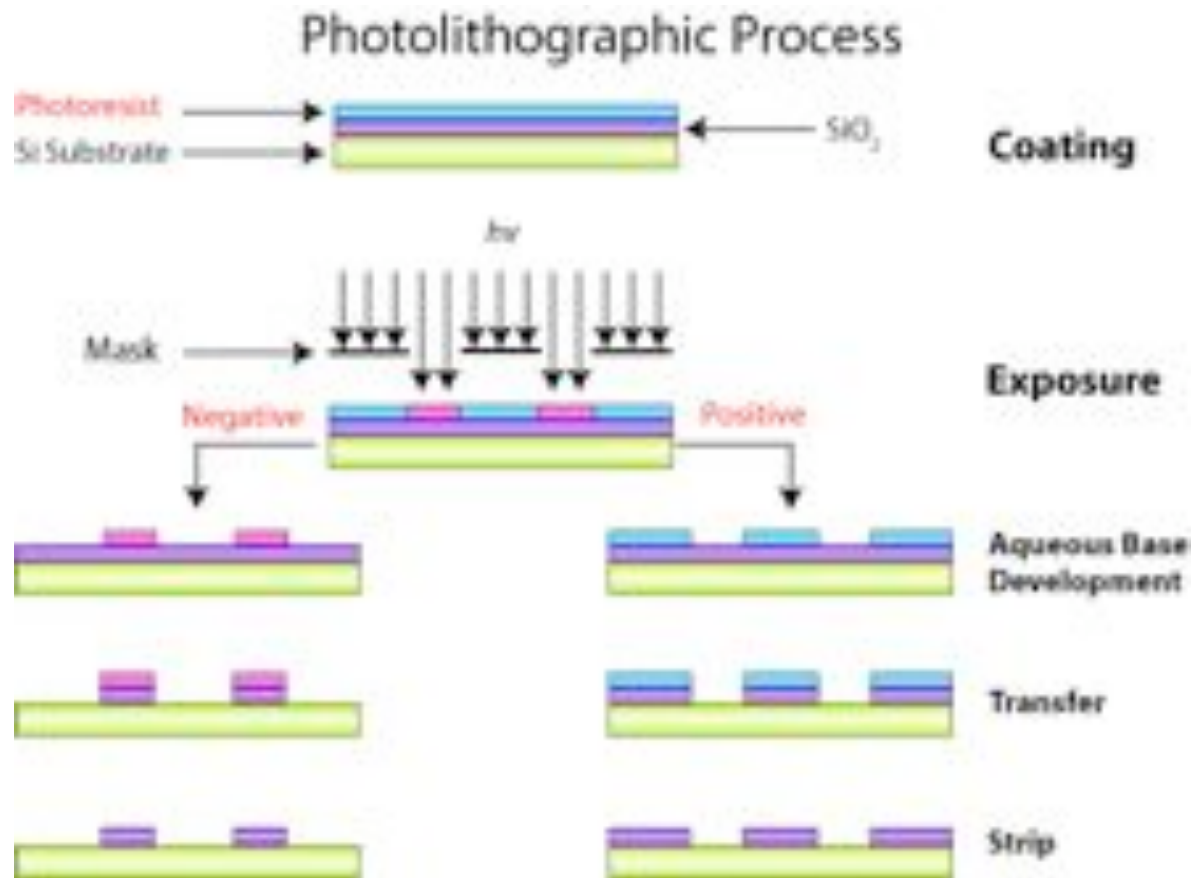
# Surface texturing methods

Two broad categories involving chemical and physical methods:

- Lithography
- Direct write

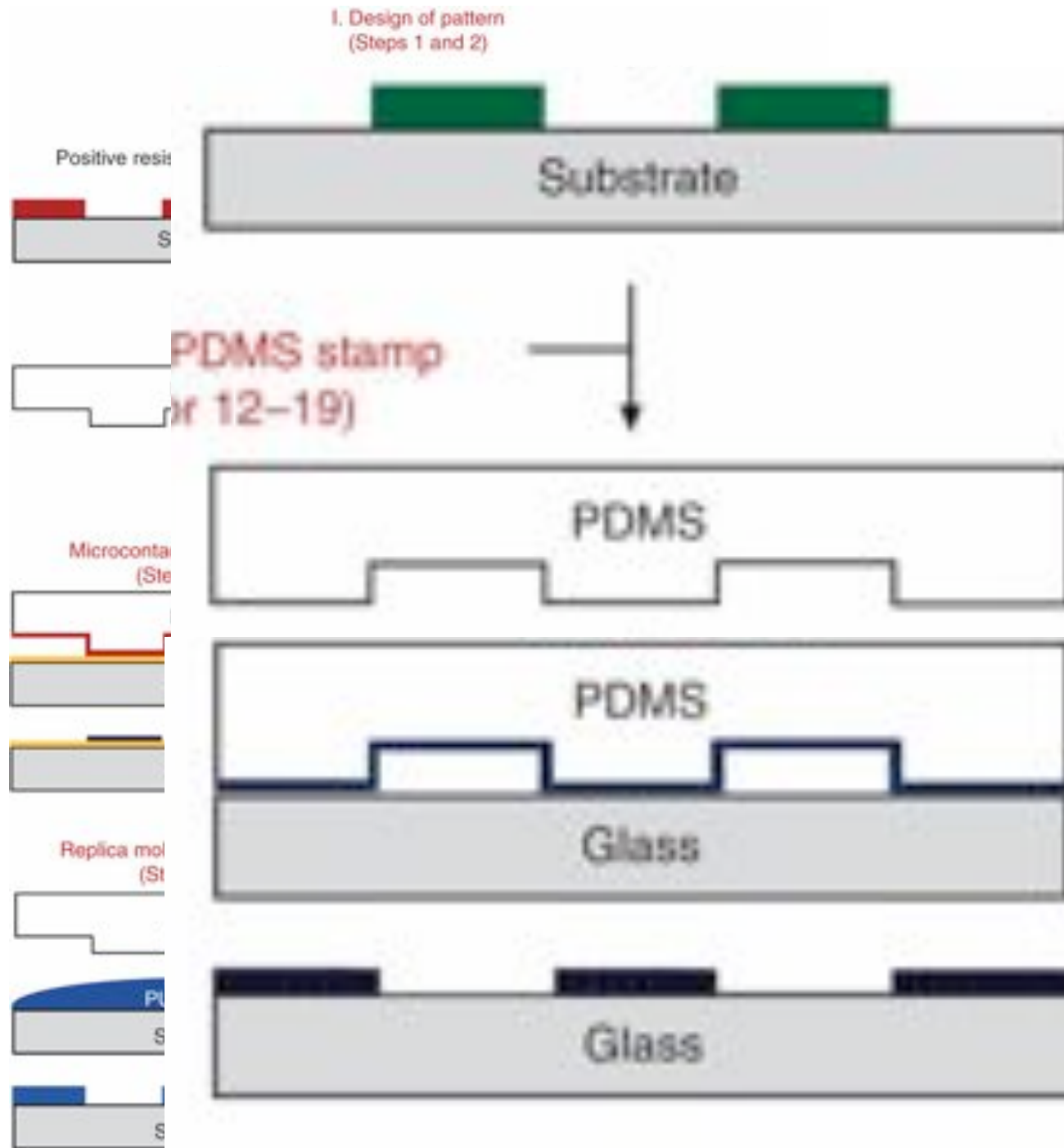
# Lithography

Old standby: photolithography





# Soft Lithography



# Micro-texturing stainless steel.1

## Preparing the steel substrate

Nail polish was diluted in acetone in a 1:2 ratio. The solution was spin-coated on the steel surface at 3000 RPM to create a thin polymer layer.



## Making the stamp

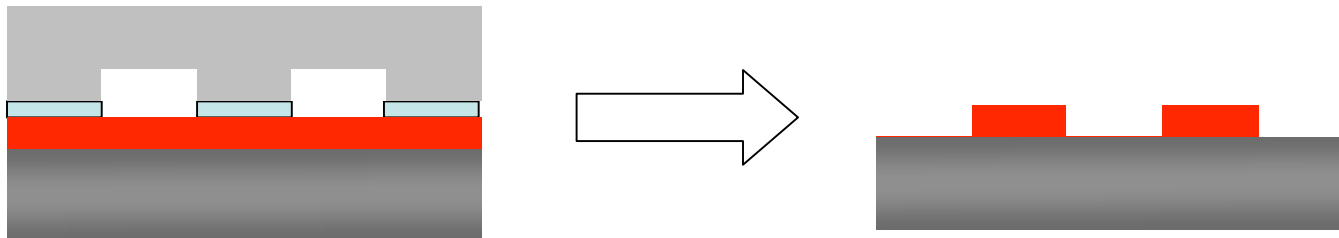
Use lithographic technique to produce a PDMS stamp with the required texture (2-micron lines)



# Micro-texturing stainless steel.2

## Making the pattern

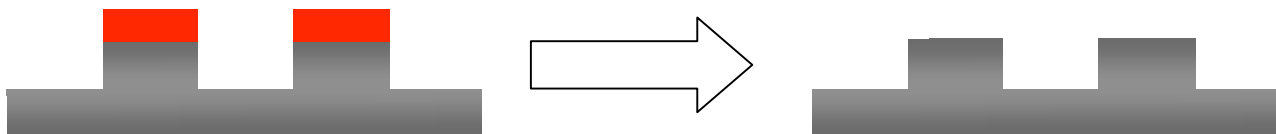
A drop of acetone was put on the stamp, and the substrate was placed on top. Where the high features of the stamp contact the steel surface, the acetone dissolves the nail polish, thus replicating the stamp pattern.



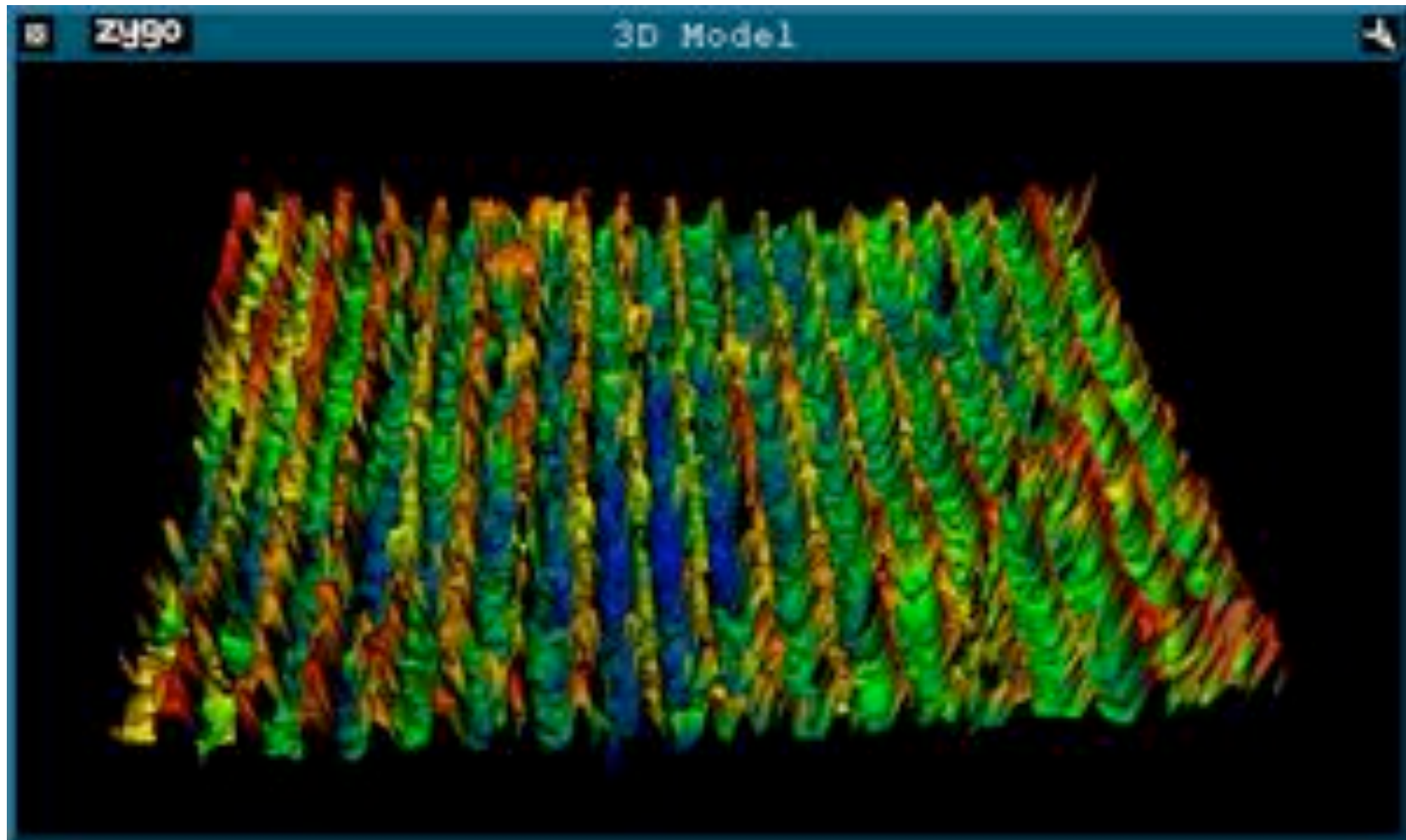
# Micro-texturing stainless steel.3

## Developing the pattern

- The steel substrate was put into an etchant under sonication, consisting of 70% w/v  $\text{FeCl}_3$  1.37 M HCl. Etching time: 30 - 120 seconds
- Excess etchant was washed away with water.
- The remaining nail polish was washed with acetone, and the substrate was then washed with isopropyl alcohol.



# Micro-texturing stainless steel.4



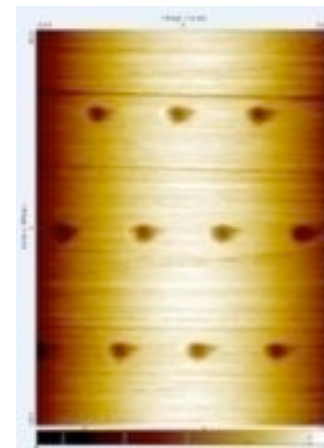
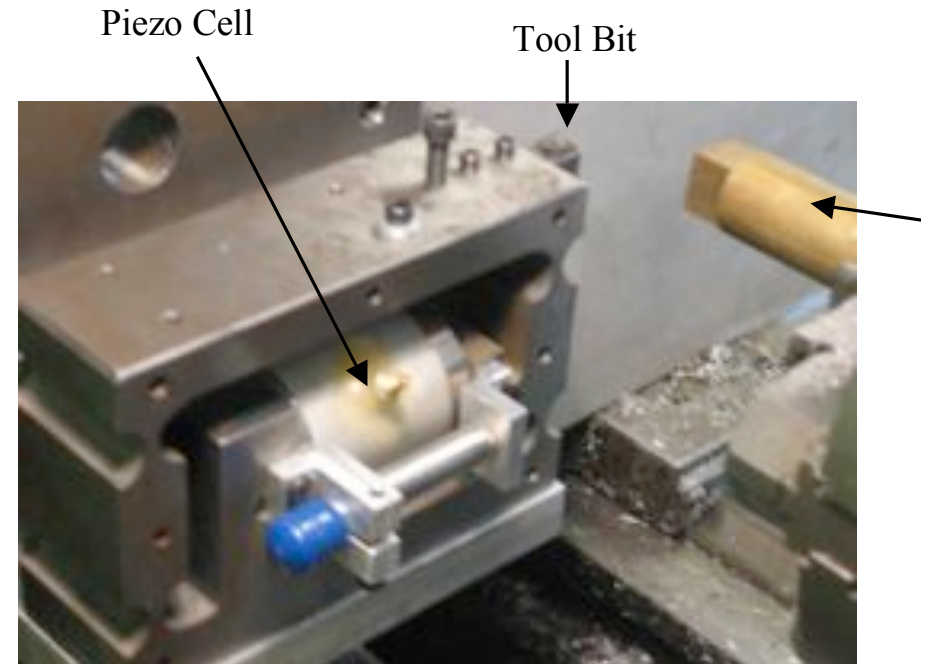
# Direct Write

Three broad approaches:

- Mechanical
- Printing
- Optical

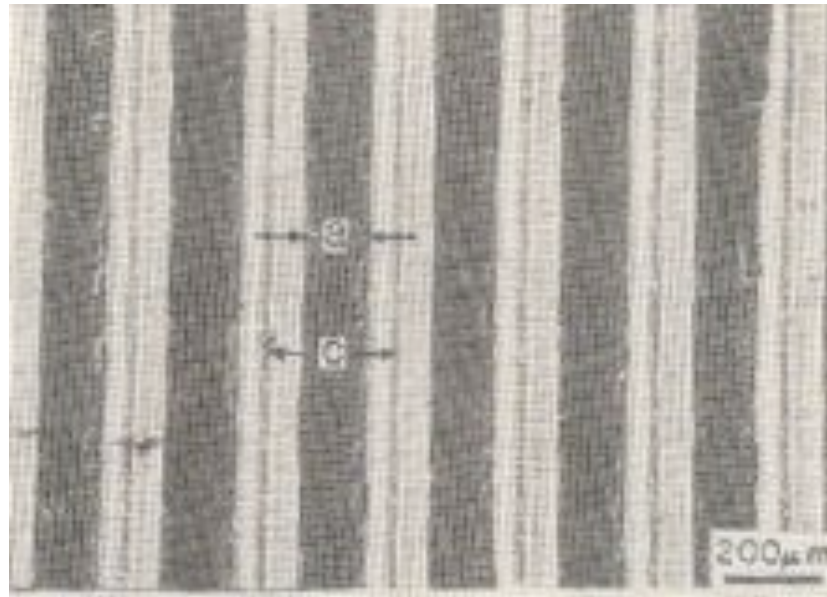
# Direct Write: Mechanical

## *Diamond- or vibro-machining*



# Example of Mechanical Direct Write.1

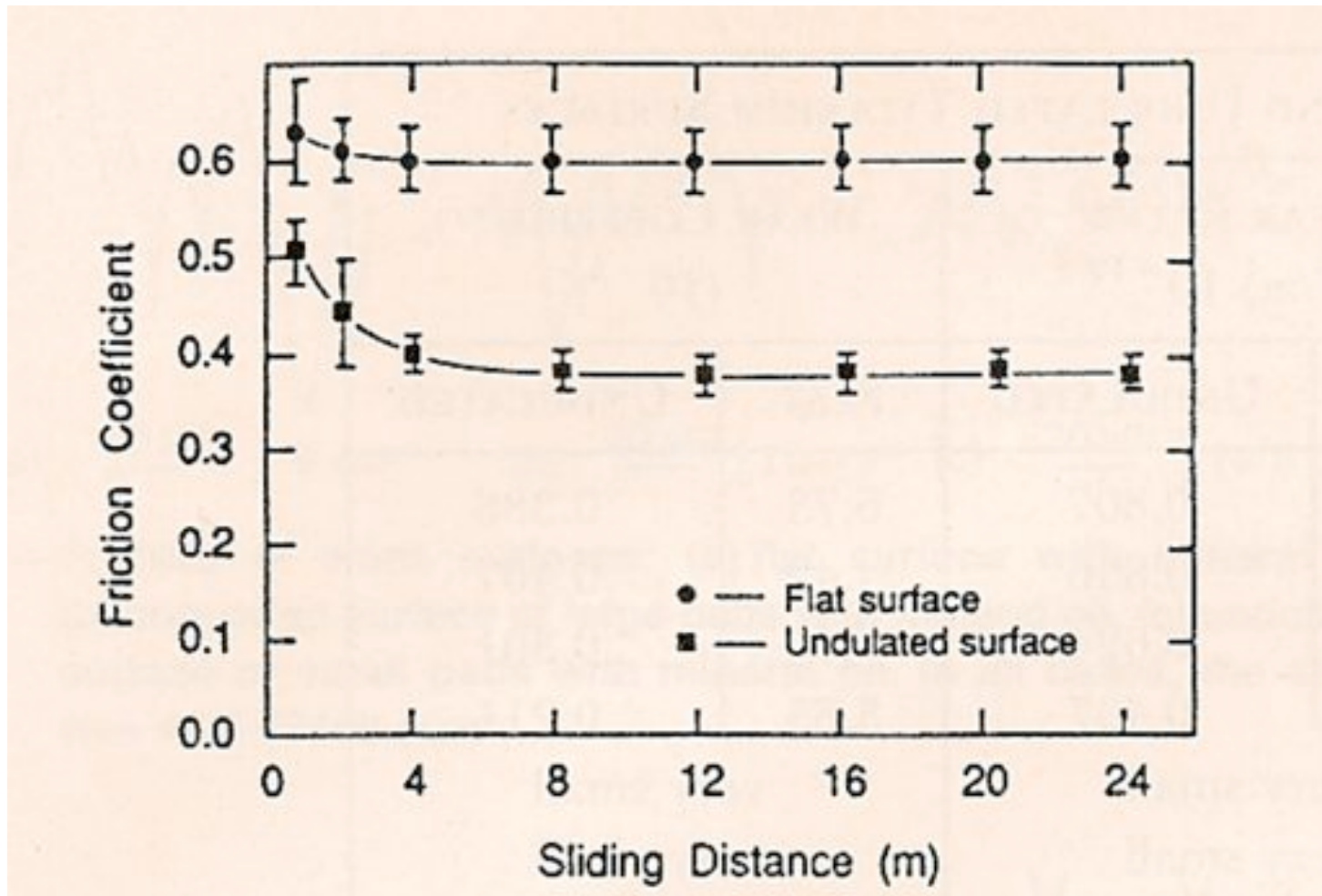
Tian, Saka, and Suh (1989) showed the texture effect on friction by first machining grooves in Ti:





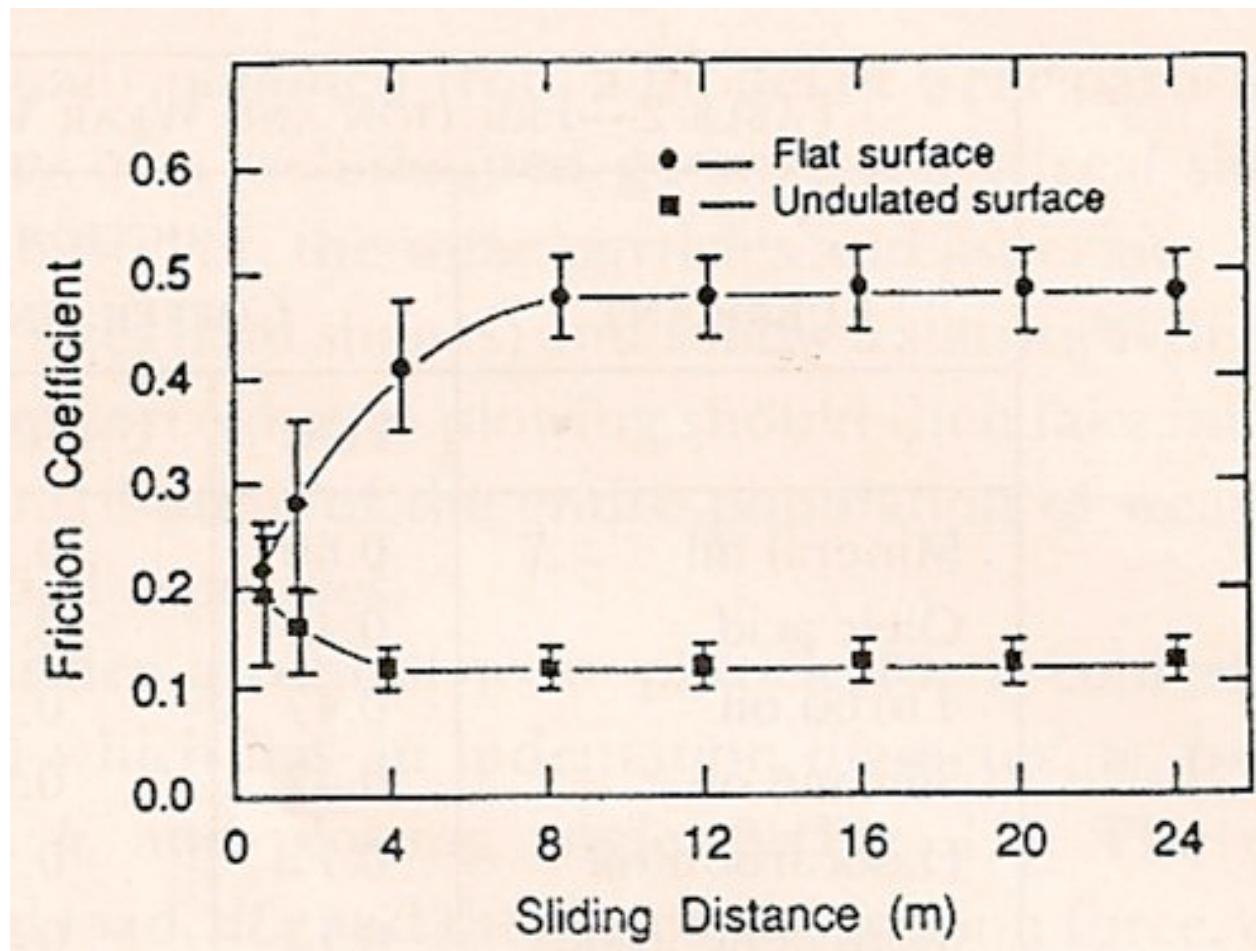
# Example of Mechanical Direct Write.2

52100 sliding on “undulated” Ti with mineral oil as lubricant



# Example of Mechanical Direct Write.3

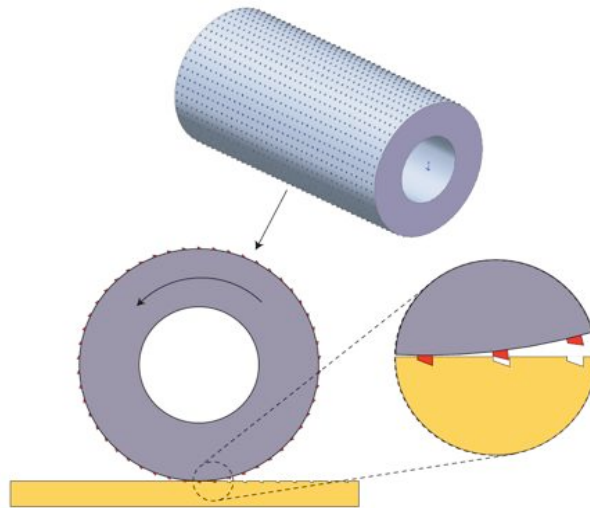
52100 sliding on “undulated” Ti with oleic acid as lubricant



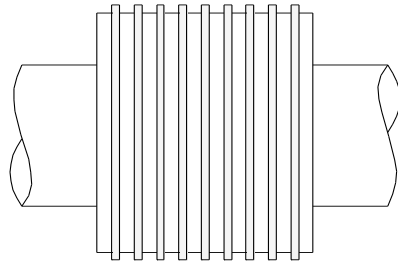
# Direct Write: Mechanical

## *Micro-rolling and -stamping*

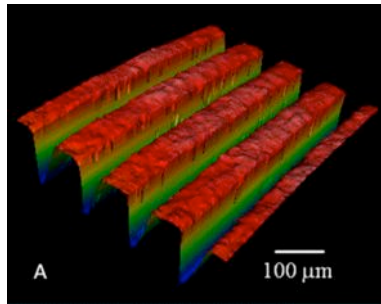
- Mechanical analog of soft lithography
- Texturing fidelity depends on speed and mechanical properties
- Major features: fast, can texture internal surfaces



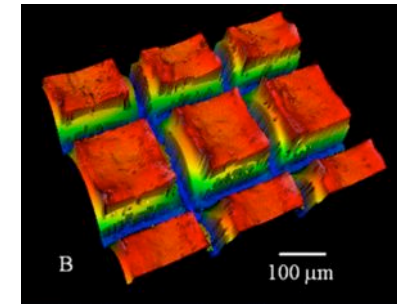
# Mechanical direct write: example



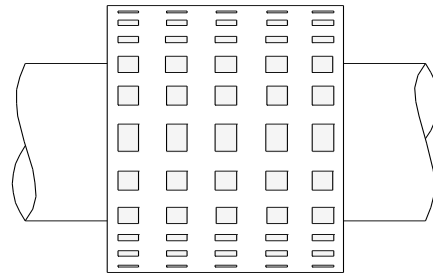
First  
pass



Rotate the sample  
by 90° and roll the  
second pass



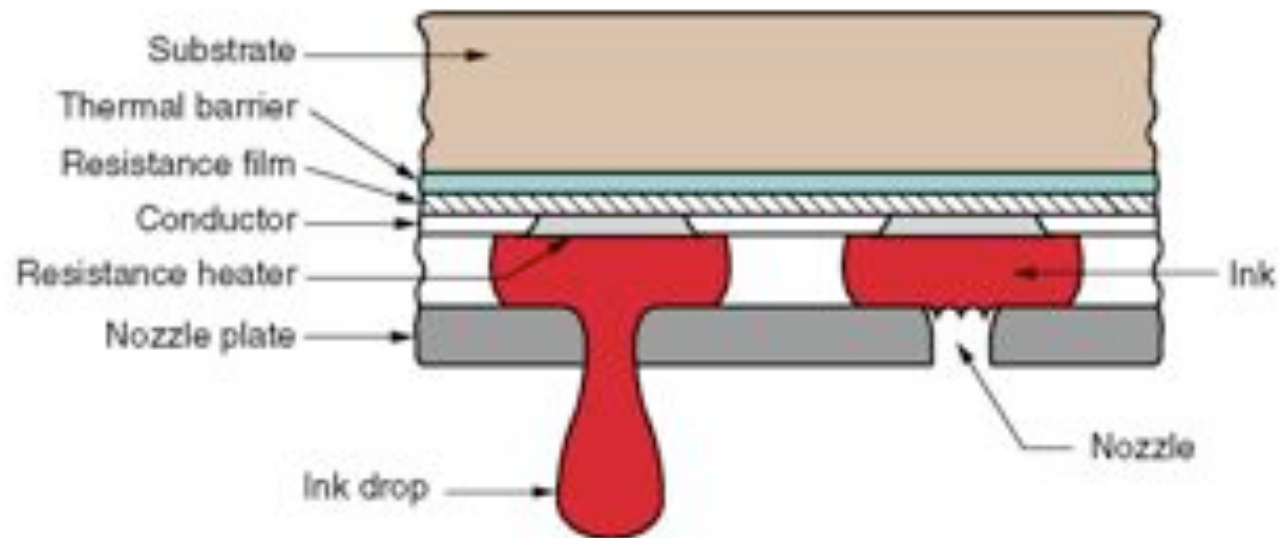
Alternatively



# Direct Write: Printing

## *Traditional ink-jet*

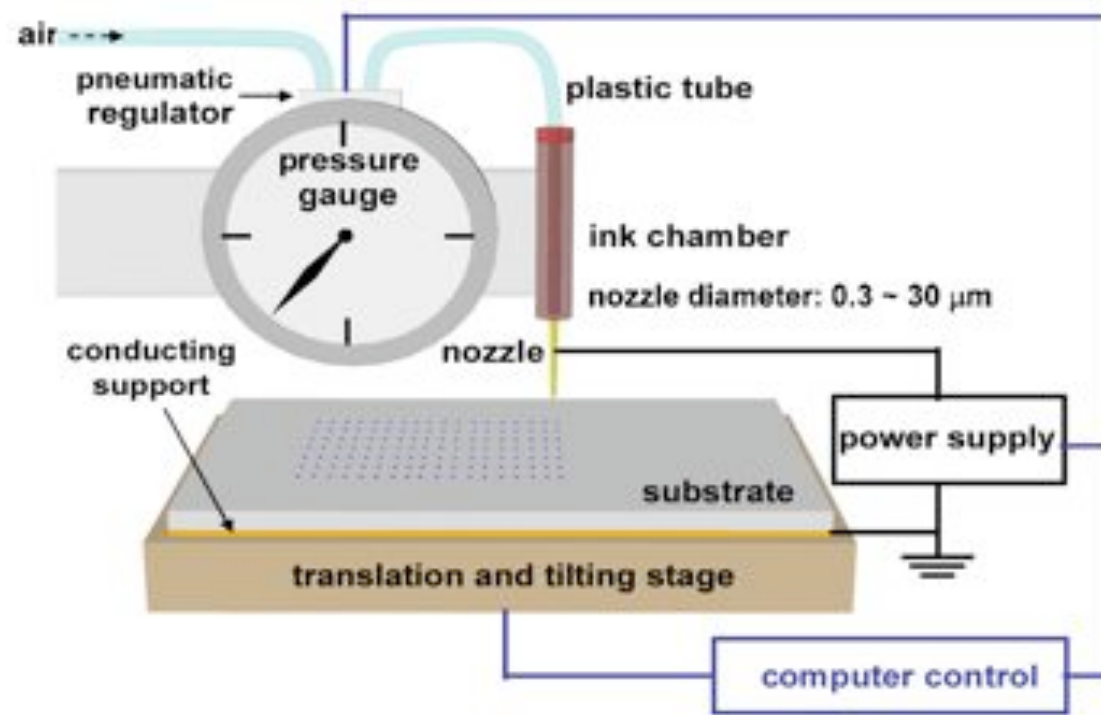
- Relatively fast
- Dot size ~ tens of microns



# Direct Write: Printing

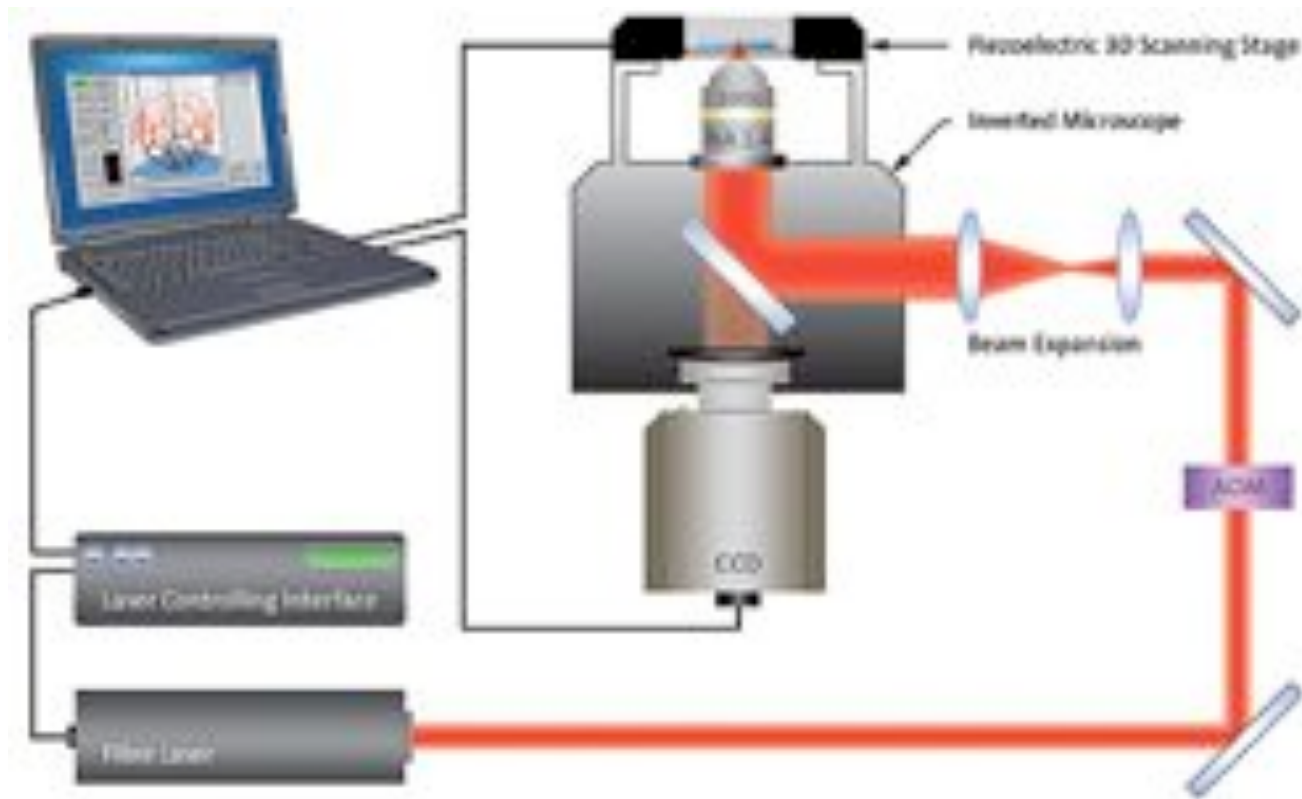
*E-jet printing: pushing the limits*

- Dot size  $\sim 0.1$  micron, line width  $\sim 0.5$  micron
- 500 microns/sec



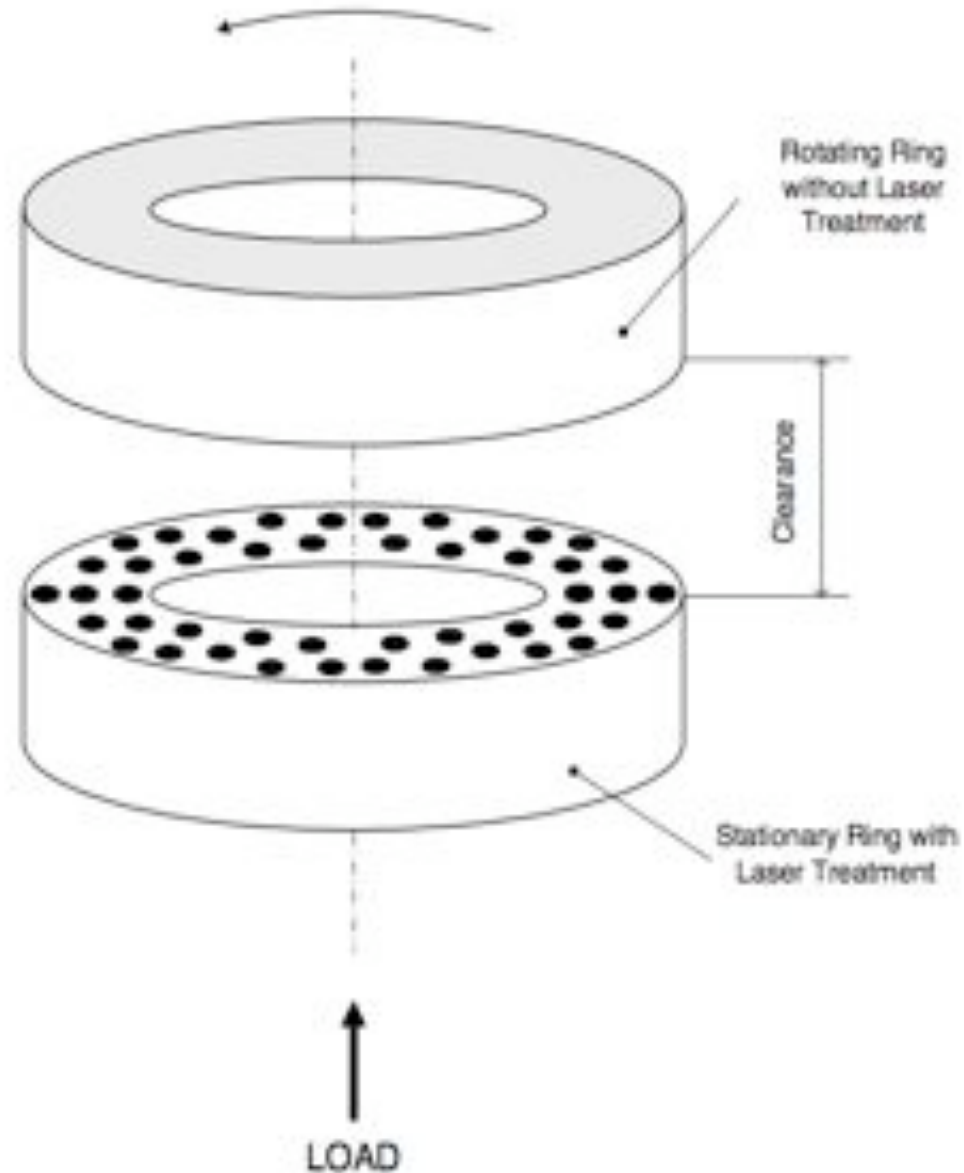
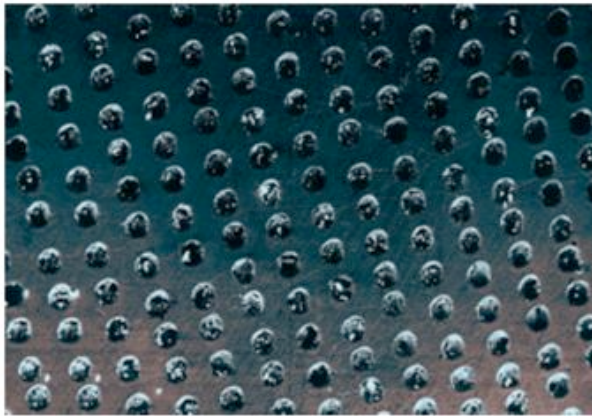
# Direct Write: Optical

## *Laser texturing*



# Example: Laser texturing a mechanical seal

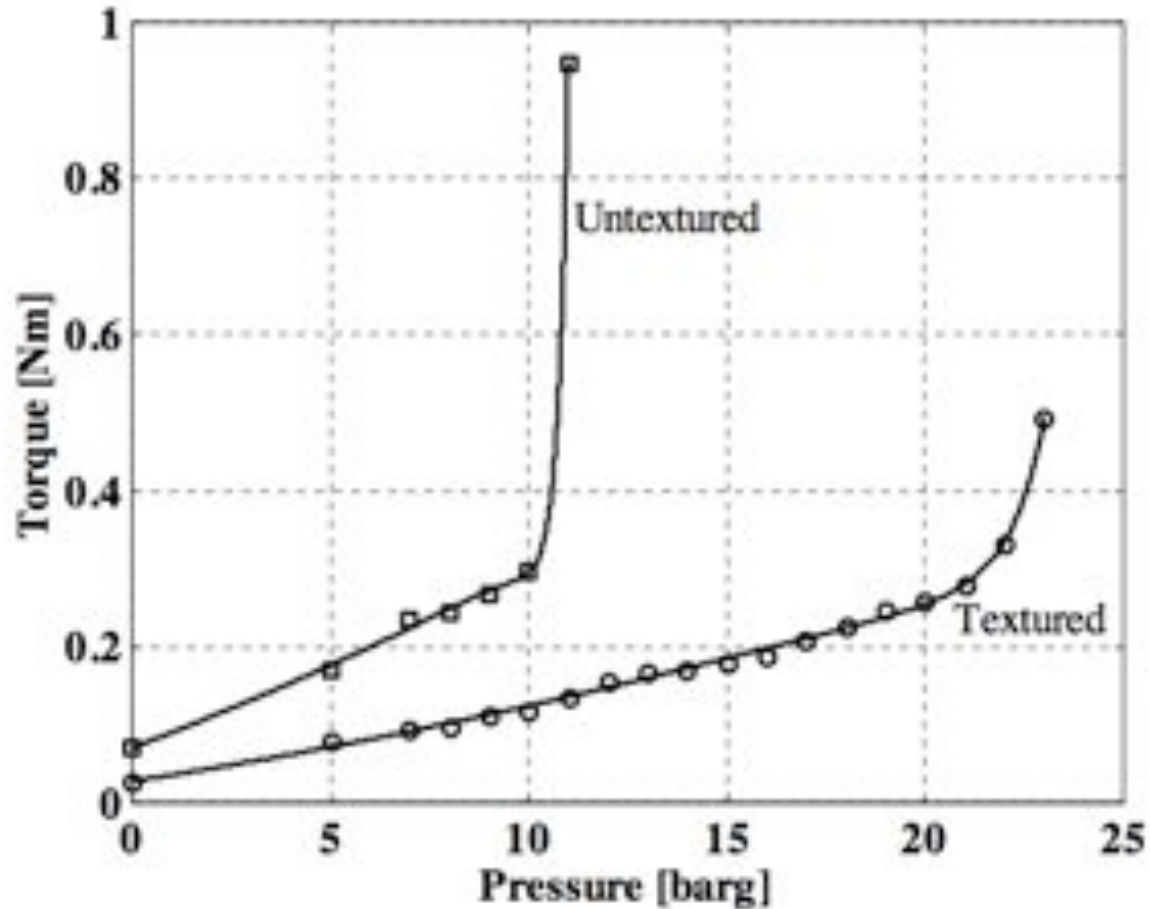
## Test geometry





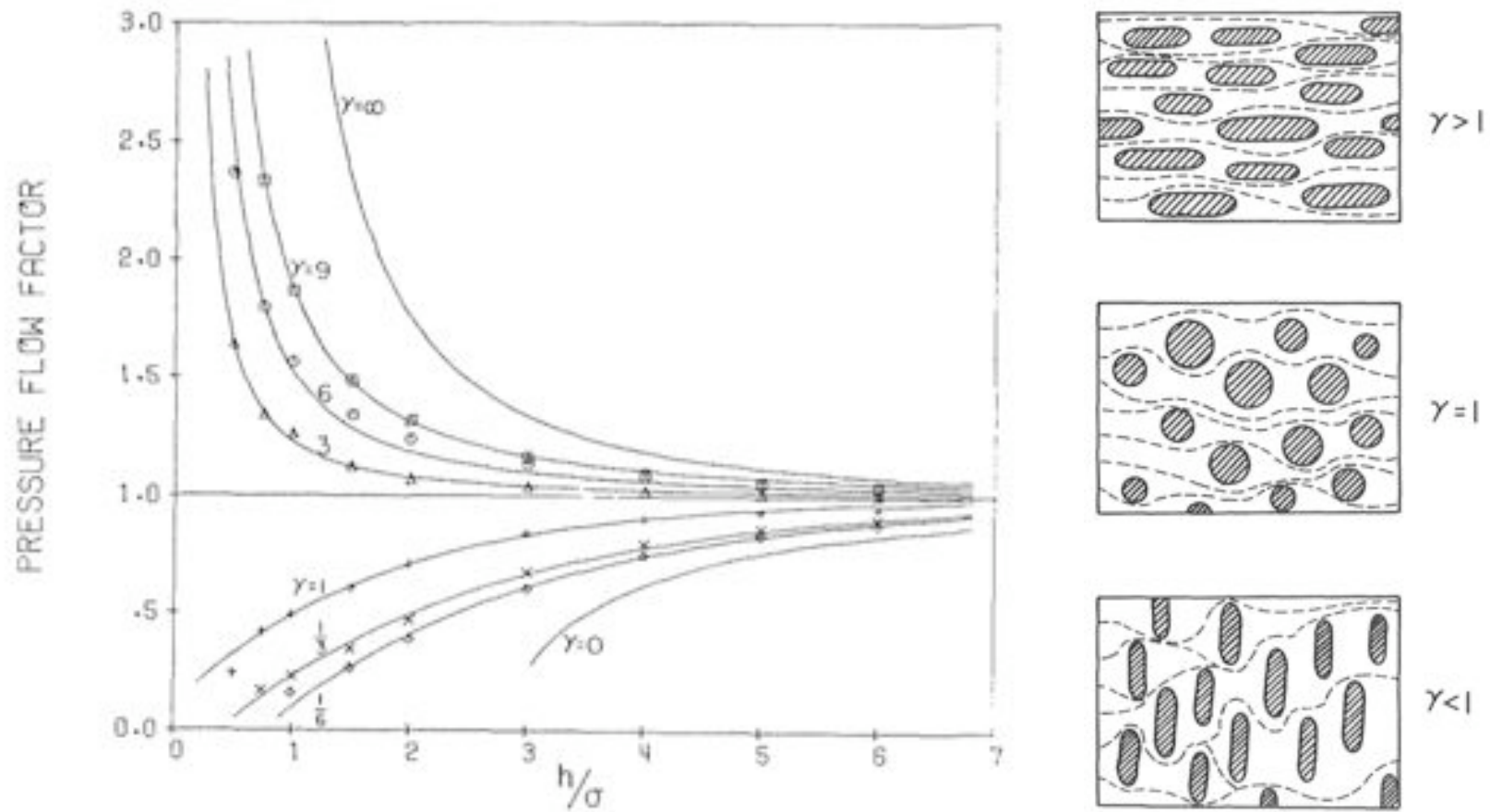
# Example: Laser texturing a mechanical seal

## Test results

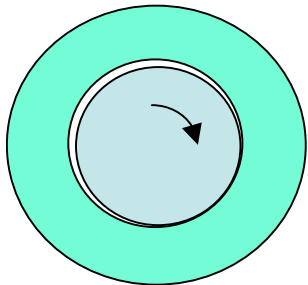
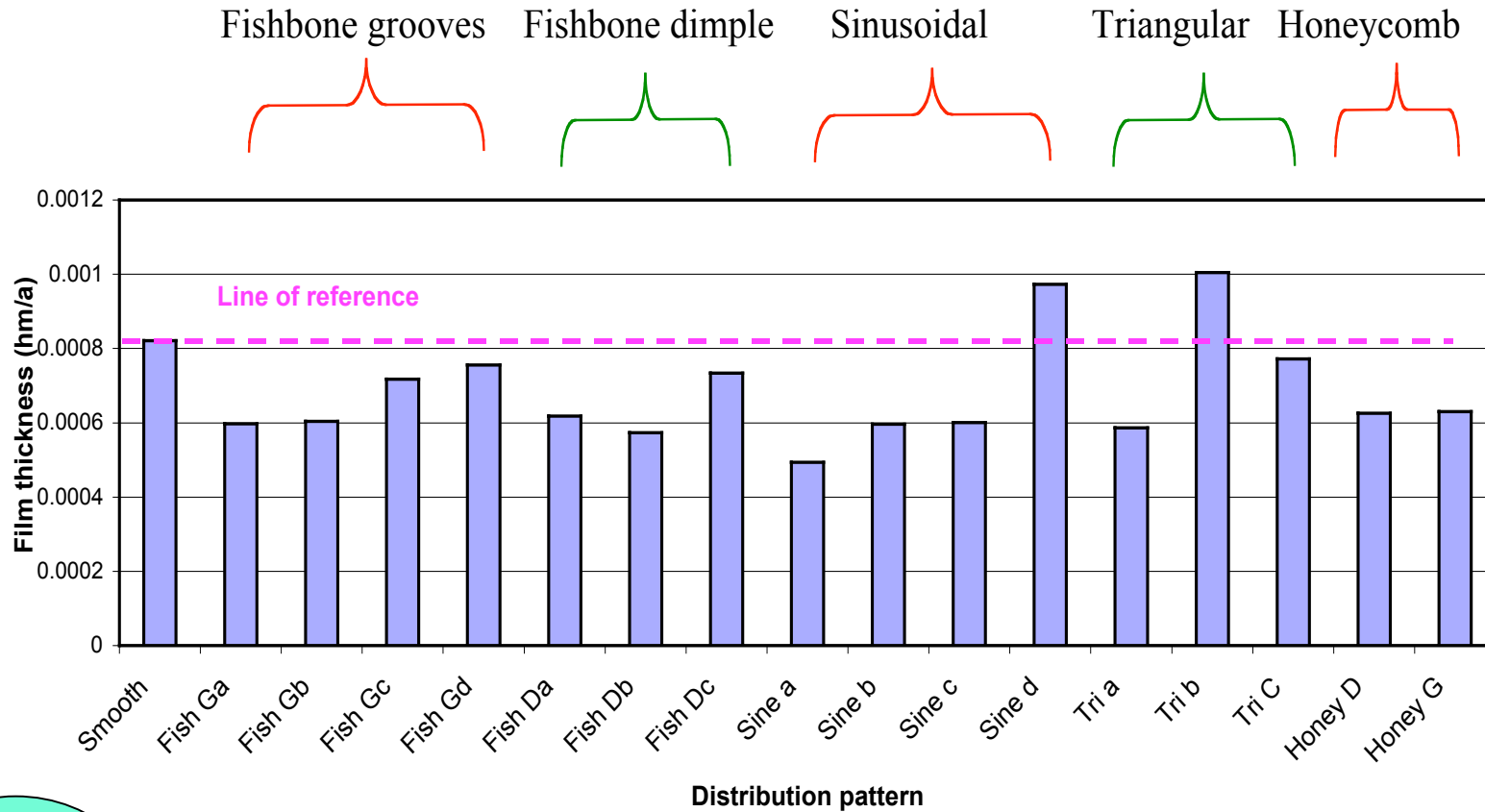


# Effect of texturing on lubrication

Patir and Cheng (J. of Lub Technol 100, 12 (1978)) showed that surface texture affects average lubricant film thickness



# Effect of texturing on lubrication



Distribution pattern  
 Feature size  $\sim 58-140 \mu$ ; depth  $\sim 4-6.5 \mu$

*Ren, N., Nanbu, T., Yasuda, Y., Zhu, D. and Wang, Q., Tribology Letters 28, 275 (2007)*

# Laser texturing: how far can we push?

- Speed
  - Fundamental limit:  $\sim$  one dot/ps for ps lasers
  - Practical limit: texture density and depth
- Resolution
  - Far field limit: diffraction
  - Practical limit: optics and material
- Substrate curvature
  - Flat *vs* curved



*CMS-0619284*

*CMII-0923000*

# Laser texturing: how far can we push?

*Texturing a curved surface*



- 200-micron diameter dimples
- 5% coverage density
- Depth ~ 7 microns

# Laser texturing: how far can we push?

## *Resolution*

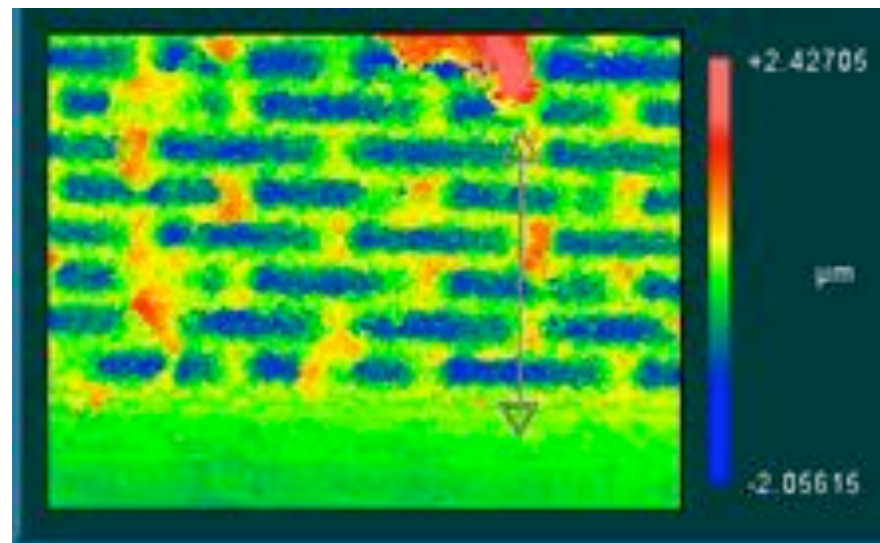
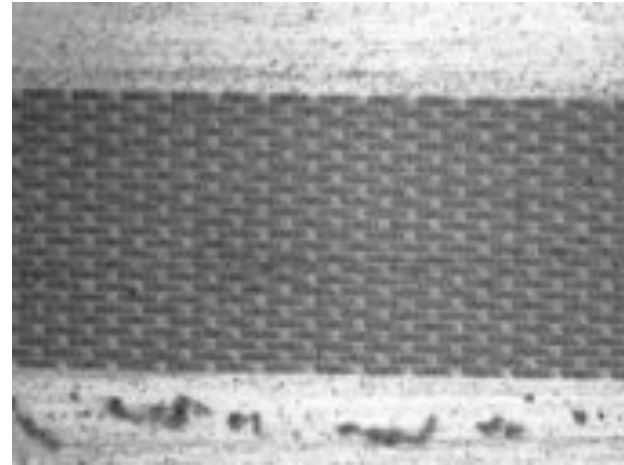
### Stainless steel

20-micron channel length

2-micron channel width

2-micron channel spacing

1.5-micron channel depth



# Surface Texture and Life

Surface texture affects cell growth in several ways:

Morphology

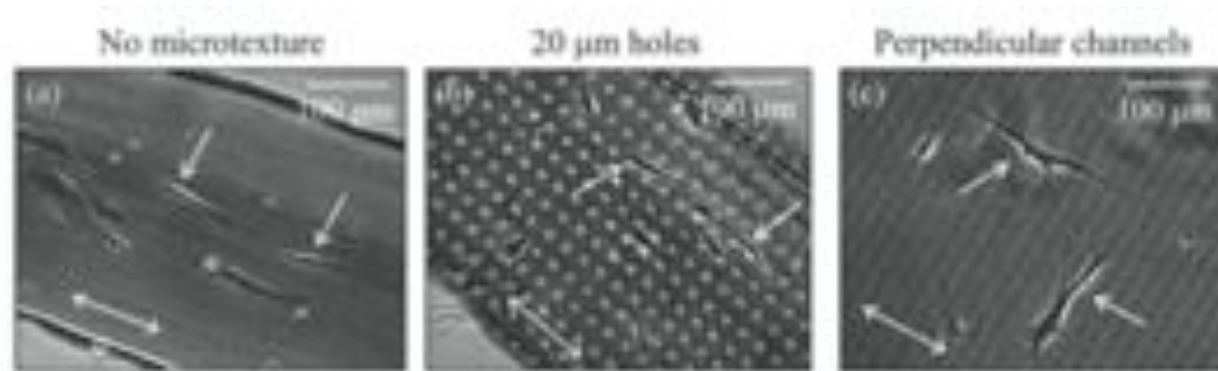
Functionality

Mortality



# Surface Texture and Life: Morphology

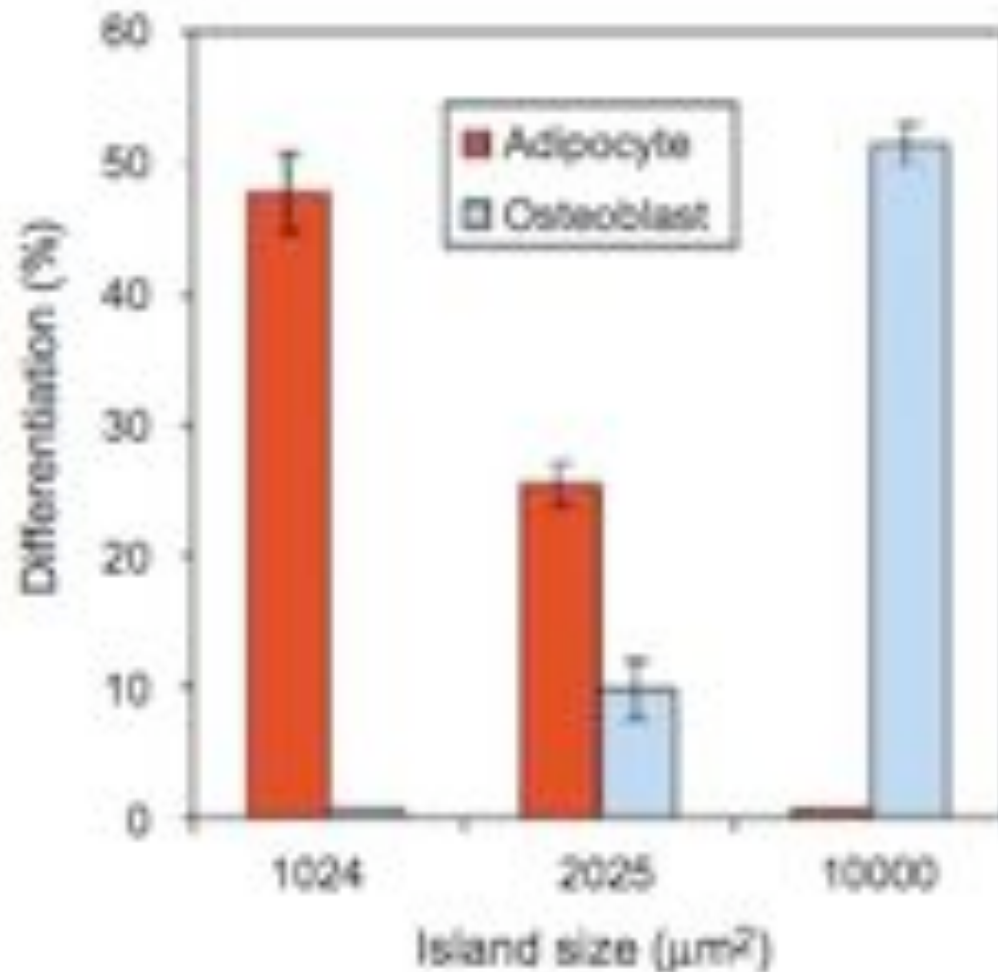
## Alignment of human mesenchymal stem cells



Stem cells tend to align with the substrate texture

# Surface Texture and Life: Functionality

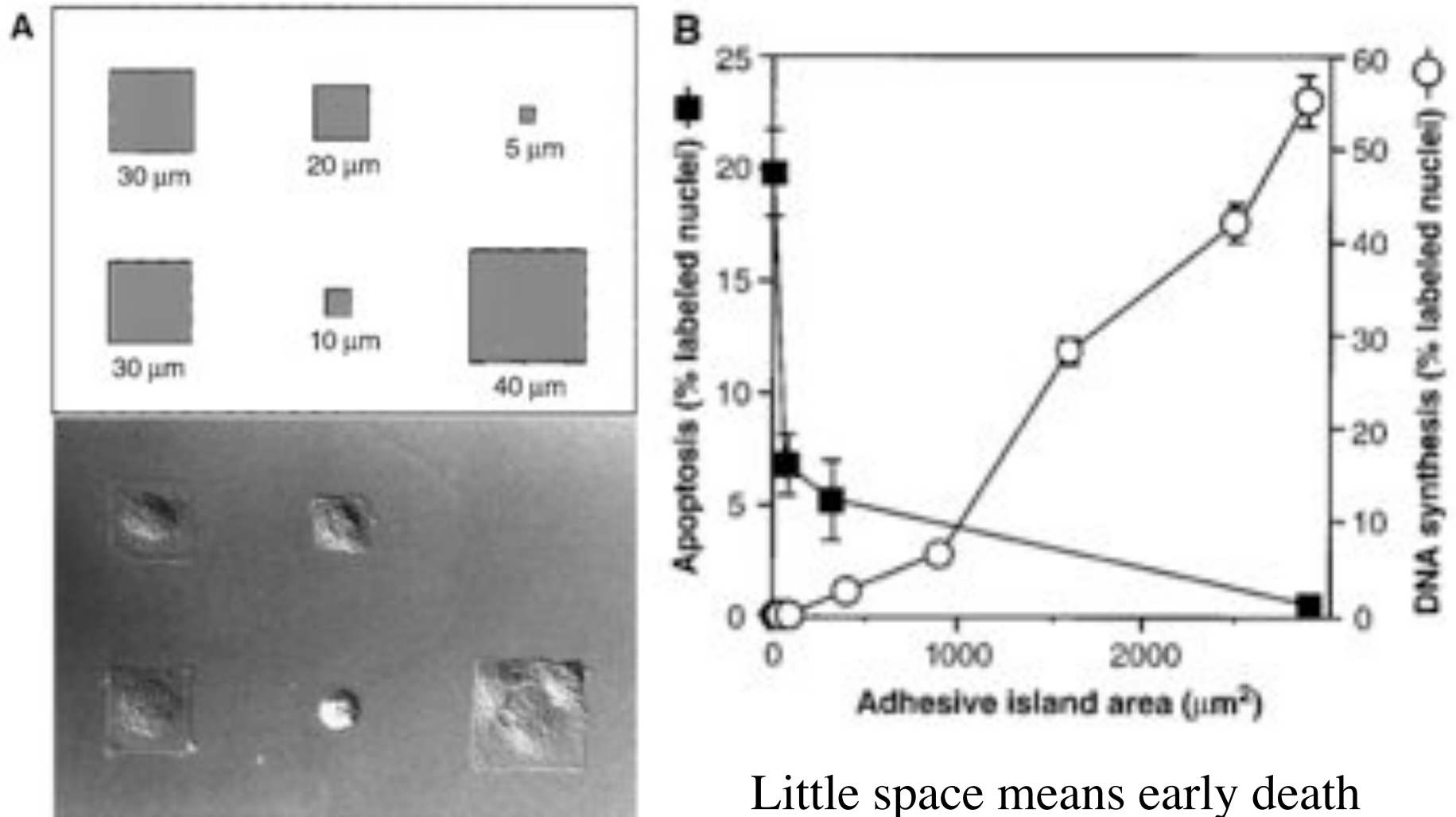
## Stem cell differentiation



Fat cells need little space!

# Surface Texture and Life: Mortality

## Apoptosis of capillary endothelial cells



Little space means early death

# Concluding Thoughts

- Many techniques available for large-scale surface texturing
- Surface texturing affects biological, mechanical, and physical properties
- Scientific challenge
  - *Understanding the surface texture-property relationship*
- Engineering challenge
  - *Faster and cheaper texturing with high fidelity*

# A page from Mythbusters



Smooth car: 26 mpg

Dimpled car: 29.65 mpg!

*(<http://dsc.discovery.com/videos/mythbusters-dimpled-car-minimyth.html>)*