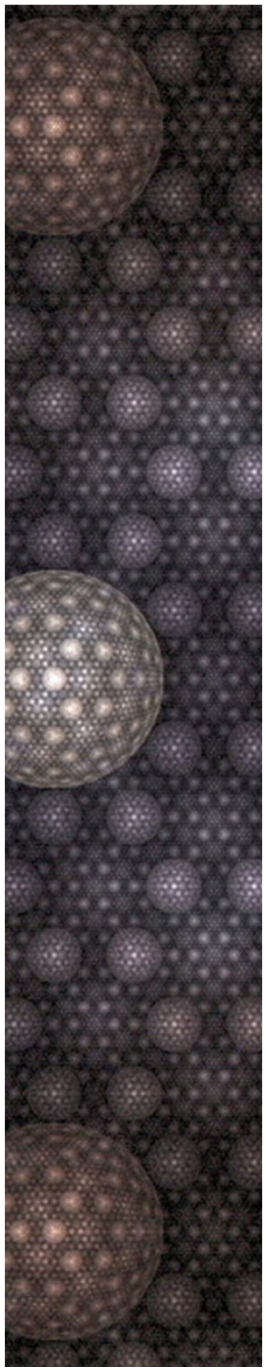

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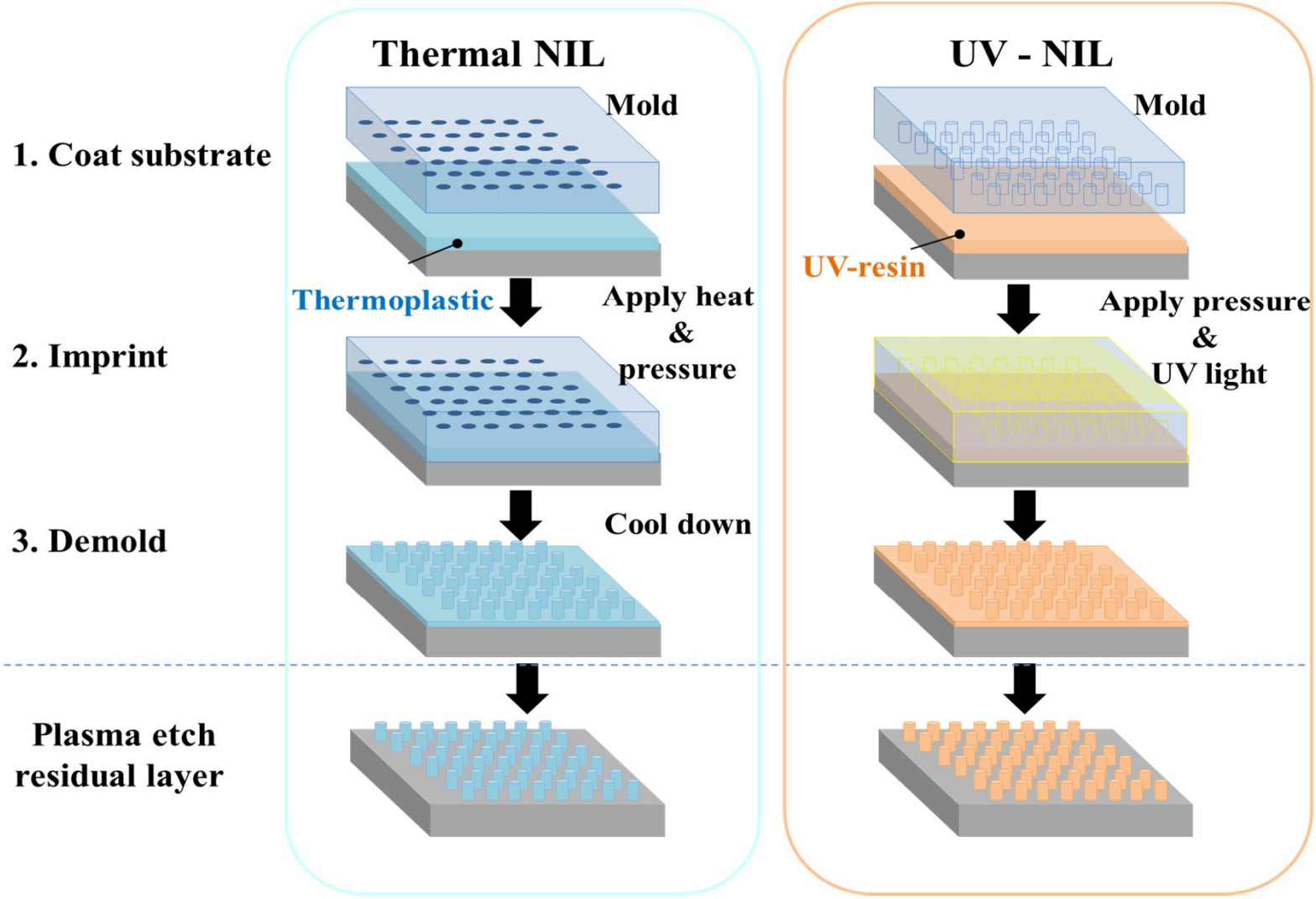
GOBIERNO DE ESPAÑA
MINISTERIO DE ECONOMÍA Y COMPETITIVIDAD
UNIÓN EUROPEA
FONDOS ESTRUCTURALES
La Suma de Todos
Comunidad de Madrid
www.madrid.org
EXCELENCIA SEVERO OCHOA 2017 - 2021
AGENCIA ESTATAL DE INVESTIGACIÓN

Functional soft-nanoimprinted surfaces

Isabel Rodríguez
i.rodriguez@imdea.org

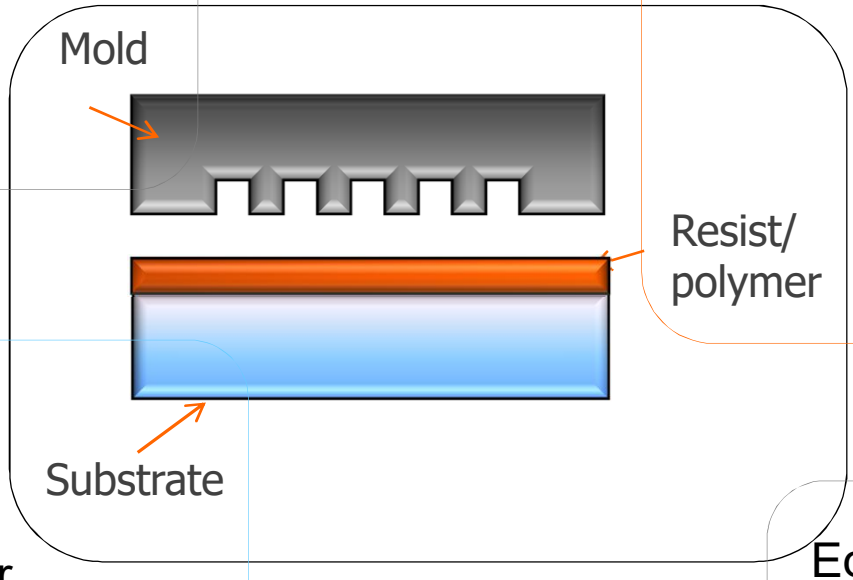
Nano Imprint Lithography - NIL

A replication process : Pattern transfer by mechanical deformation of a resist material



NIL tool box

- Silicon
- Quartz
- Nickel
- **Polymers**



- Thermoplastic polymers:
  PMMA, PC, PS, PP, PES..
- Liquid monomers
- Biopolymers
- Semiconducting polymers
- Nanocomposites
- Sol gel materials

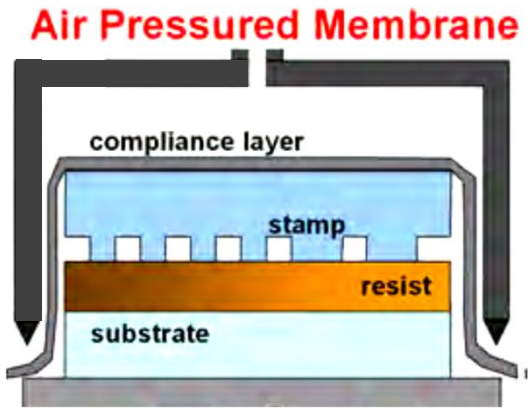
- Silicon
- Quartz, silica
- Polymers
- Textiles, paper..
- No substrate

Equipment - press
- Thermal
- UV
- Batch
- R2R

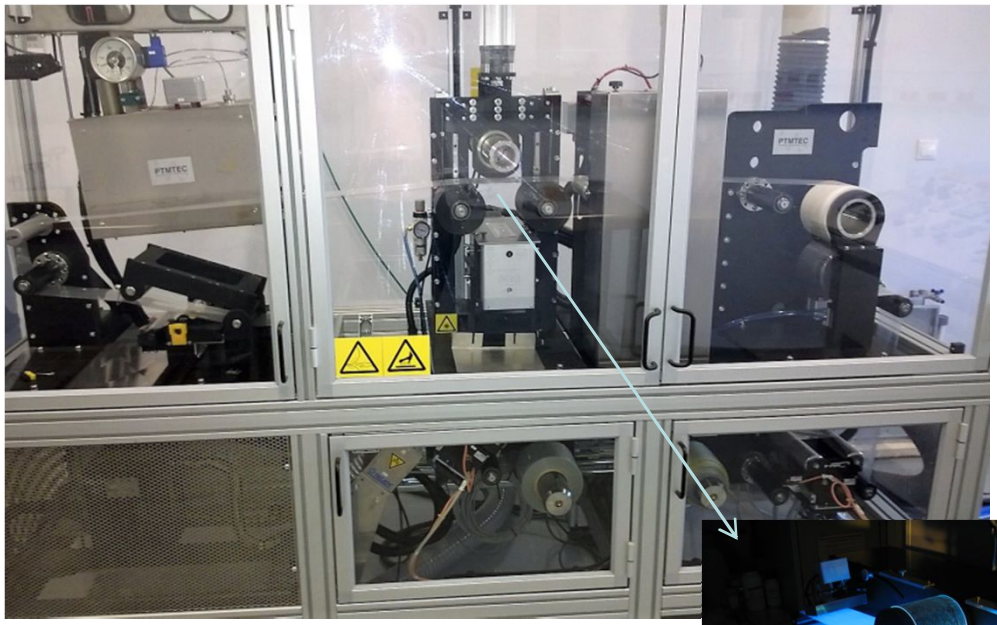
Polymer mold ⟶ Soft –NIL

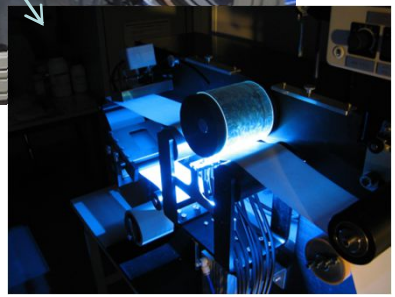
Nanoimprinting machines

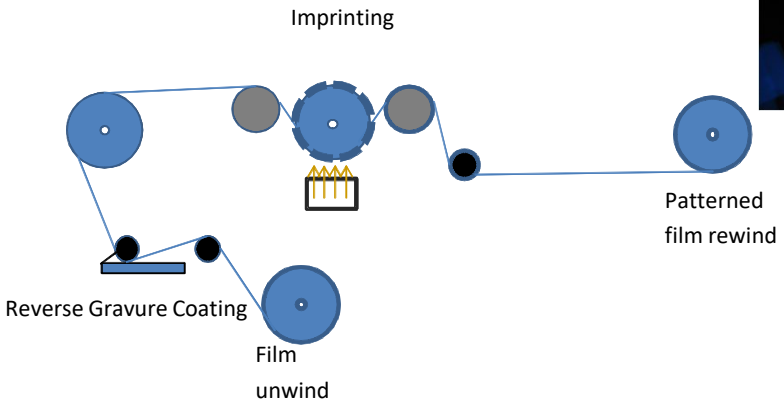
Batch

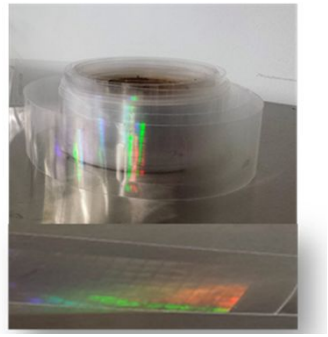


Roll to Roll



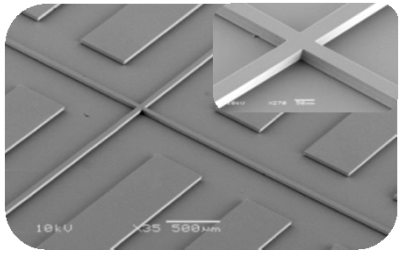




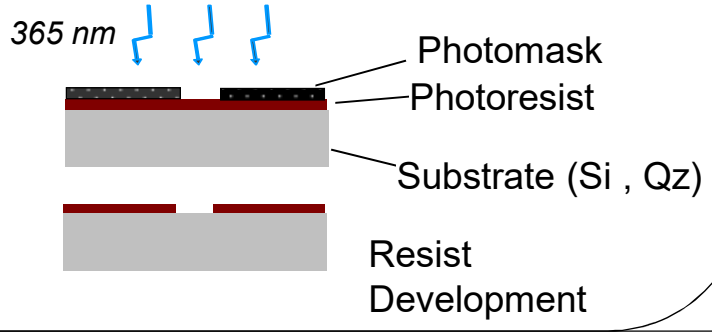


Mold fabrication

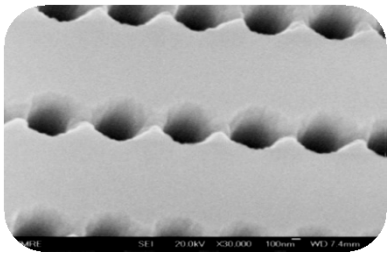
Photo lithography : Micrometer range



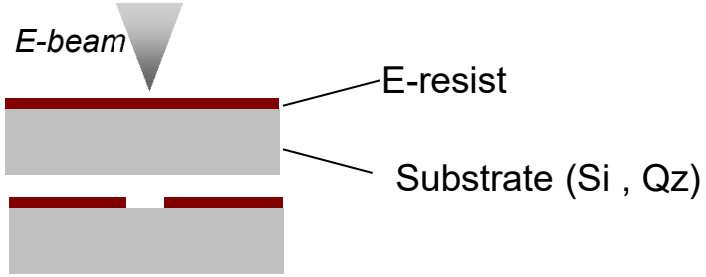
- Limited resolution to 1 μm^2
- Patterned area – 2 - 12”



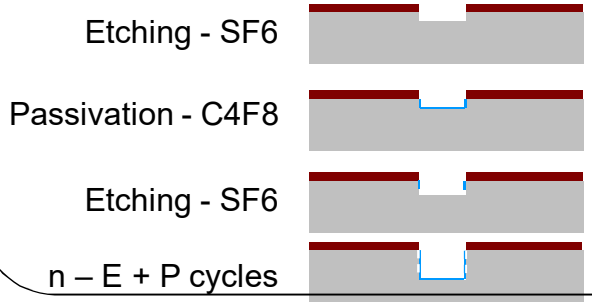
E-Beam lithography: Sub-micron and Nanometer range



- Resolution from 600- 5 nm
- Limited writing area



Deep Si Etching "Bosch“ Plasma process



Working mold Replication

Ni Electroplating

Polymers: PDMS, PFPE …

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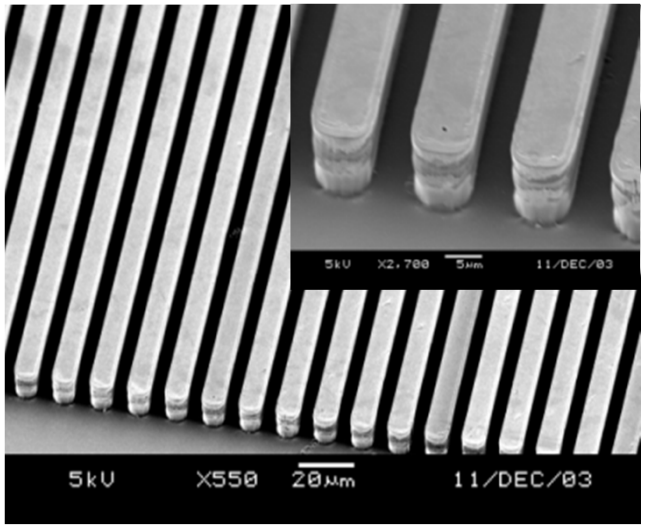
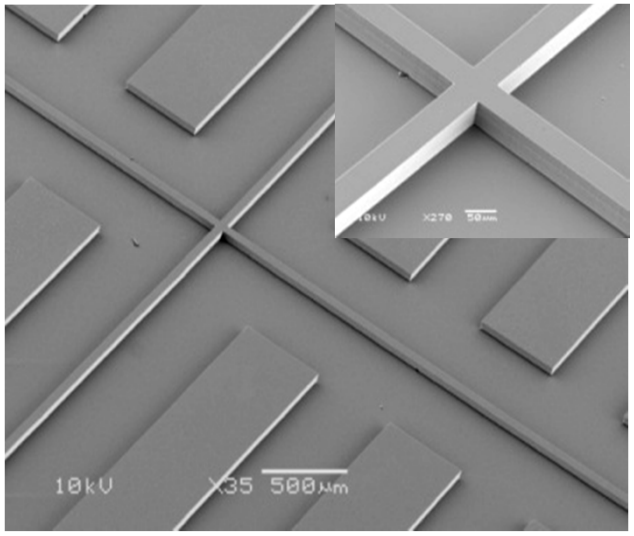
Molds - stamps

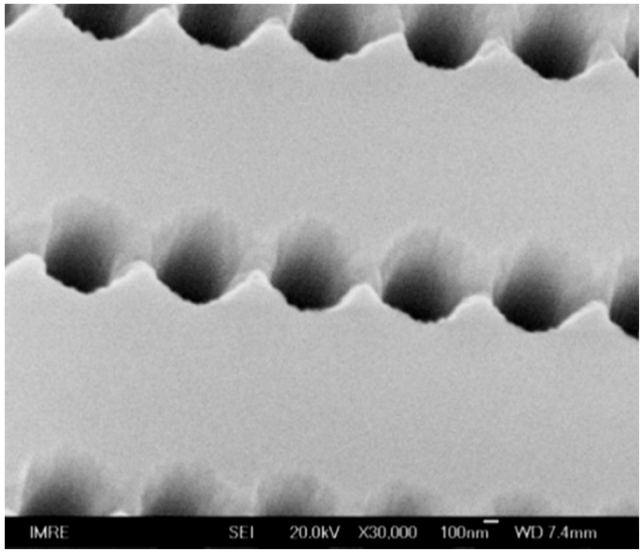
Quartz



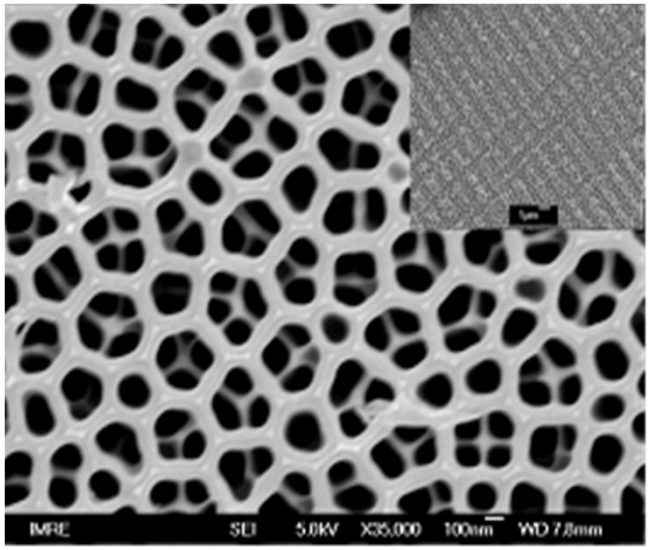
Silicon



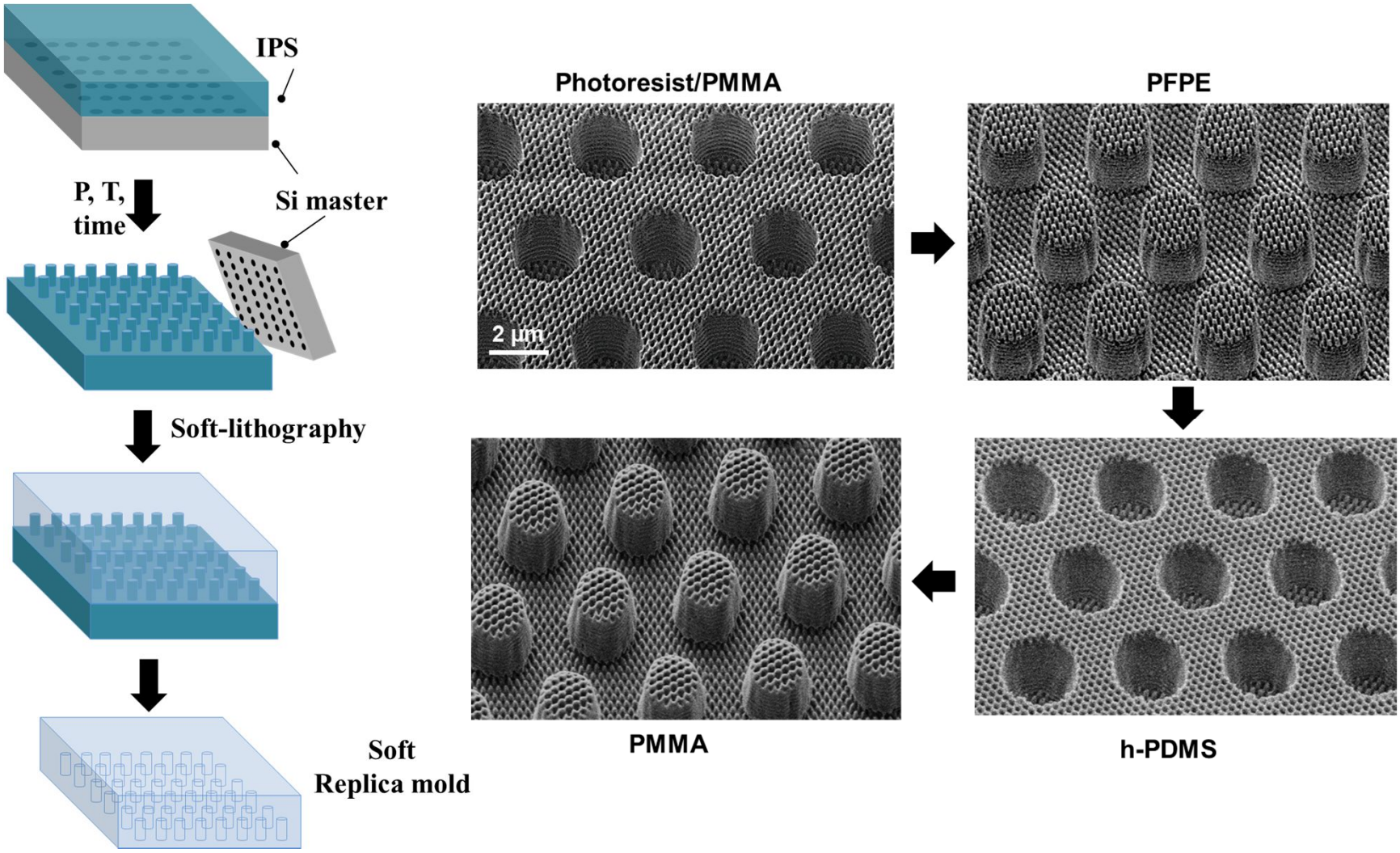
PDMS



Alumina



Soft –NIL



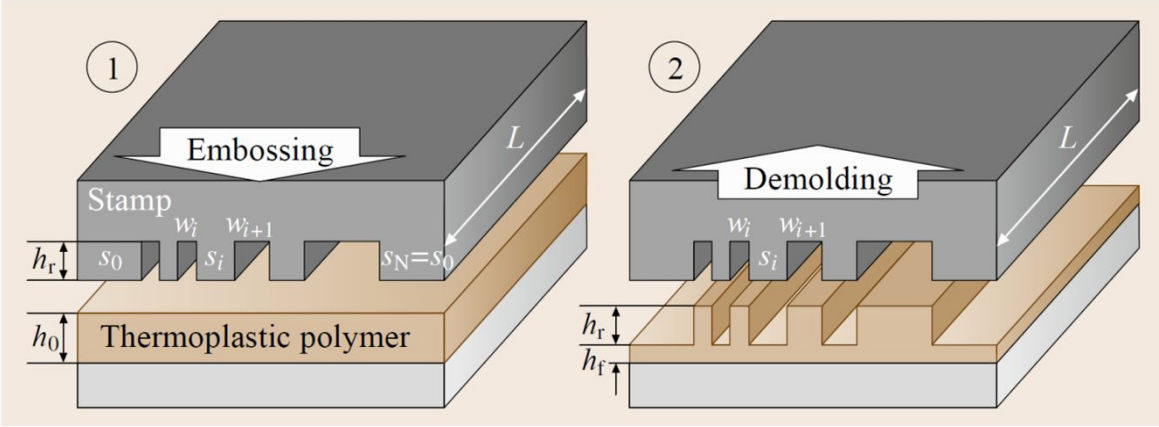
IPS- Intermediate polymer stamp

Nanoimprinting process

Mechanical displacement of (polymer) material by pressure:

1. External pressure: Thin film squeeze flow
2. Laplace pressure: Capillary action

1. **Thin film squeeze flow:** The polymer flow into the stamp protrusions



Stefan's equation:

$$t_f = \frac{\eta_0 s^2}{2p}\left(\frac{1}{h_f^{\,2}} - \frac{1}{h_0^{\,2}}\right)$$

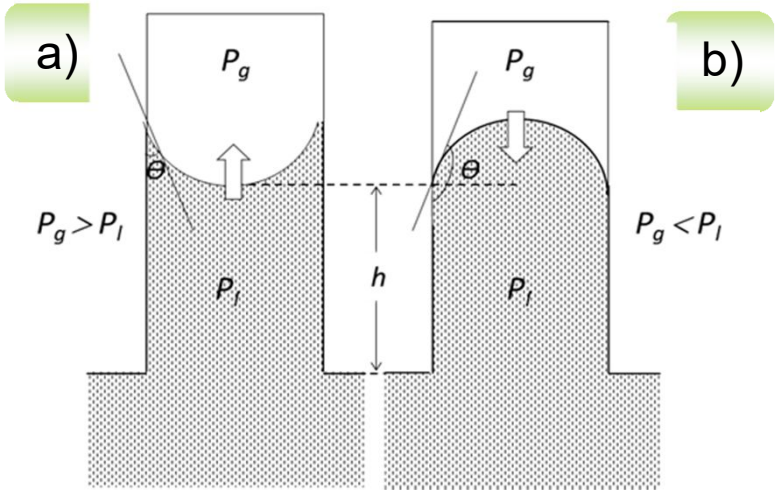
viscosity, stamp width, pressure, initial polymer height, final polymer height

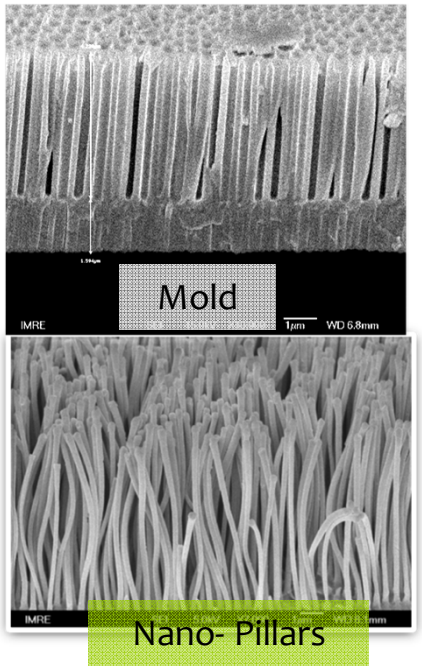
Schift, H. and A. Kristensen Nanoimprint lithography–patterning of resists using molding, in Springer Handbook of Nanotechnology. 2010, p. 271-312.

High Aspect Ratio NIL

2. Laplace pressure : Capillary action

$$\Delta P_c = P_g - P_l = \frac{2\,\gamma cos\theta}{r}$$





a) polymer wets the capillary (θ < 90°)

b) polymer does not wet the capillary (θ > 90°)

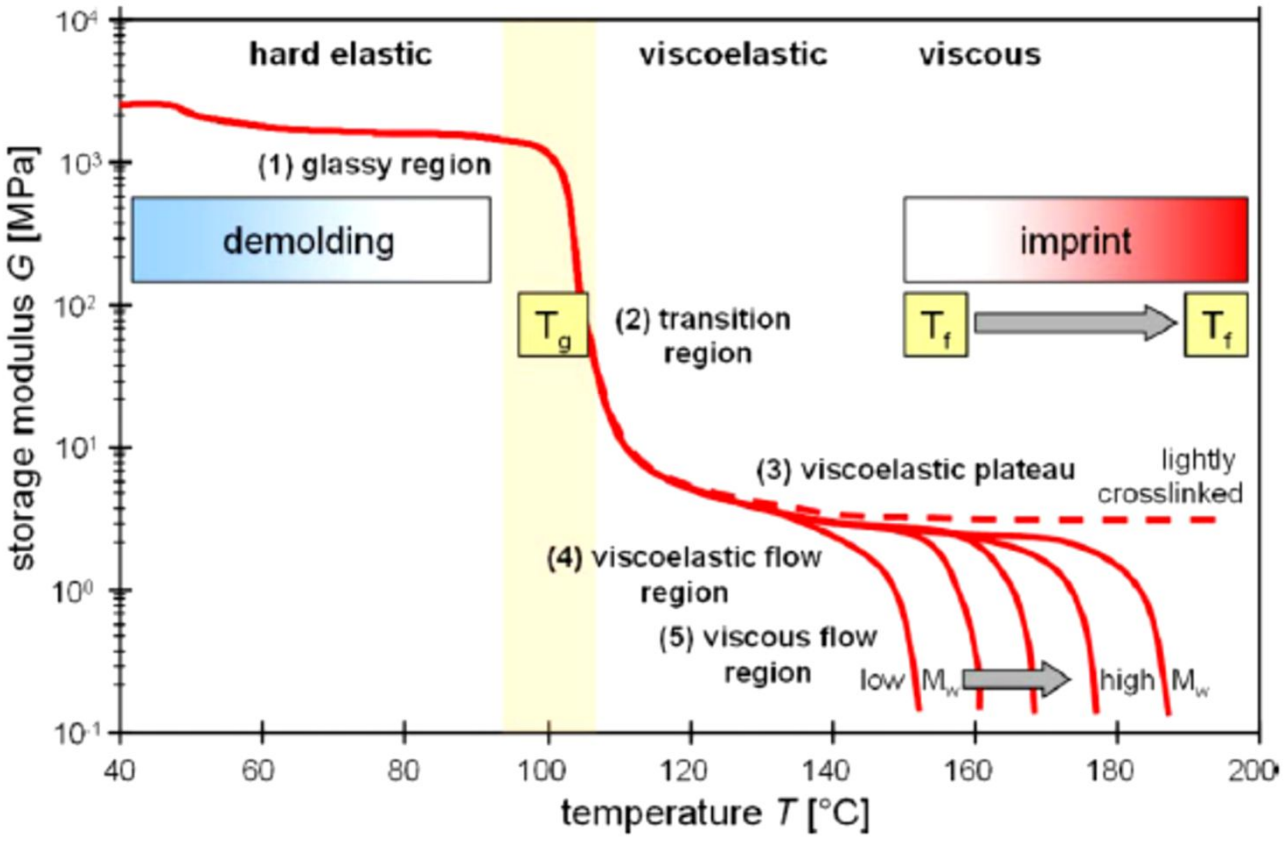
Lucas-Washburn equation:

$$\frac{dh}{dt} = \frac{r\,\gamma cos\theta}{4\eta h} \qquad t = \frac{2\,\eta\,h^2}{r\,\gamma\,cos\theta}$$

γ_p is surface tension of the viscous polymer
η is the viscosity
θ is the solid-liquid contact angle
r is the capillary radius.

Choice of process temperature

Mechanical properties of thermoplastics change with temperature



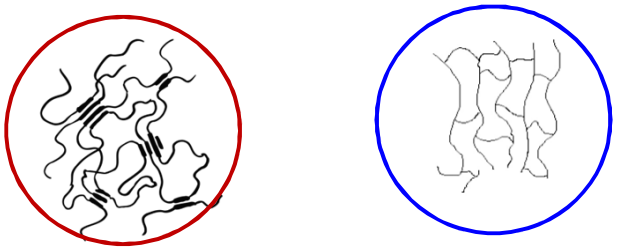
$T_f = T_g$ +50 C

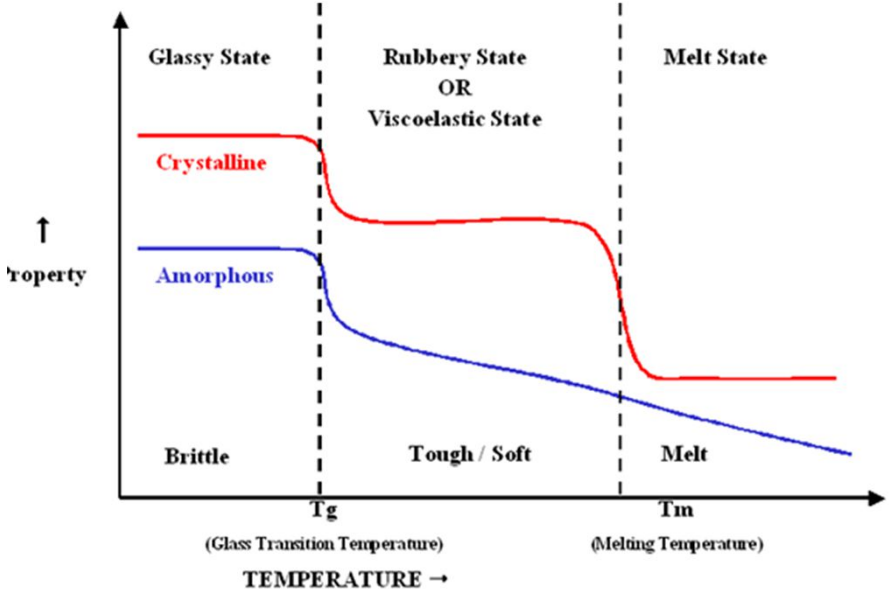
Optimum viscosity : 10^3–10^7 Pa.s

H. Shift, J. Vac. Sci. Technol. B 2008, 26, 458

The imprint material – critical resolution

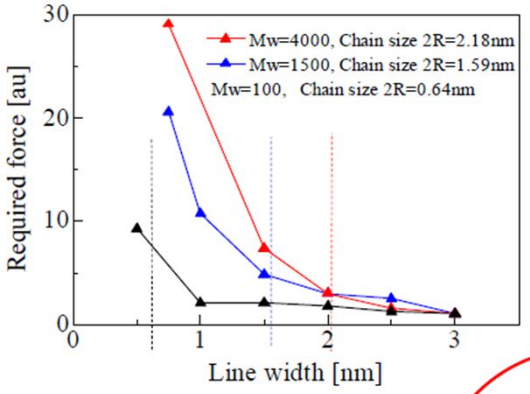
Thermal phase transitions Crystalline vs amorphous

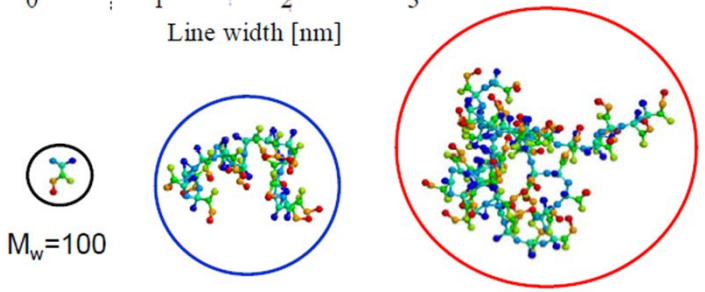




http://injectionmoldingonline.com/Molding101/Polymers.aspx

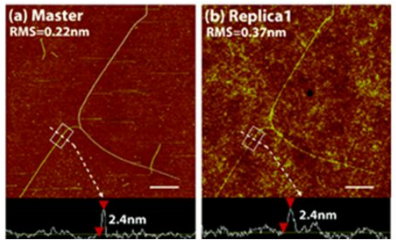
Molecular weight





Y Hirai et al , J. Vac. Sci. Technol. B 2010, ***28****, C6M68*

Ultimate Resolution -1 nm



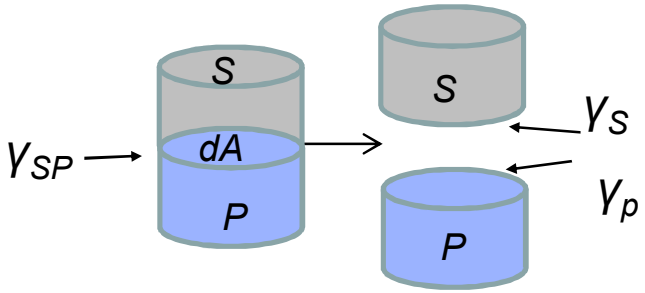
Hua ..J Rogers, "Polymer imprint lithography with molecular-scale resolution", Nano Lett. 2004

Demolding

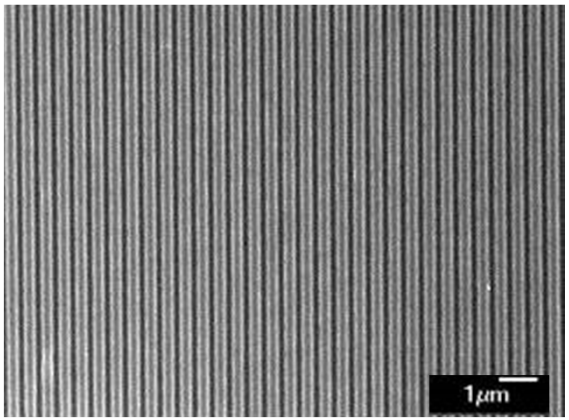
Adhesion + friction forces

Work of adhesion :

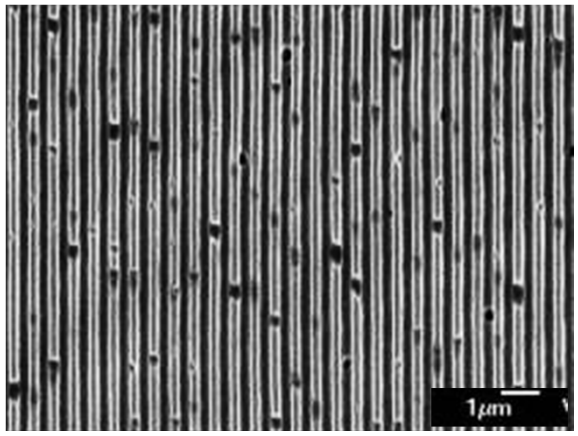
$$dW_{SP} = (\gamma_S + \gamma_p - \gamma_{SP})\, dA$$



Mold with anti-stick coating

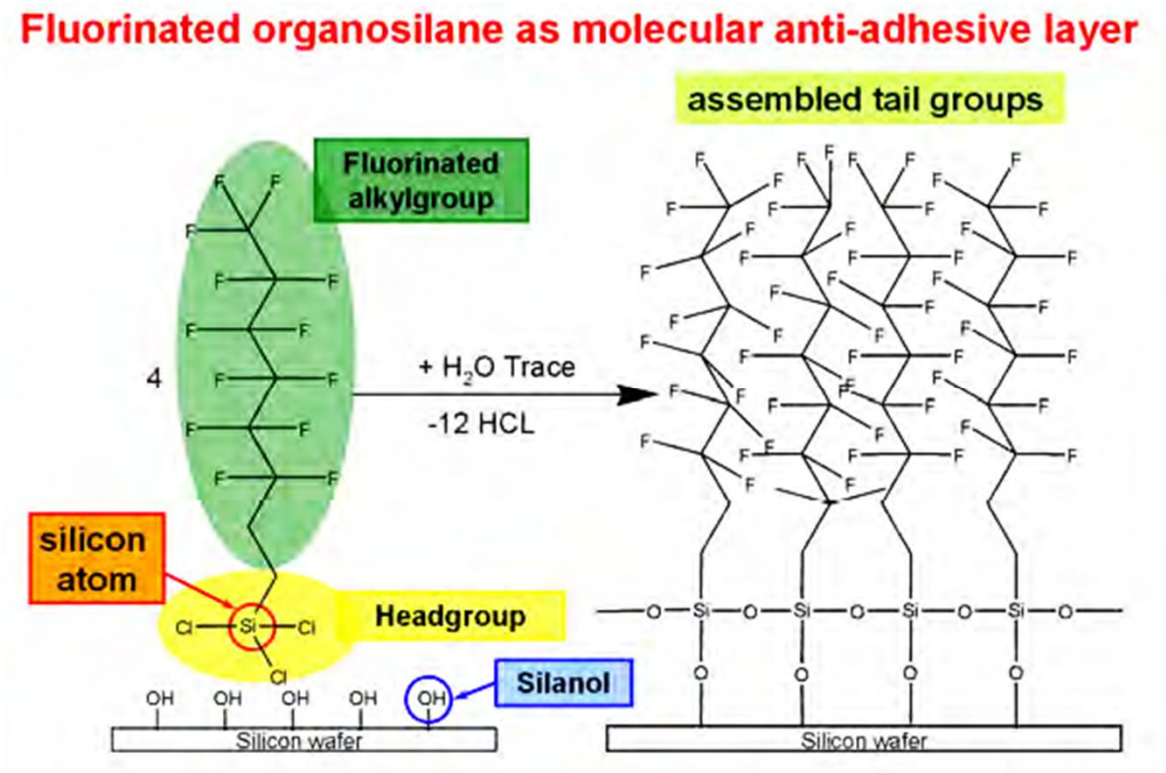


Mold without anti-stick coating



Anti-sticking coatings

Anti-adhesion surface treatment to reduce the surface energy

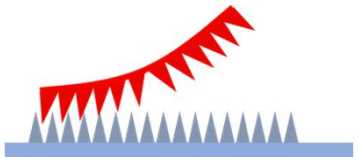


Perfluorodecyltrichlorosilane (FDTS)
Heptadecafluoro-1,1,2,2-tetrahydrooctyl)-trichlorosilane (F13-TFS),

Surface energy values range: 10 mJ/m^2 < γs < 20 mJ/m^2

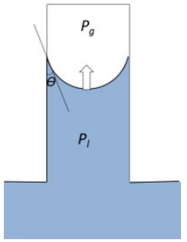
Source: NAPANIL Library process pg 33. Ed H Shift

Advantages of soft-NIL



- Sequential action of peeling the mold from substrate

- High gas permeability



- Conformal contact to substrate

- Low surface energy

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- Common thermoplastic polymer used in T-NIL and their processing conditions

Thermoplastic polymer	Young´s modulus* (MPa) 25 °C	Surface energy ($mJ \cdot m^{-2}$) 20 °C	T_g (°C)	T imprint (°C)	Viscosity* (mPa·s) T imprint	Young´s modulus* (MPa) T imprint
PMMA	2500	41.1	100-120	140-190	10^7-10^4	380-540 (80 °C)
PS	2350	10.7	110	140-190	10^7-10^5	100 (110 °C)
PC	2270	34.2	150	160-200	10^6-10^4	438 (160 °C) 2.18 (170 °C)
PP	1300	30.1	-20 to -10	200	10^6-10^3	200 (125°C)
PVDF	1500	30.3	-40 to -35	200	10^4-10^3	-

* Molecular weight dependent

- Common soft mold materials properties

Material	Young´s modulus (MPa)	Surface energy ($mJ \cdot m^{-2}$)	Viscosity (mPa·s)	Resolution (nm)
s-PDMS	1.8 - 2	25	3900	250
h-PDMS	10 - 14	35	< 490 (tunable)	15
PFPE	315	12.7	430	15

Nanoimprinting highpoints

- **High-resolution** - Not limited by diffraction but by the mold size (1 nm resolution demonstrated)
- **High-throughput** - Roll to roll scalable, roll to plate
- **Low-cost**
- **Versatility** - Material flexibility
  Process flexibility : UV, thermal
  Feature flexibility : micron- nanoscale
- **Low environmental impact : G**reener - less use of solvent, developers etc.

- Defects, mold patterning and mold wear
- Mechanical resistance of the nanofeatures

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Nanofabrication

Direct writing techniques

E-beam lithography
Ion beam lithography
Scanning probe lithography
Direct Laser Writing Lithography
Two-photon Lithography - 3D printing

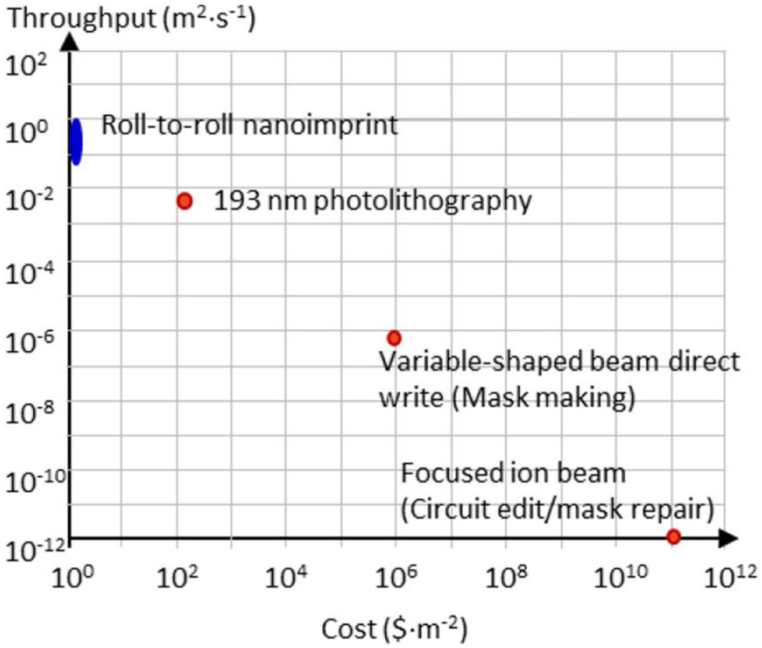
Nanomanufacturing

Replication techniques

mass fabrication processes

Optical lithography
X-ray lithography
Nanoimprint technology

Resolution ~ Throughput – Cost



Patterning techniques used in integrated circuit manufacturing.
J. A. Liddle & G. M. Gallatin, Nanomanufacturing: A Perspective ACS Nano 2016, 10, 2995.

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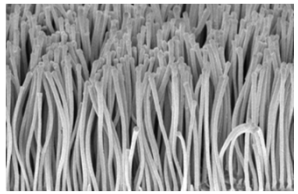
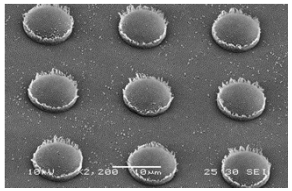
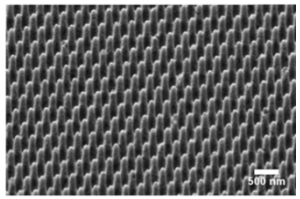
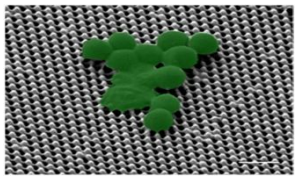
Surface functions & bio-applications

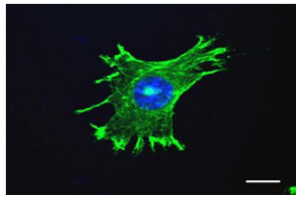






- Gecko like dry adhesives
- Superhydrophobic lotus
- Anti-reflective moth-eye





- Bactericidal Moth Eye Inspired Topography
- Cell Instructive Patterned Topographies

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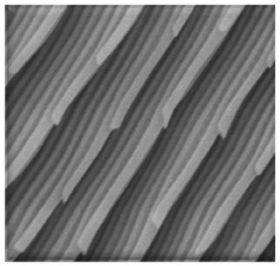
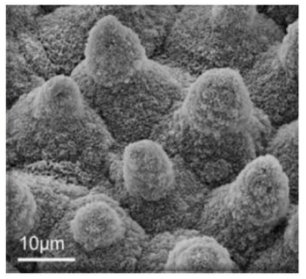
Natural functional surface structures

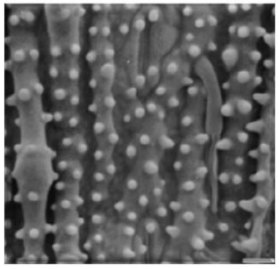



Structural colour

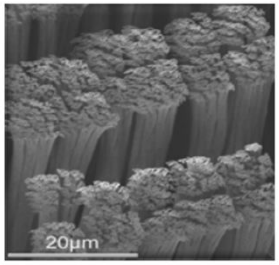

Anti-reflective

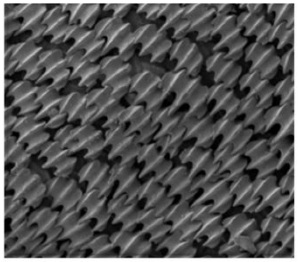
Super hydrophobic

Anisotropic wetting

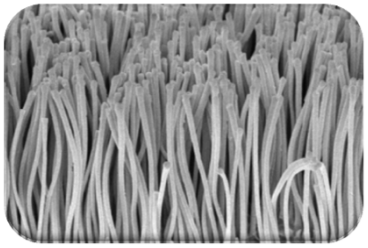



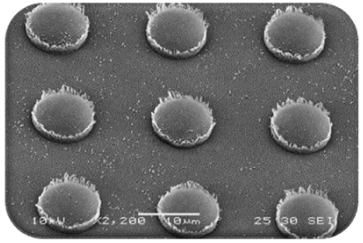
Adhesive

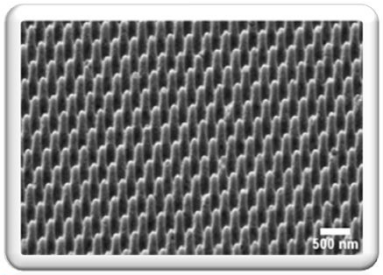



Non adhesive

Surface functions & applications







- Gecko like dry adhesives
- Superhydrophobic lotus
- Anti-reflective moth-eye

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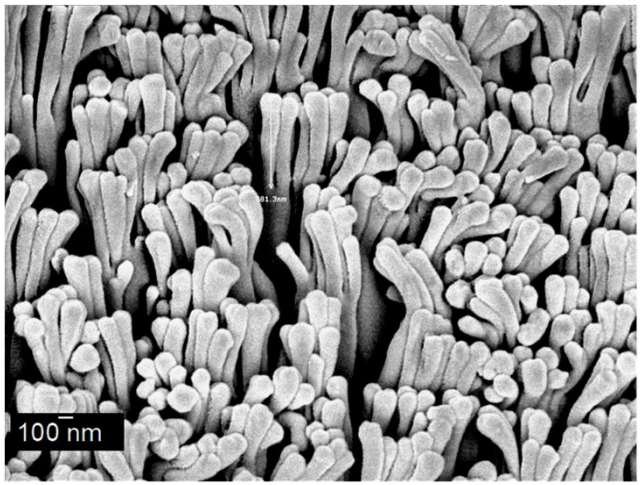
Gecko like dry adhesives

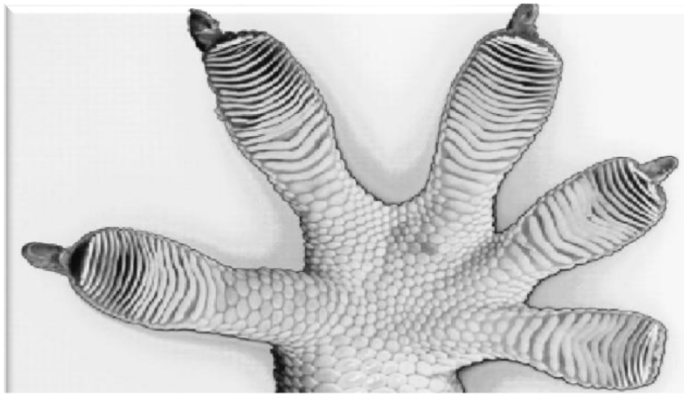
van der Waals adhesion - residue free



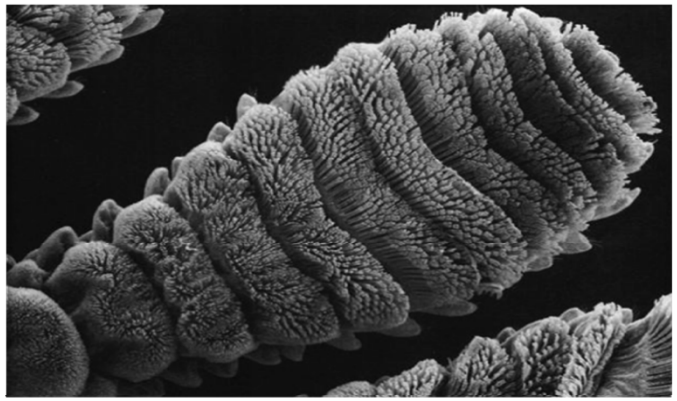
Polymeric hierarchically branched fibrils

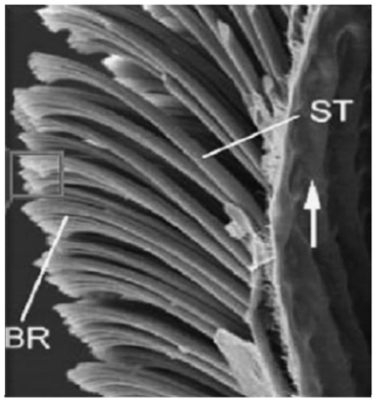
Fabrication and Analysis of Gecko-Inspired Hierarchical Polymer Nanosetae, ACS NANO , 5, 1897-1906, 2011

Gecko's Hierarchical Attachment System



Autumn, K., et al., Nature, 2000. **405**(6787): p. 681.





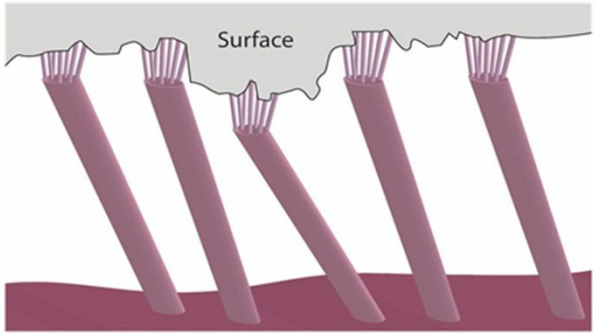
Bhushan, B., J. Adhesion Sci. & Tech., 2007. **21**(12/13): p. 1213.

Hierarchy (β-keratin)	**Name**	**Diameter**	**Height**	**Aspect Ratio**	**Density (#/mm²)**
Level 1	Seta	~ 4 μm	~ 110 μm	~ 25	14×10^3
Level 2	Branch	~ 1 μm	~ 25 μm	~ 25	-
Level 3	Spatula	~ 100 nm	~ 2.5 μm	~ 25	$1.4 - 14 \times 10^6$
End of Level 3	Tip of Spatula	**Width**	**Length**	**Thickness**	
		200 -300 nm	500 nm	10 nm	

Hierarchy allows for conformal contact - Adhesion via van der Waals forces

Gecko adhesive hierarchy of compliant structures

Conformational contact to surface roughness



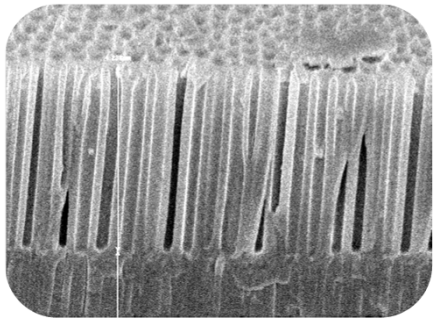
Benchmark functional properties:

1. Anisotropic , directional attachment - shear force adhesion
2. High pull off to preload ratio
3. Low detachment force
4. Material independence / van der Waals adhesion
5. Self-cleaning
6. Anti-self matting
7. Non-sticky in default state

K. Autumn (MRS Bulletin, June 2007)

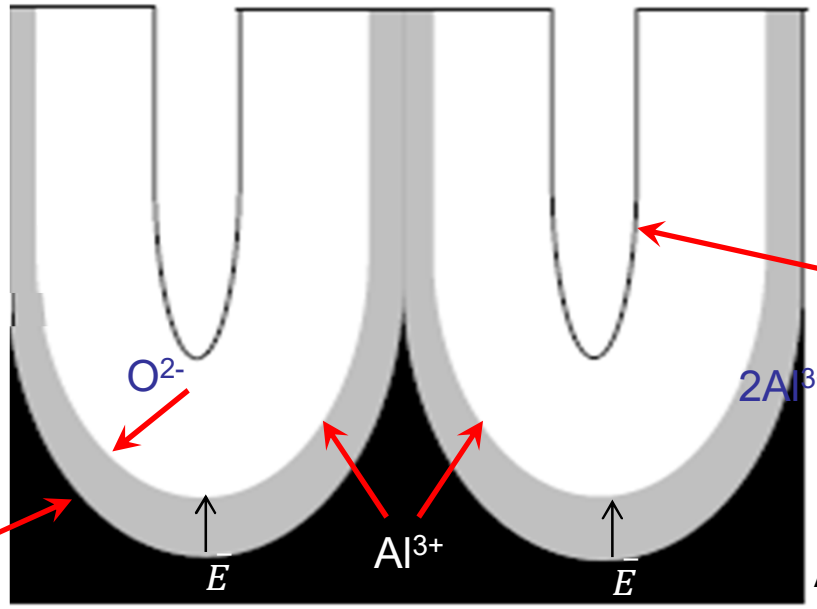
Mold fabrication: Nano porous alumina

Aluminium anodization - Alumina Pore Formation



Platinum as cathode (-)

$6H^+ + 6e^- \rightarrow 3H_2$



Oxide/Electrolyte Interface

$2Al^{3+} + 3H_2O \rightarrow Al_2O_3 + 6H^+$

Metal/Oxide Interface

$2Al + 3O^{2-} \rightarrow Al_2O_3 + 6e^-$

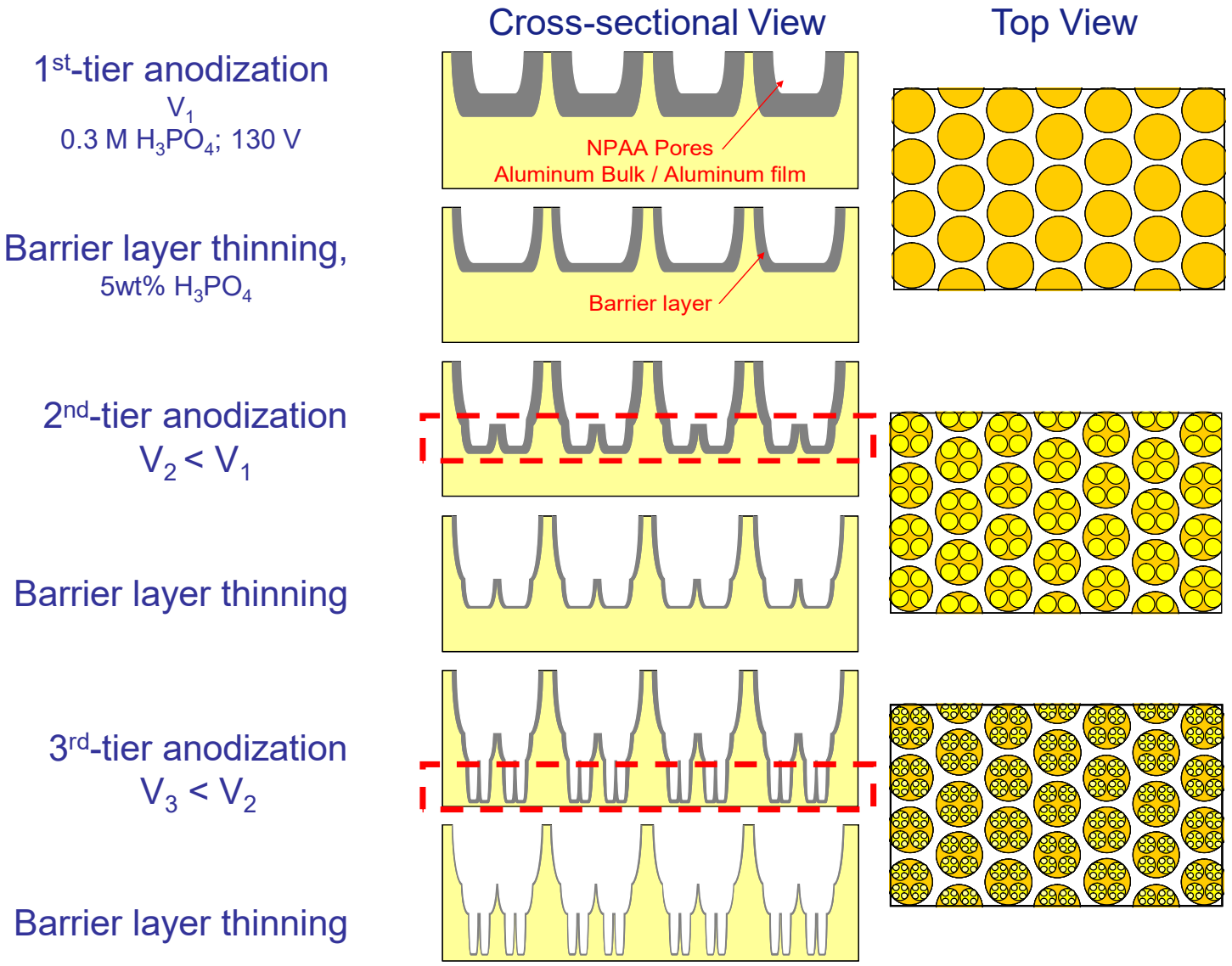
Aluminum as anode (+)

$2Al \rightarrow 2Al^{3+} + 6e^-$

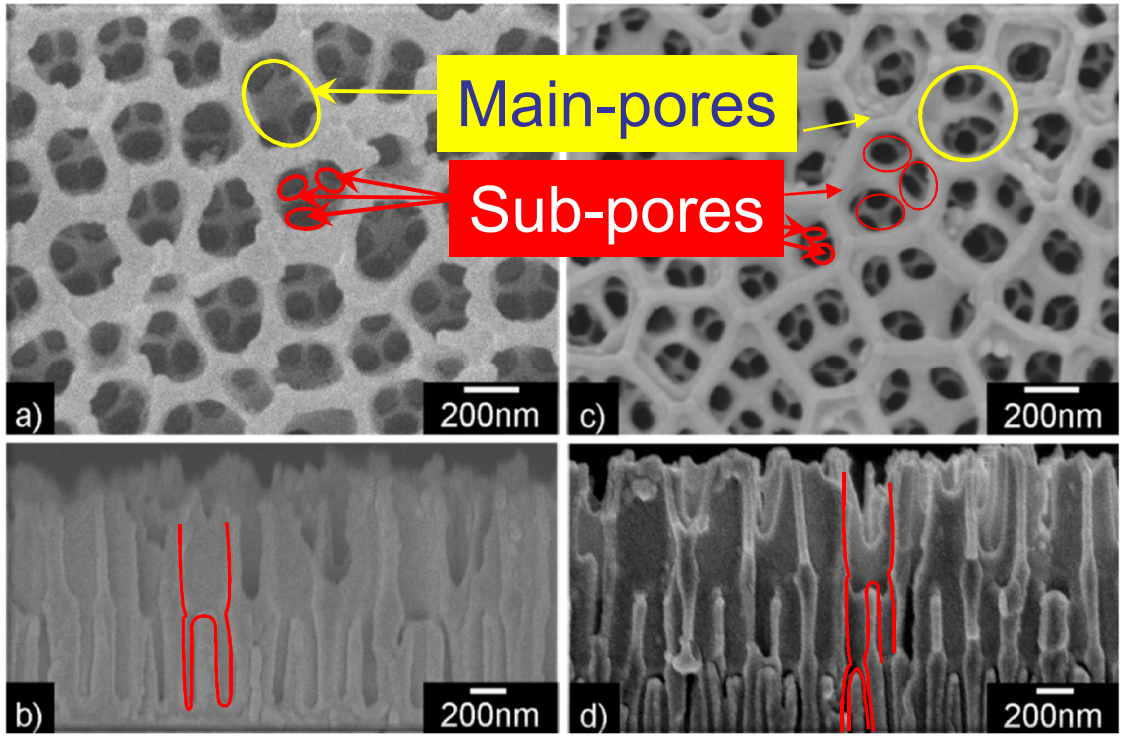
Overall anodization reaction: $2Al + 3H_2O \rightarrow Al_2O_3 + 3H_2$

Fabrication of hierarchical PAA template

Anodization reaction: $2Al + 3H_2O \rightarrow Al_2O_3 + 3H_2$



Tiered Branched Porous Alumina Template



Advanced Functional Materials 2008, 18, 2057-2063.

2-3 step aluminum anodization

1st-tier anodization
V_1 (130V)
0.3 M H3PO4
130 V for 35 min

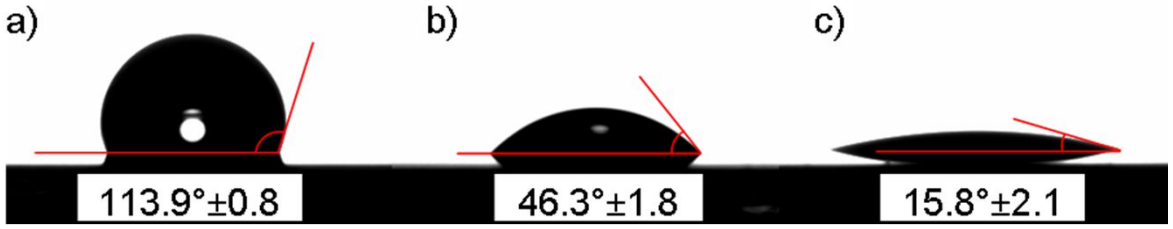
Barrier layer etch
5wt% H3PO4

2nd-tier anodizatio
V2 (80V)
0.15 M C2H2O4
80 V for 3.5 min

Barrier layer etch
5wt% H3PO4

3rd-tier anodization
V3 (50 V)
0.3 M C2H2O4
50 V for 15 min

Barrier layer etch
5wt% H3PO4

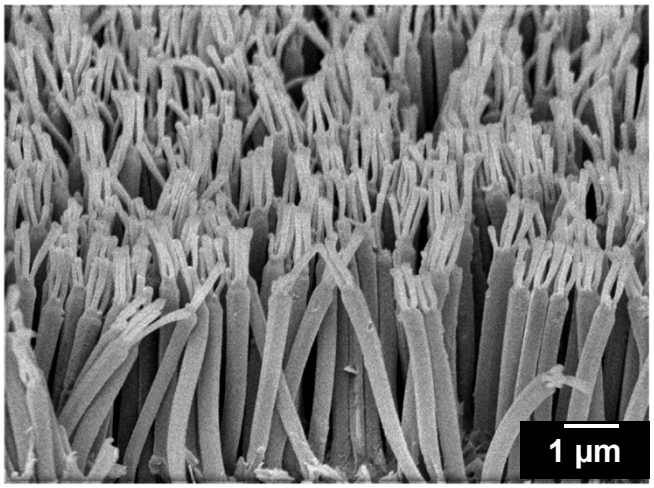


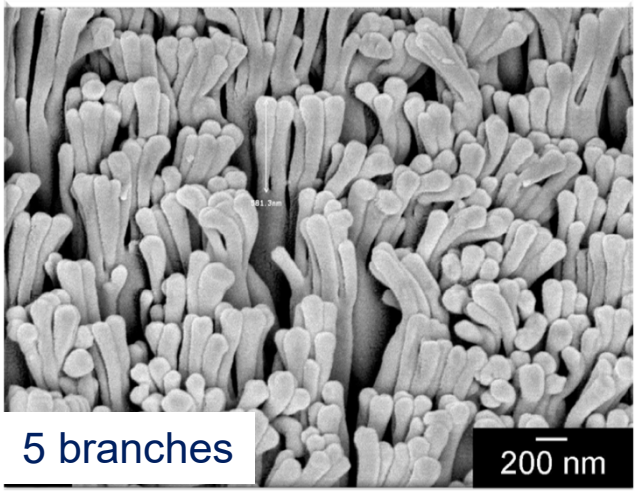
Aluminium | Single tiered PAA | 2 – tiered PAA

Increased wettability ⟶
- filling of the pores

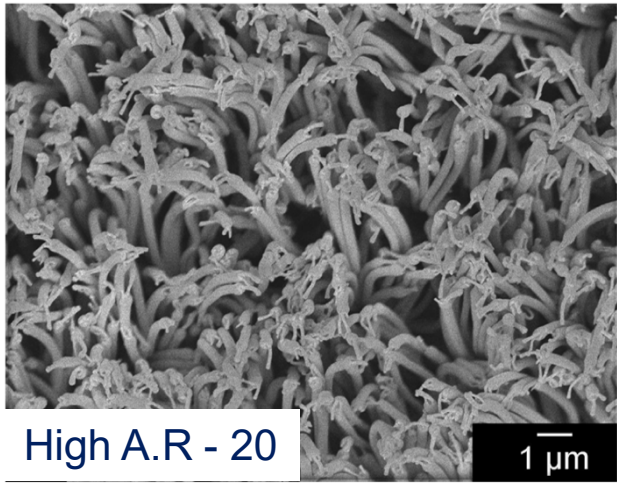
Hierarchical gecko like dry adhesives

Main fibril's Ø: 250 nm , A.R – 10, ρ – 6.2 x 10^6 fibrils/mm^2

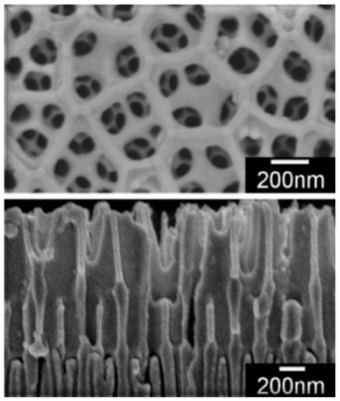




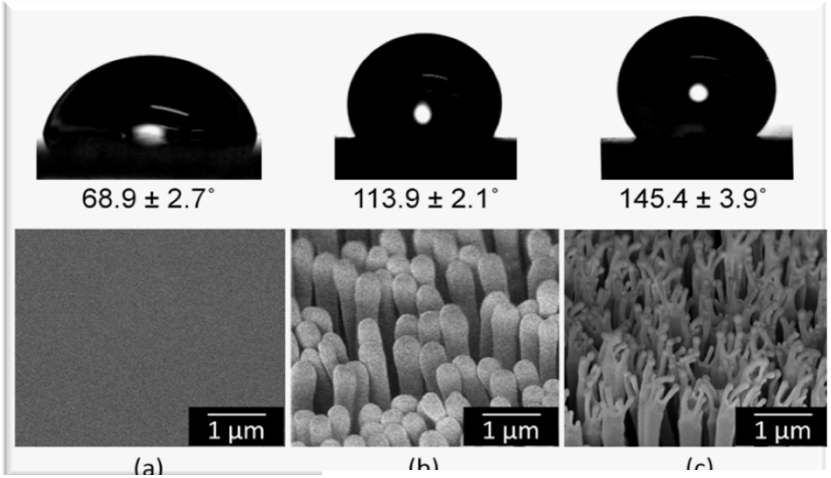
5 branches



High A.R - 20

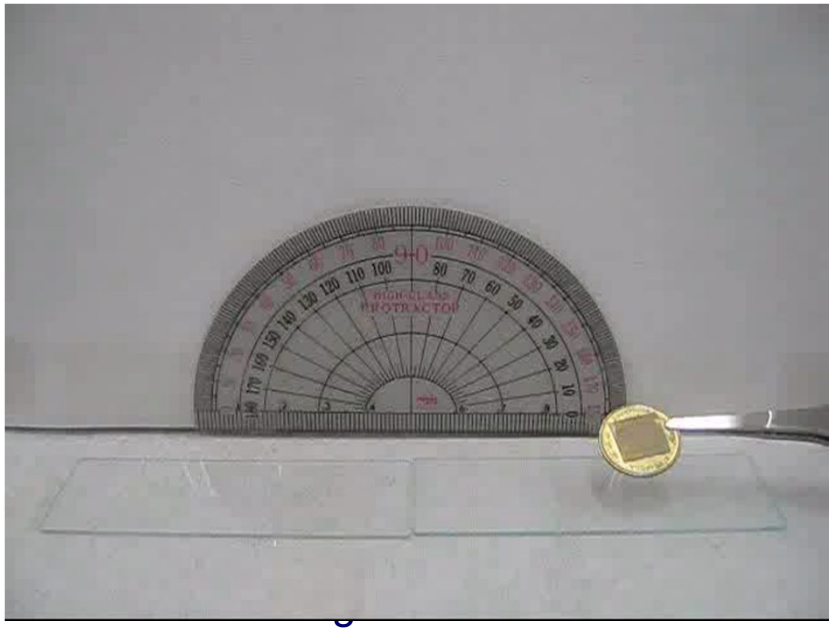


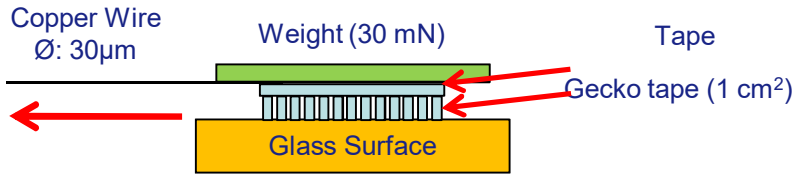
Wetting characteristics



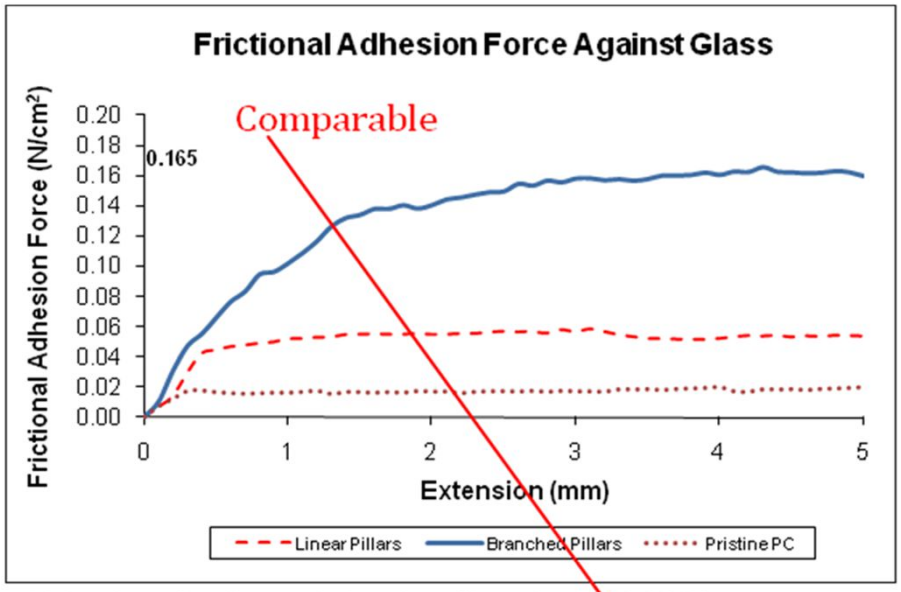
Pristine Polycarbonate | Linear pillars | Branched pillars

Frictional Adhesion Measurements





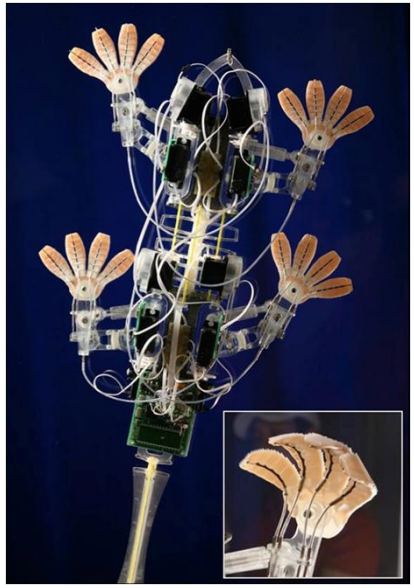
Gecko tape friction test set up



Values by estimating contact region with preload of 0.03 N/sq.cm.

Typical weight of Gekko Gecko : 43.4 ±1.48 g
Pad area : 2.271 ± 0.109 cm²
→ Frictional Adhesion Force : **0.188 N/cm²**

D.J. Irschick et al., Biological *Journal of the Linnean Society* **(1996), 59: 21-95.**



Stickybot

Biomimetic Robotics Lab , MIT

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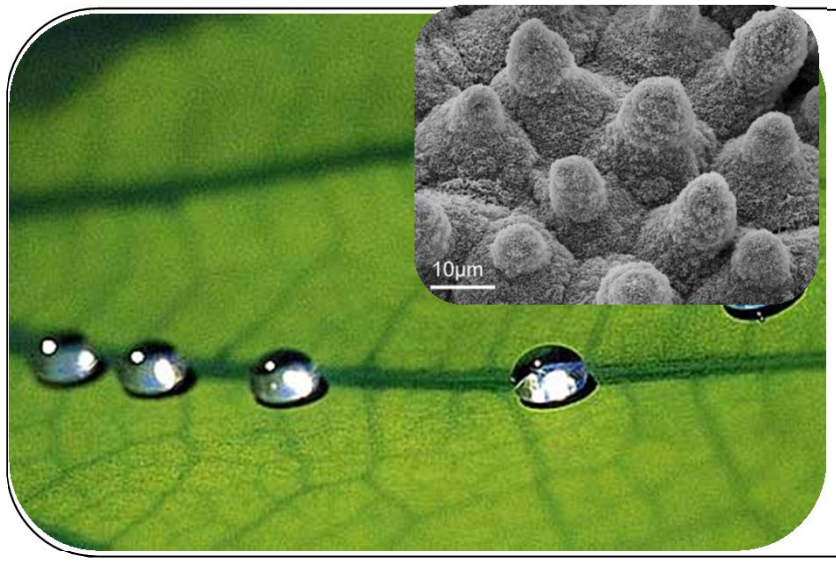
Superhydrophobic, self cleaning lotus leave

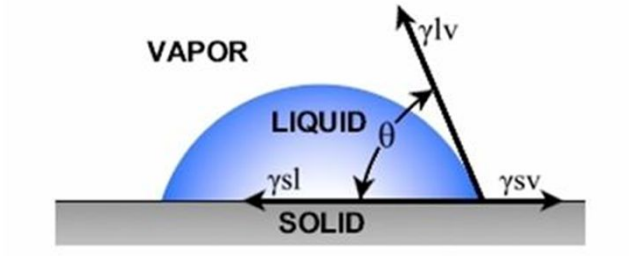


Hierarchical

micro/nano topography

Ho, Audrey et al. Lotus bioinspiredsuperhydrophobic, self-cleaning surfaces from hierarchically assembled templates. Journal of Polymer Science Part B: Polymer Physics, 2014, 52, 603.

Wetting properties : contact angle

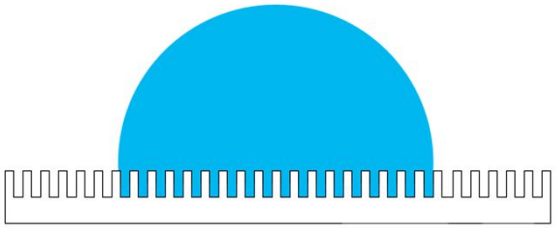


$$\cos\theta_o = \frac{\gamma^{sv} - \gamma^{sl}}{\gamma^{lv}}$$

Young's equation

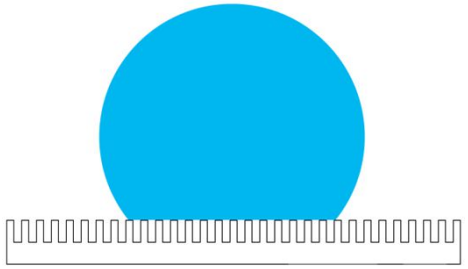
https://en.wikipedia.org/wiki/Ultrahydrophobicity

Wenzel state



$$\cos\theta = r\cos\theta o$$

Cassie- Baxter state

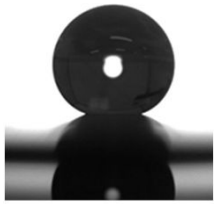


$$\cos\theta = rf\cos\theta o - 1 + f$$

Super hydrophobic surfaces

~ Synergy : surface energy + topography ~

Apparent contact angle (θ) above 150º



160 º

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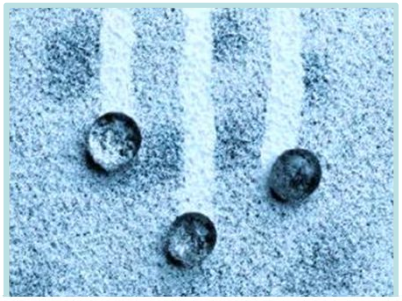
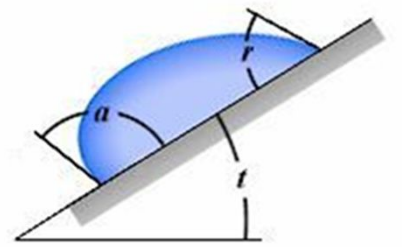
Self-cleaning surfaces





~ Synergy : surface energy + topography ~

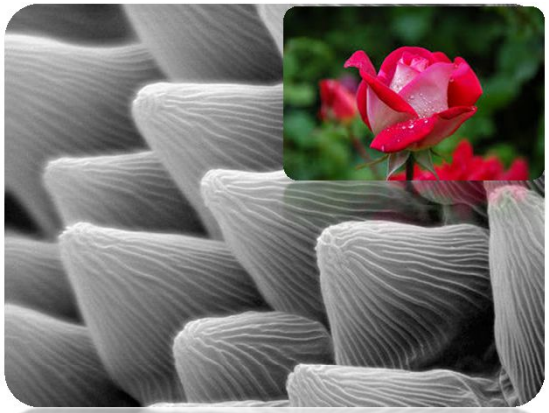
apparent contact angle (θ) above 150º

+ contact angle hysteresis below 10 º

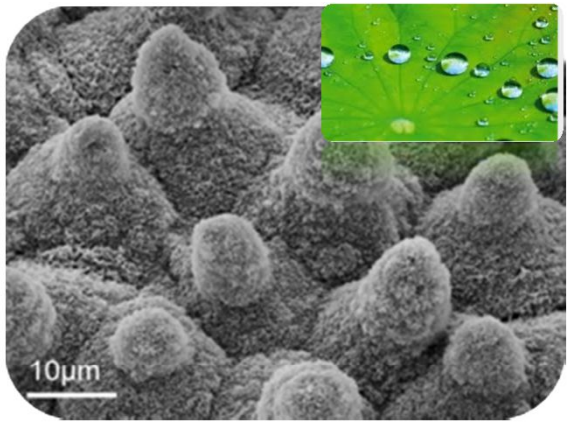
$H = \theta_a - \theta_r$

Topography modulated wettability

Self-pinning



Self-cleaning



Petal (Cassie impregnating wetting state)

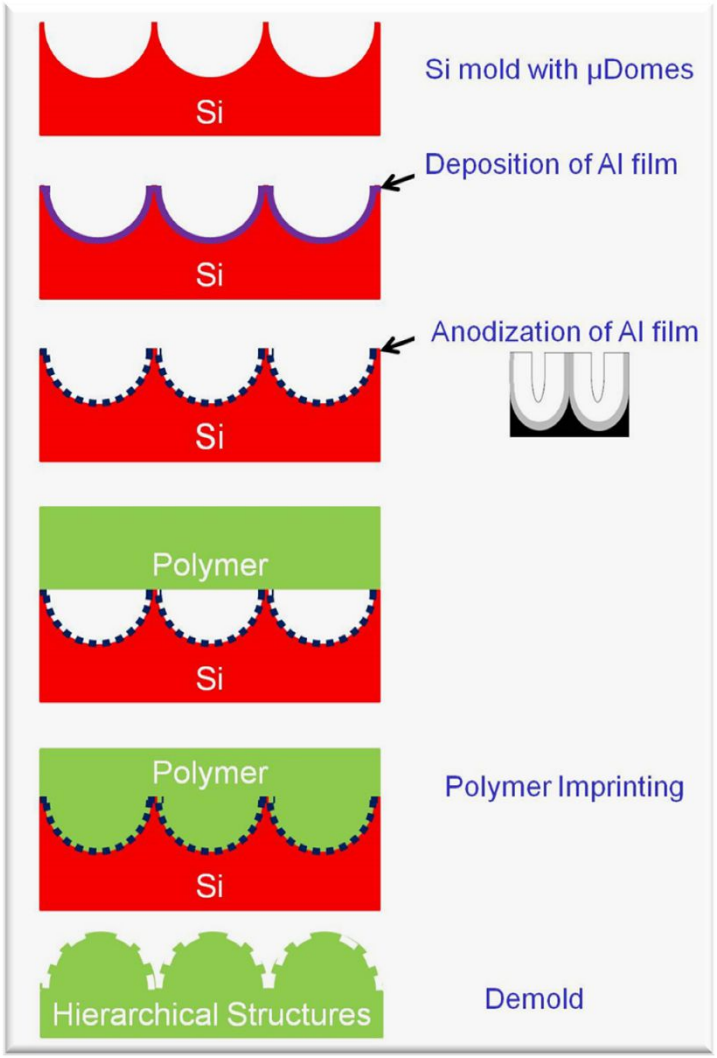
Lotus (Cassie's state)

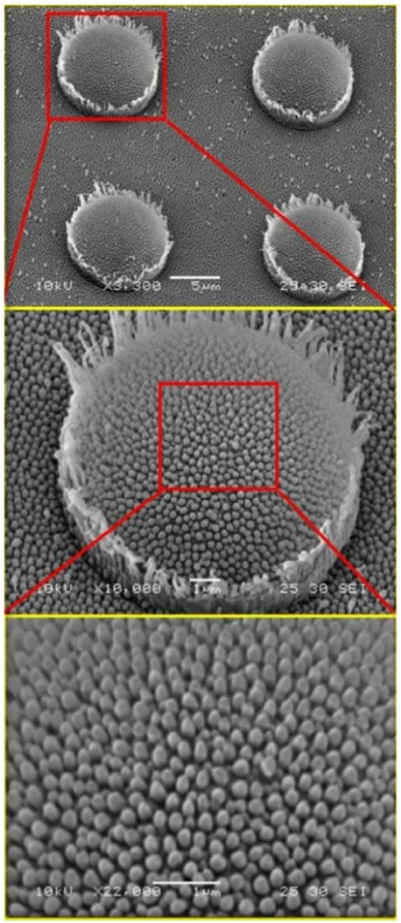
Feng et al. Langmuir 24, 8, 4114-4119

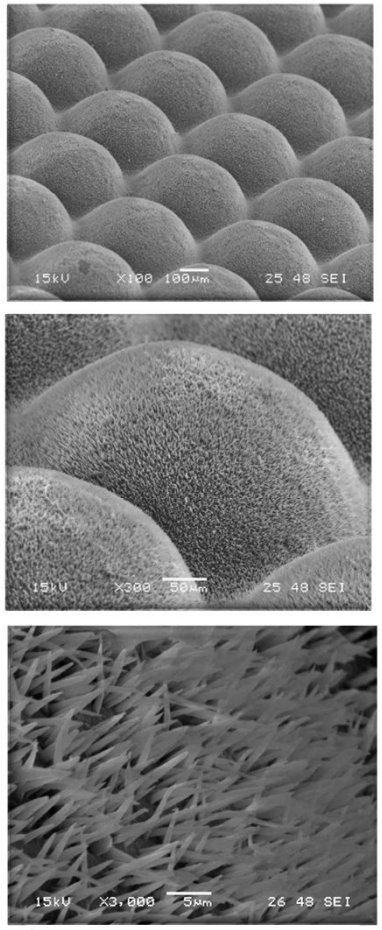
https://en.wikipedia.org/wiki/Ultrahydrophobicity

Lotus-like structure fabrication

Fabrication process steps





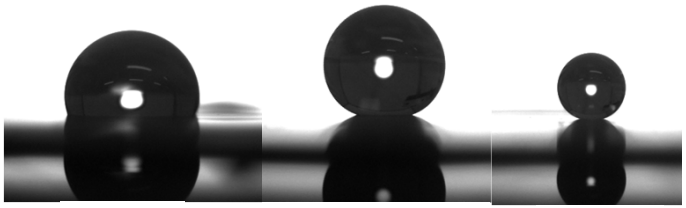


10 um/ 250 nm

200 um/ 800 nm

SHS - Wetting properties

Water Contact Angle

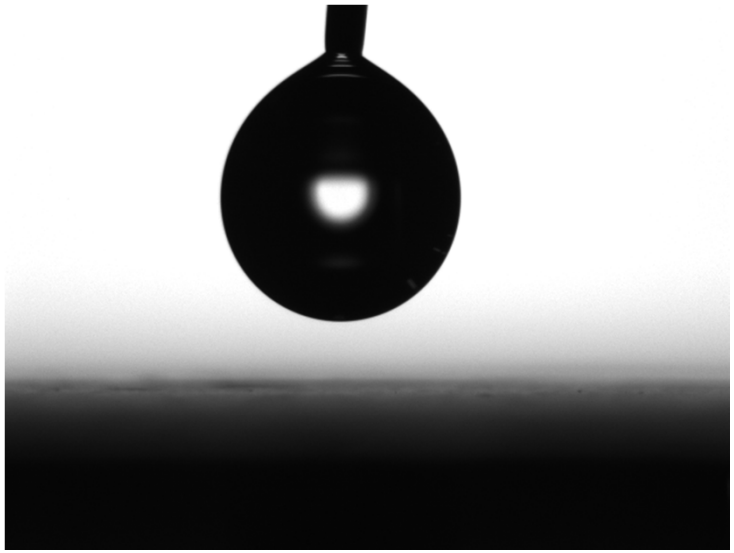


113 º 160 º 163 º

Water contact angle on 10 µm/ 200 nm hierarchy

	Static contact angle(deg)		
Topographies	*Flat*	*Micro*	*Hierarchical*
Pristine (PP)	103 ± 3	-	-
400 µm / 0.8 µm		104 ± 9.1	153 ± 4.6
10 µm /200 nm		113± 2.4	160 ± 2

	Contact angles (deg)		
Topographies	*Static*	***Hysteresis***	***Sliding***
400 µm / 0.8 µm	154 ± 0.5	10 ± 4	8 ± 1.7
10 µm / 200 nm	160 ± 2	9 ± 1	4 ± 0.3



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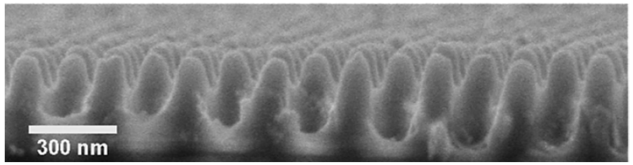
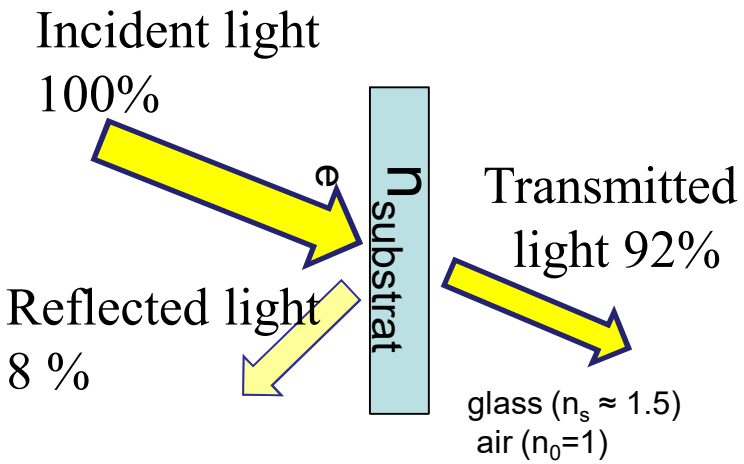
Anti- reflective surfaces

Graded
Refractive Index



Navarro-Baena et al, . *Nanoscale*, 2018, 10, 15496-15504. Jacobo el al., Nanotechnology 2021, 32(33), 335302

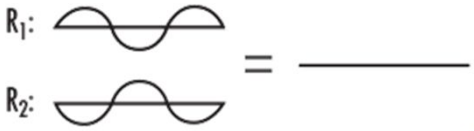
Light Reflection



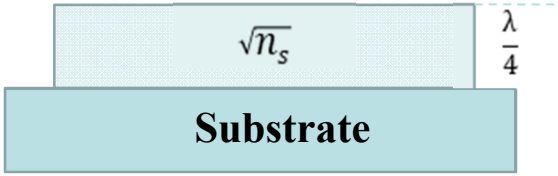
Fresnel's Equation:

$$R = \left[\frac{n_s - n_0}{n_s + n_o}\right]^2$$

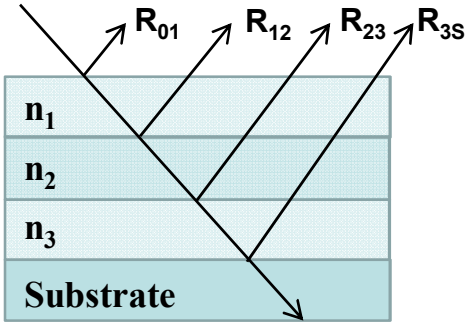
Anti-refletion: destructive interference



Single layer



Multiple layer



Refractive index for an ideal AR coating:

(1) $n_c = (n_a n_s)^{1/2}$
(2) $d = \lambda/4$

Glass ⇨ **n_s=1.2**

MgF_2 (with an index of 1.38)

$R_{sum} = R_{01} + R_{12} + R_{23} + R_{3s}$

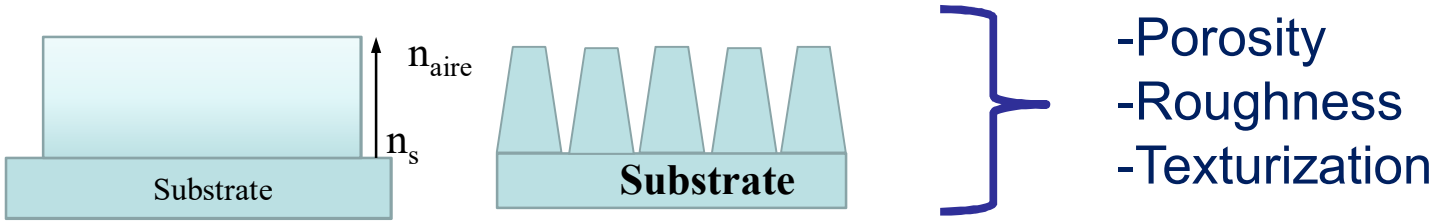
Few materials and high price!!!

Expensive approach!!!

Anti- reflective strategy

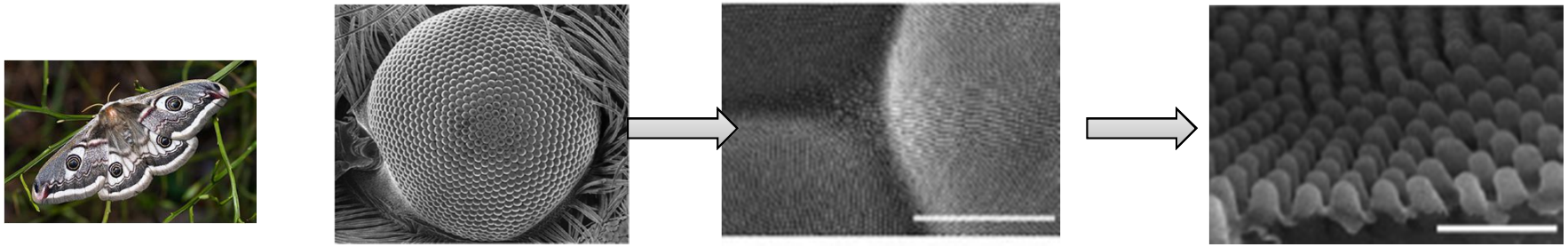
Antireflexion: Innovative alternative

Graded refractive index



-Porosity
-Roughness
-Texturization

Moth´s eye natural antireflective topography – subwavelength nanocone features



Pros of AR textured surfaces

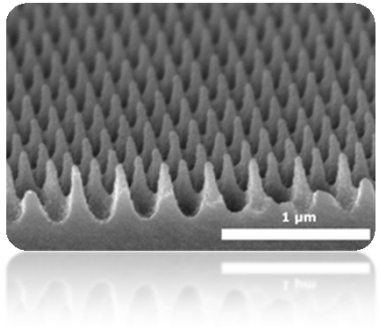
-AR Broad spectral range
- Omnidirectional
--Low cost, scalable ->R2R

Cons of AR textured surfaces

-Poor mechanical behavior
-Cleaning

Moth-eye Nanoimprinting

Moth-eye nickel mold replication by Soft lithography



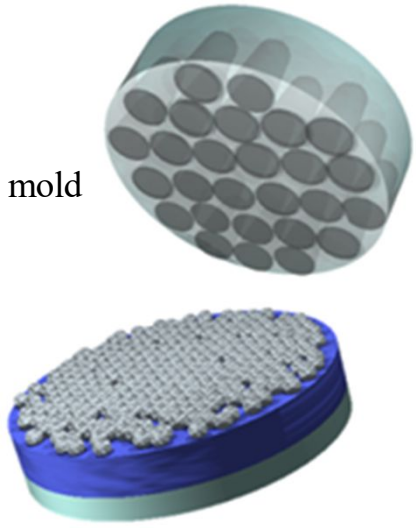
Master mold Soft lithography PDMS mold

In situ polimerization of PDMS

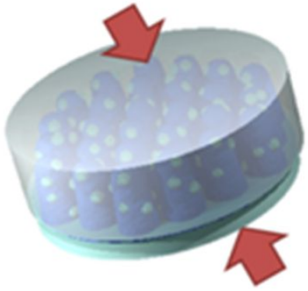
Soft Thermal NIL

Patterning polymer	**PMMA/TiO2**
Pressure (bar)	45
Temperature (°C)	170
Time (s)	300

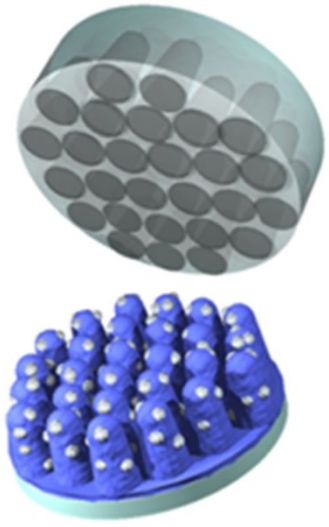
PDMS mold



PET + PMMA + Np TiO2



Nanoimprint Litography
Pressure+ Temperature

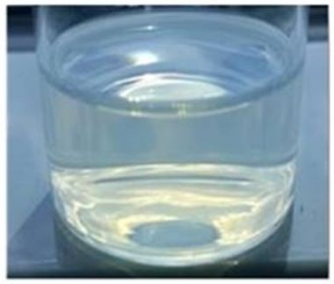


Nanocomposite surface nanostructured

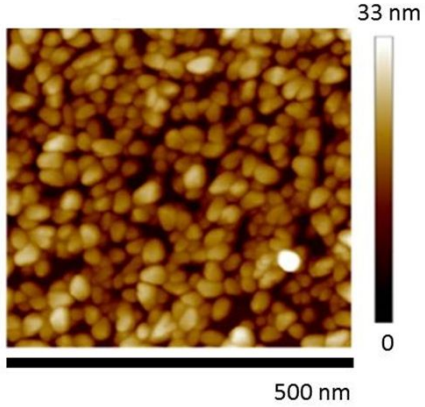
TiO_2 Surface Nanocomposite

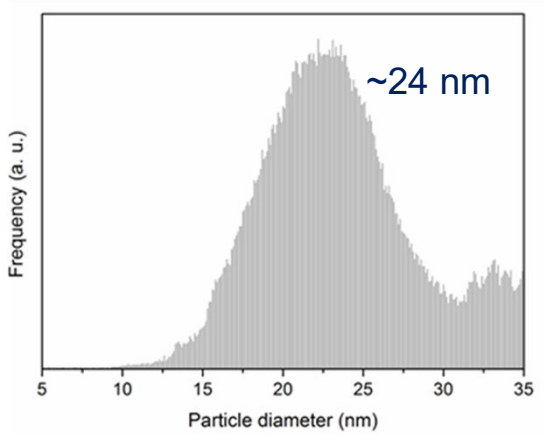
Preparation of polymer nanocomposite

TiO_2 nanoparticles: Hydrothermal synthesis

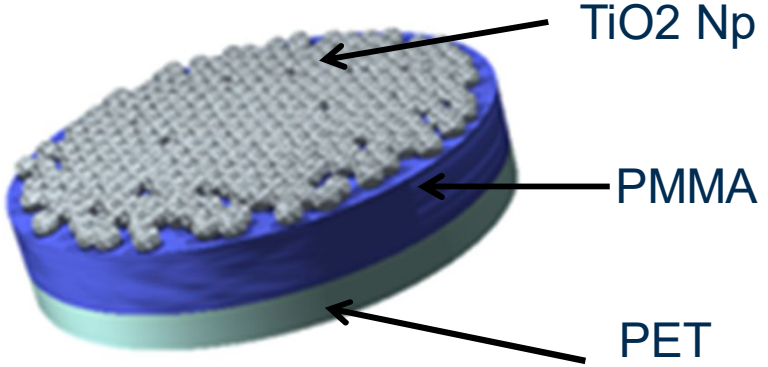


Colloidal suspension

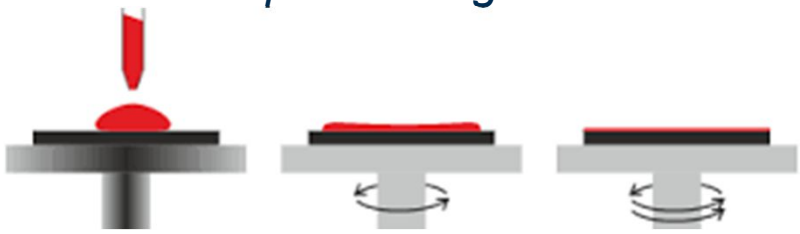




Nanocomposite preparation



Spin coating



Different ammounts of nanoparticles were deposited

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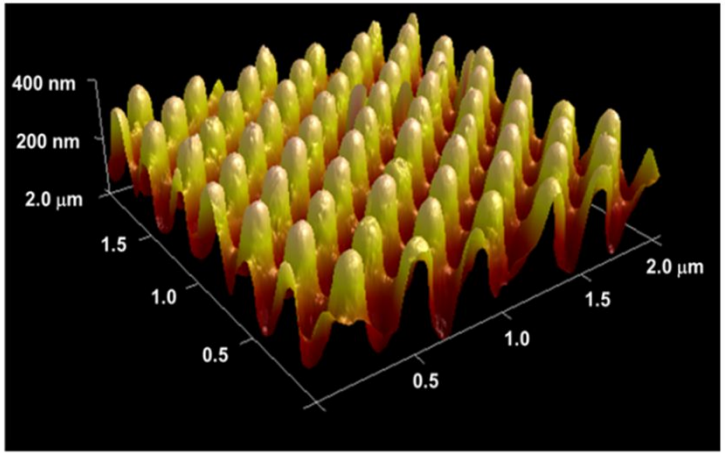
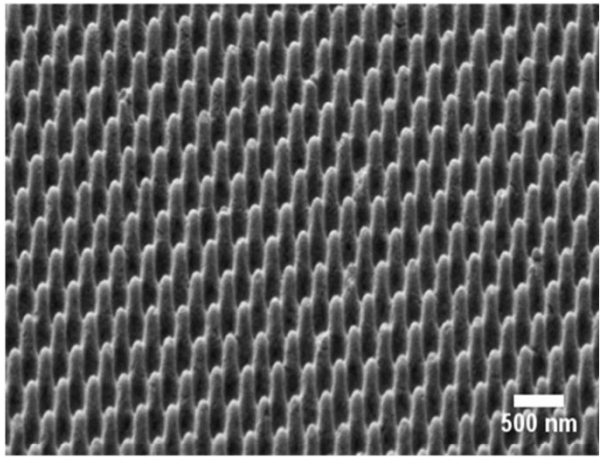
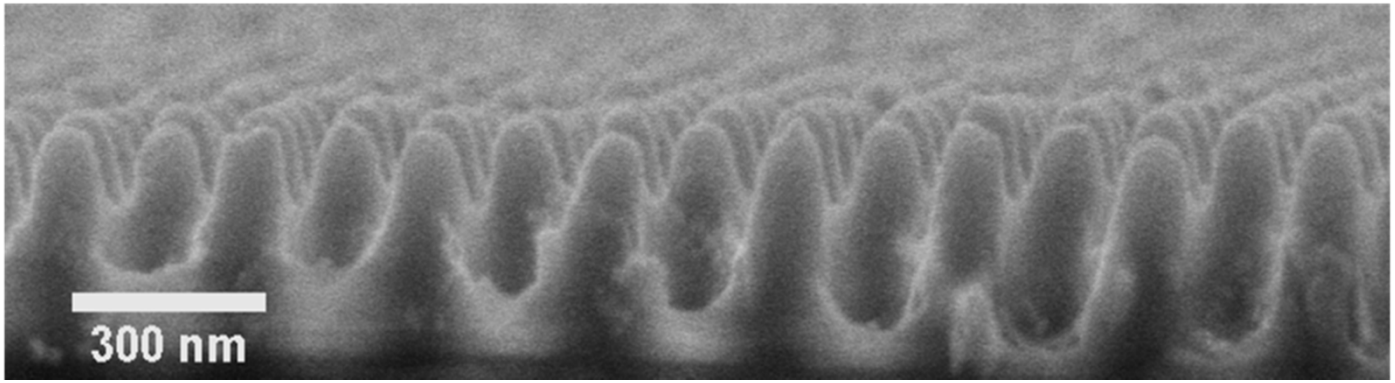
Moth-eye nanostructures

Morphology: SEM & AFM images



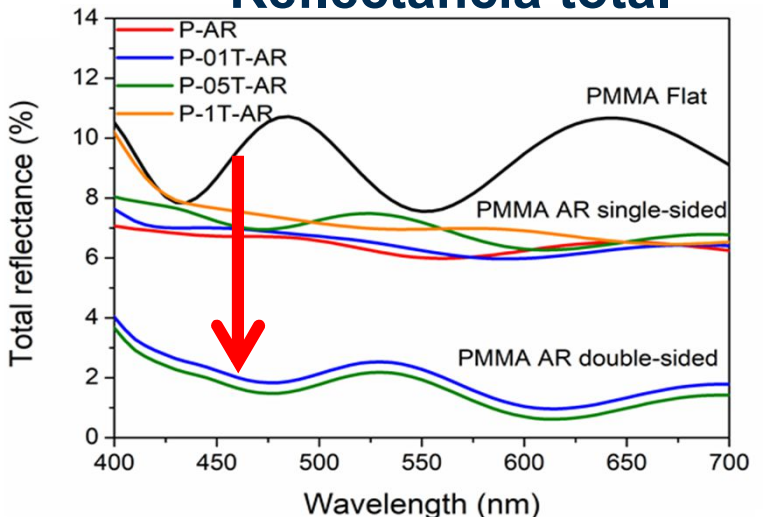




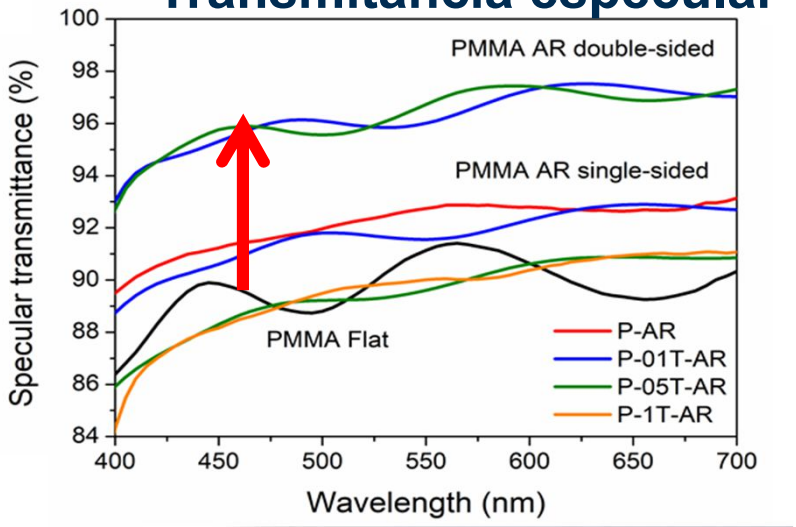
- High fidelity replication of the master mold on PMMA Nanocomposites
- Good nanoparticles dispersion
- Embedded particles within the polymer

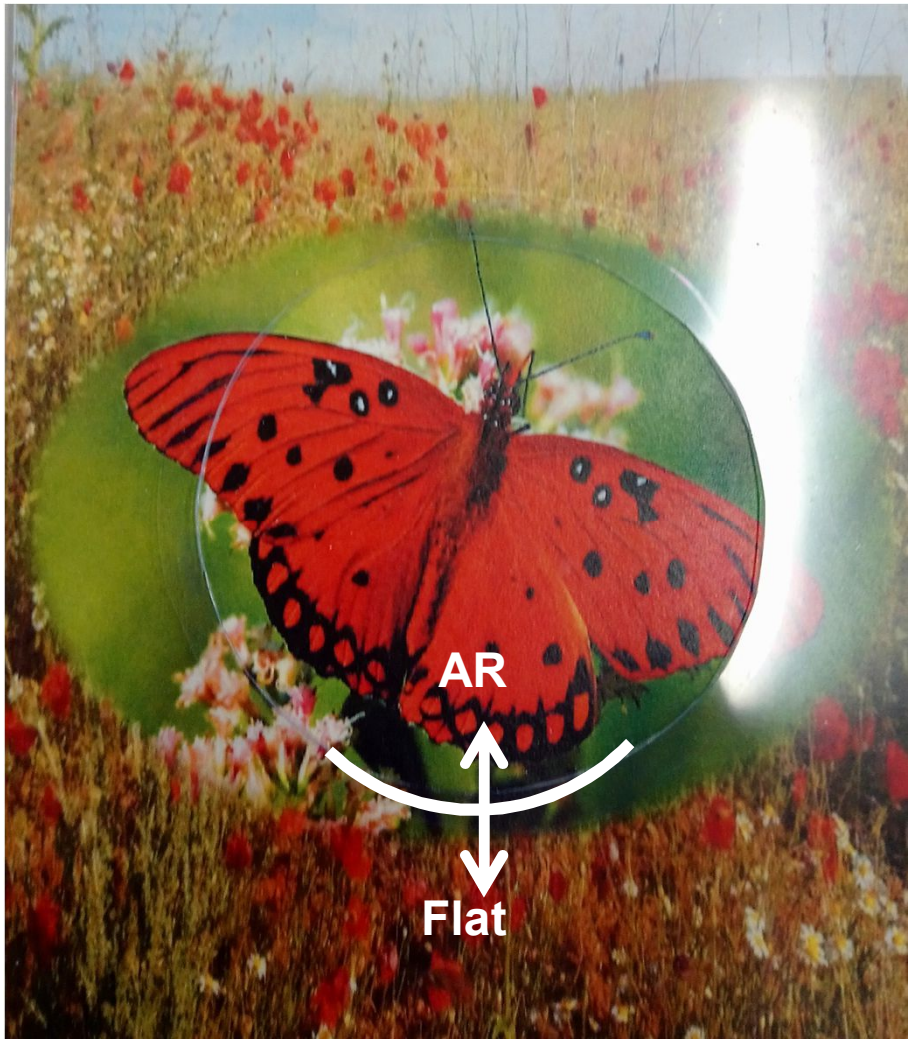
Moth-eye optical characterization

Reflectancia total

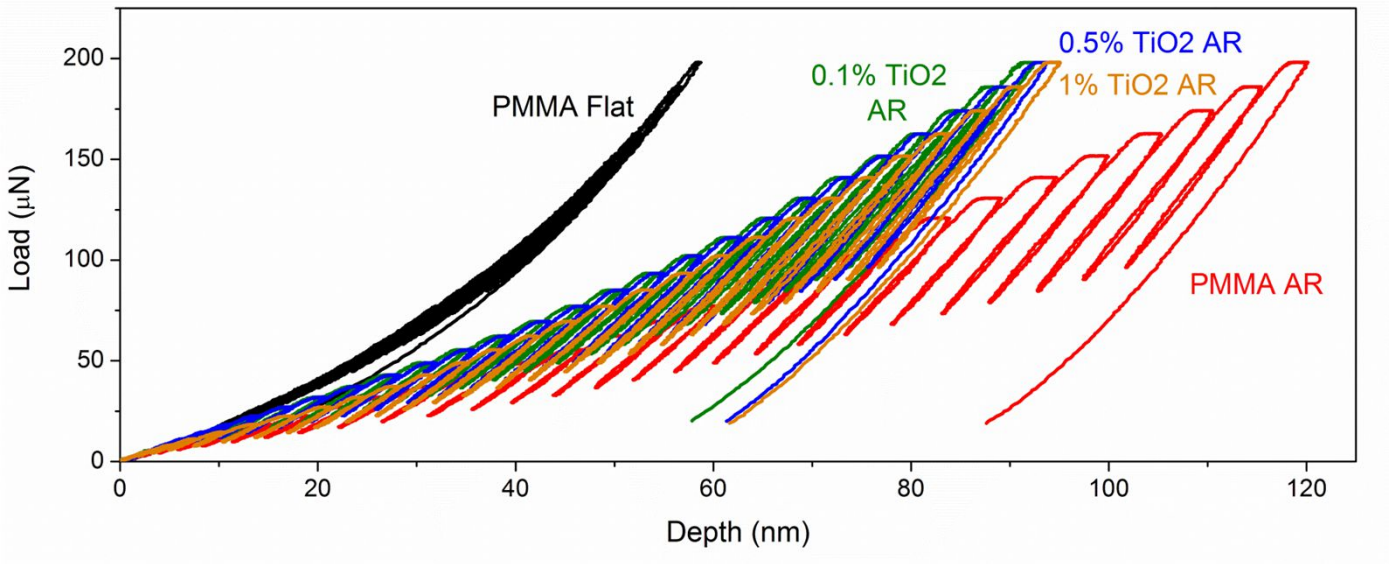


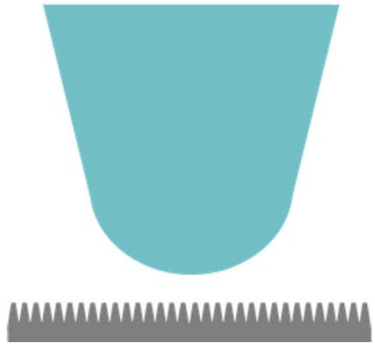
Transmitancia especular





Mechanical behavior: Nanoindentation

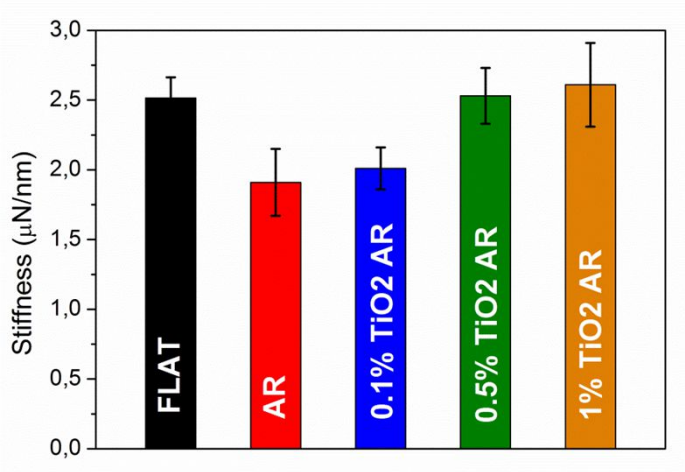


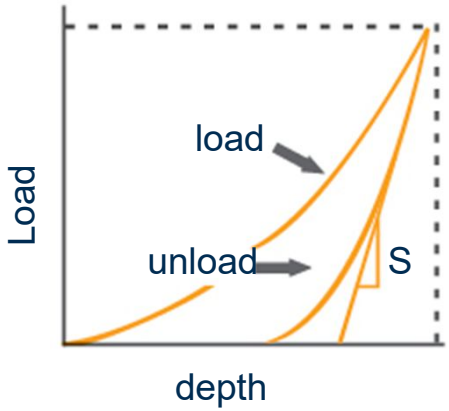


20 load/unload cycles until maximum load of 200 μN

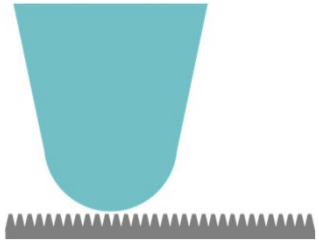
Stiffness

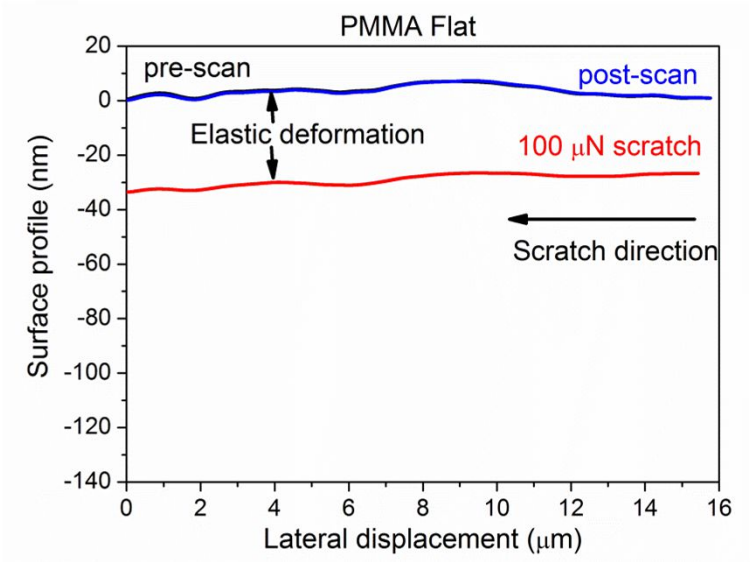
Slope of the curves in the elastic region (maximum of 10 nm)



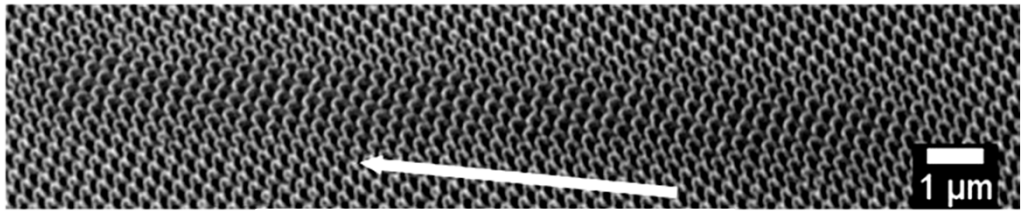


Mechanical behavior: Nanoscratch

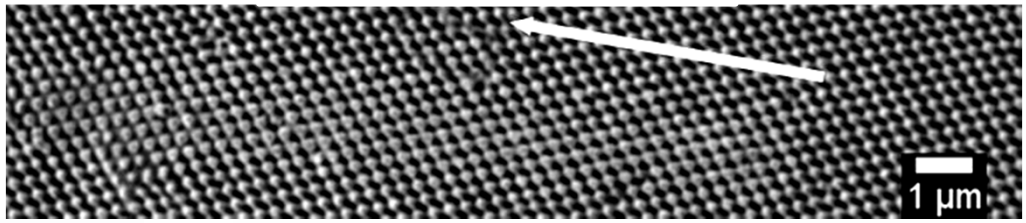


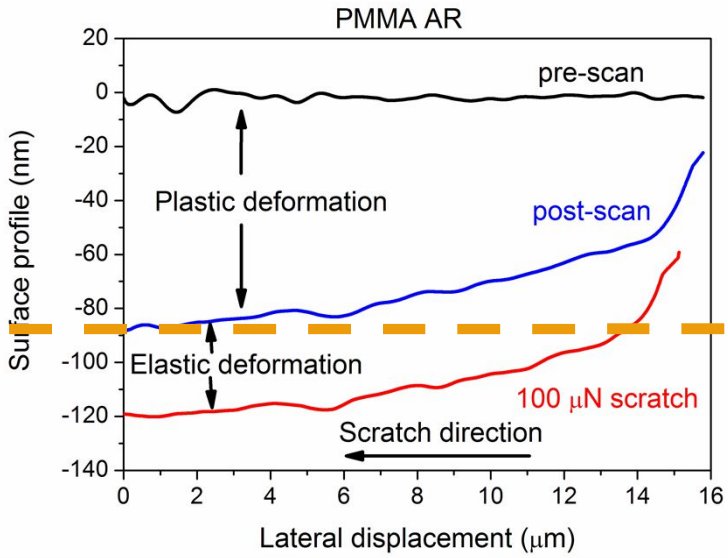


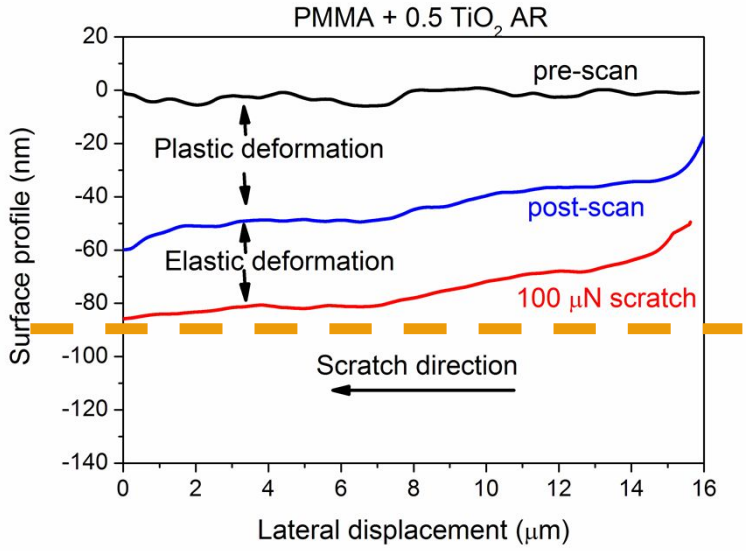
PMMA



PMMA + 0.1 wt% TiO_2

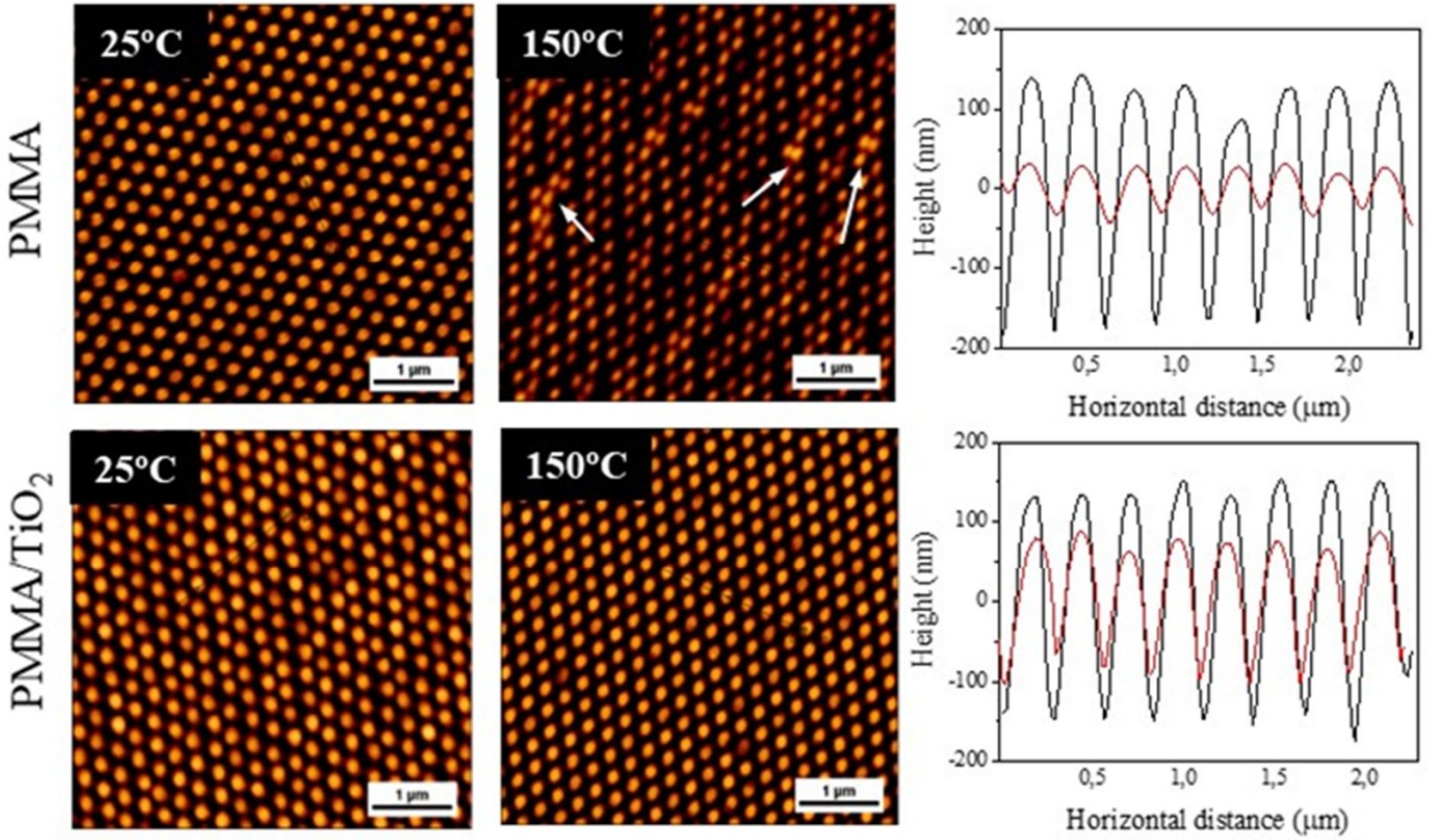






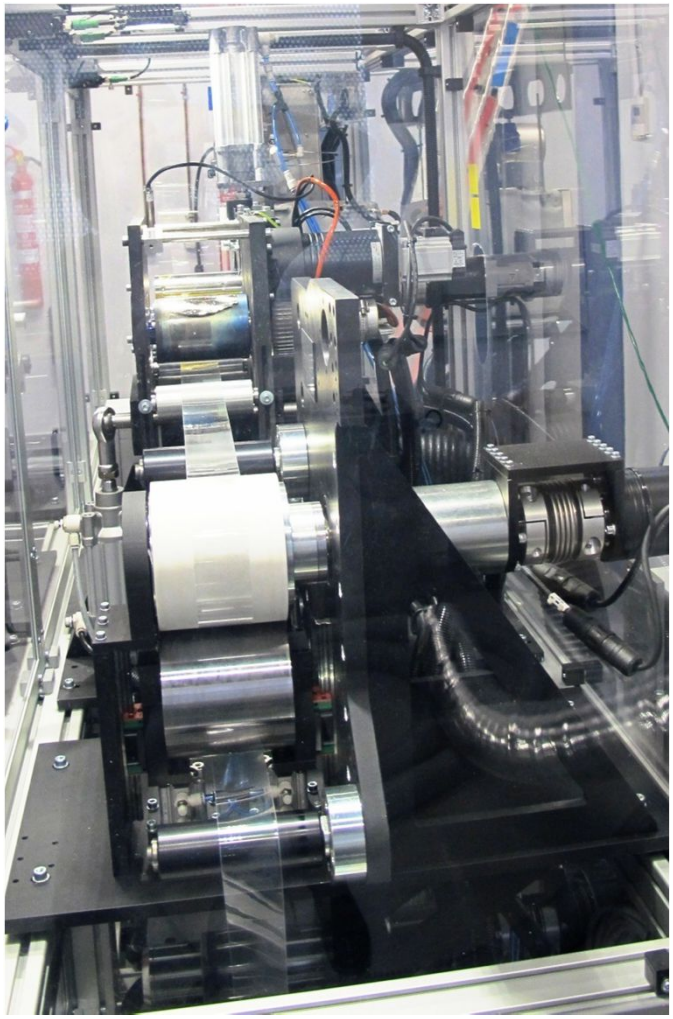
Improved thermal stability

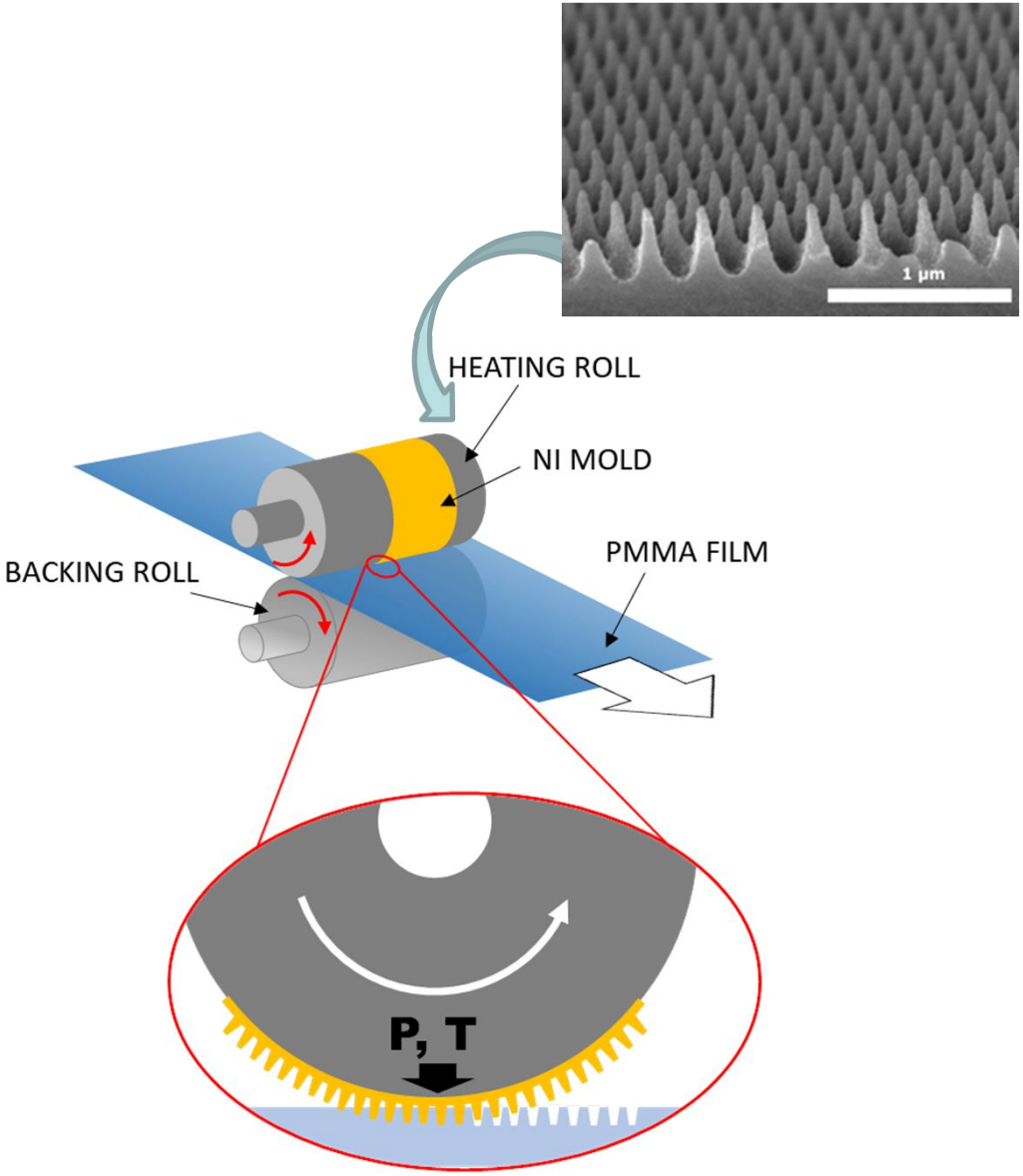
Moth-eye PMMA/TiO2 surface nanocomposites



"anchoring effect of the TiO_2 NP to the polymer chain mobility" – pattern stability

Thermal R2R imprinting of moth-eye non-reflective films





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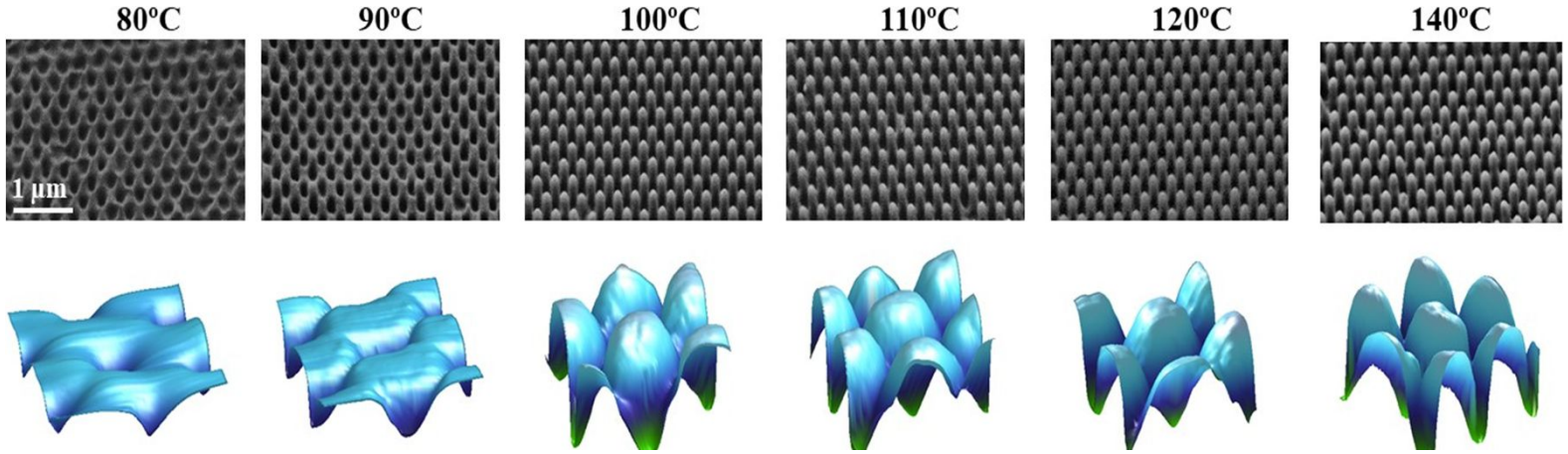
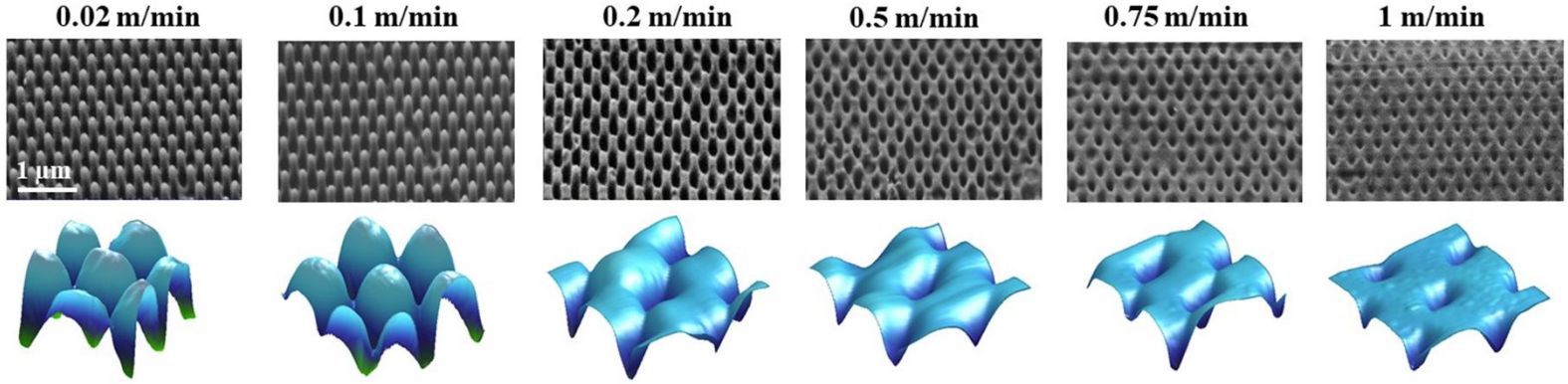
Thermal R2R imprinting of moth-eye non-reflective films

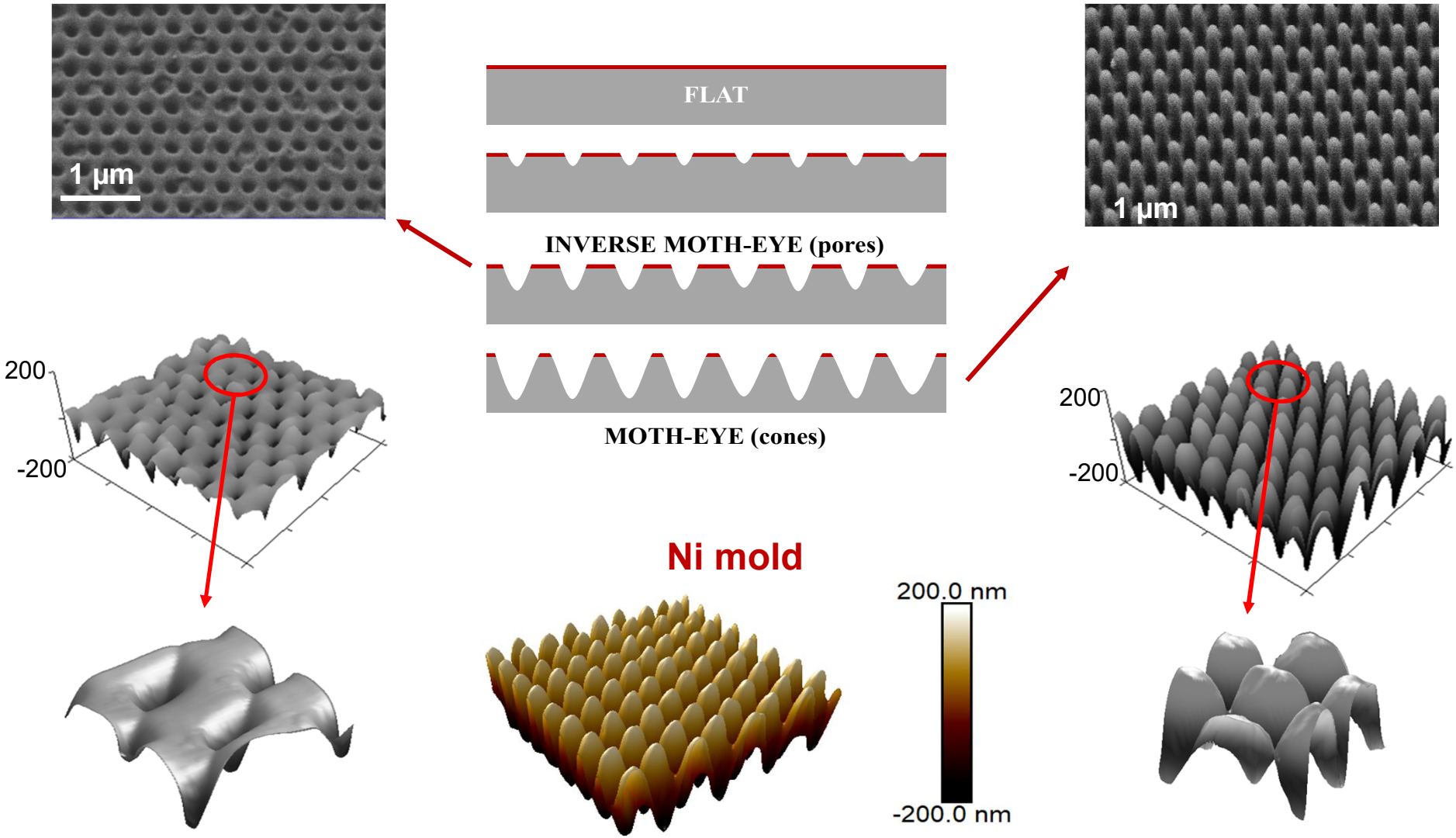
@ Variable temperature



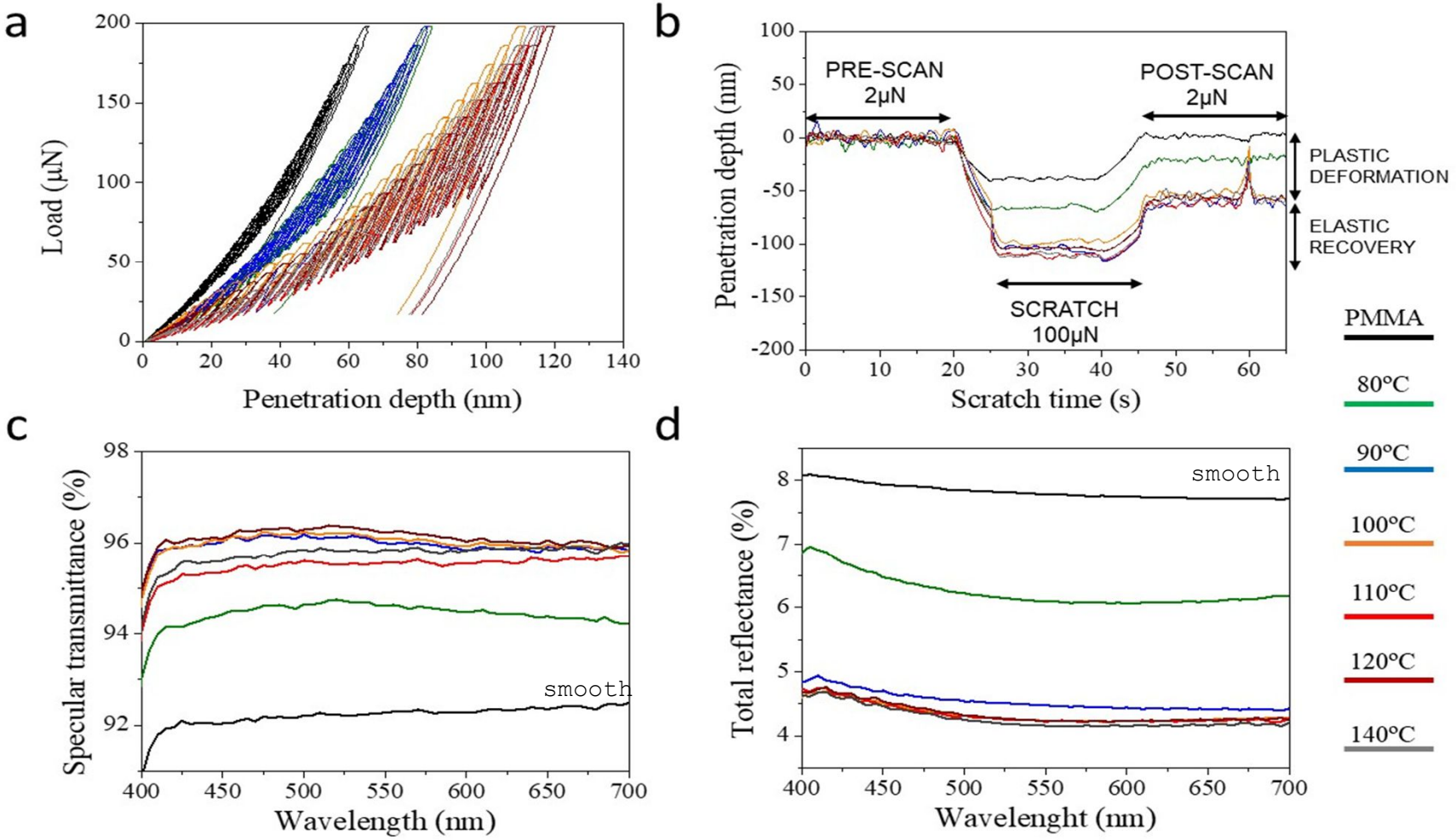
@ Variable speed



Thermal R2R imprinting of moth-eye non-reflective films



Thermal R2R imprinting of moth-eye non-reflective films



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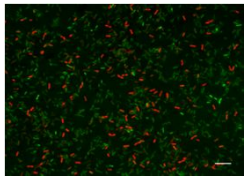
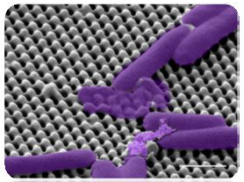
Bio-applications

1. Bactericidal Moth Eye Inspired Topography

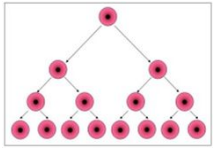
Fluorescence Microscopy



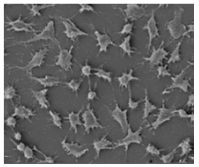
SEM



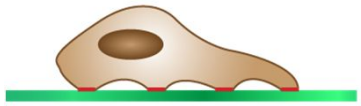
2. Cell Instructive Patterned Topographies



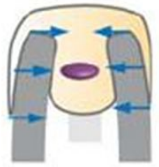
Proliferation



Morphology



Migration



Cell Traction Force

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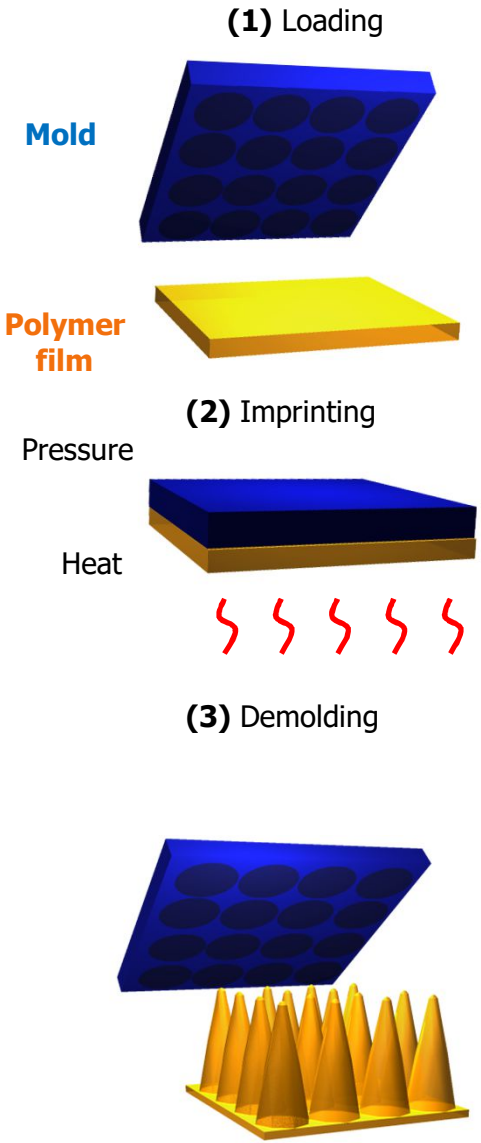
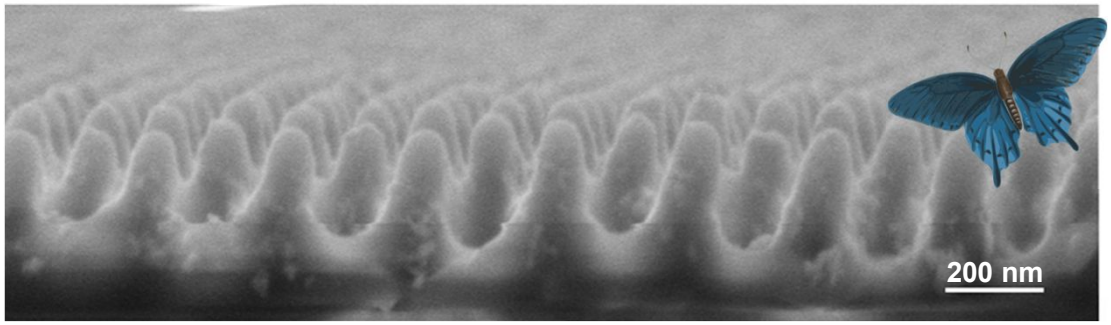
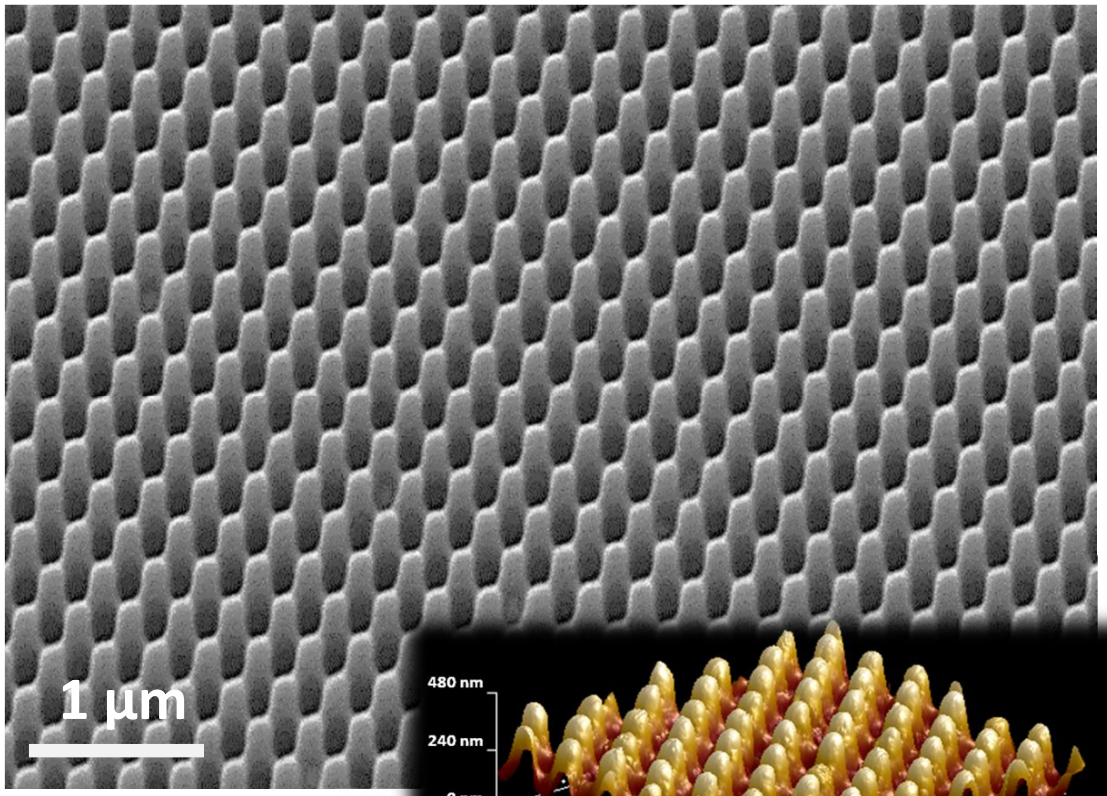
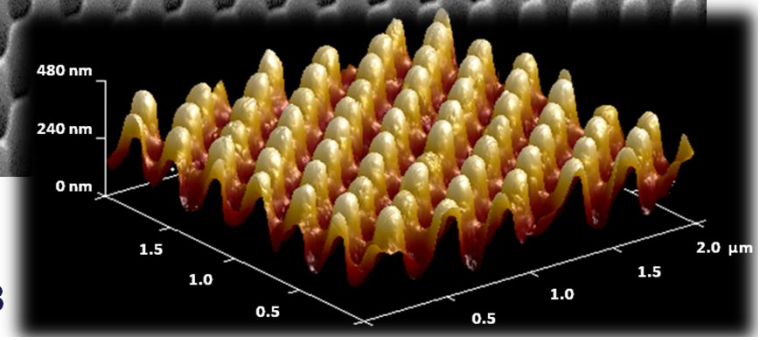
Moth-eye mimetic topography



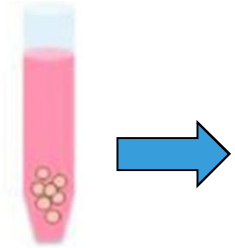




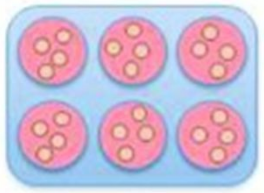


Height: 250 nm
Aspect Ratio: 2.8

EXPERIMENTAL SETUP



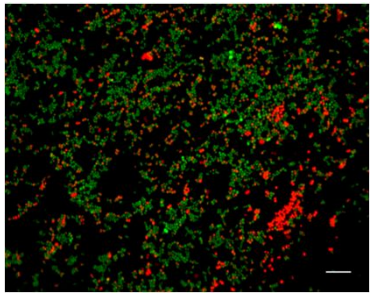
Bacterial/ Cell Supension



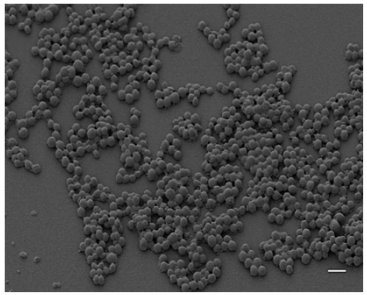
Bacterial/ Cell Culture on moth eye Inspired Topography

Bactericidal Effect

Fluorescence Microscopy

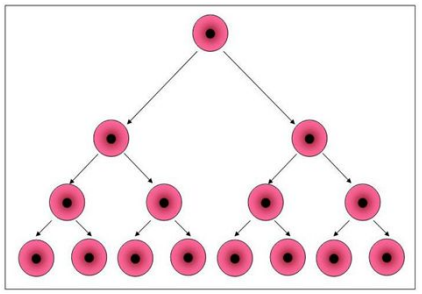


Scaning Electron Microscopy

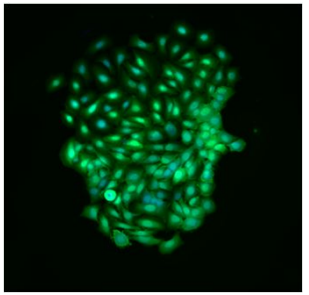


Biocompatibility

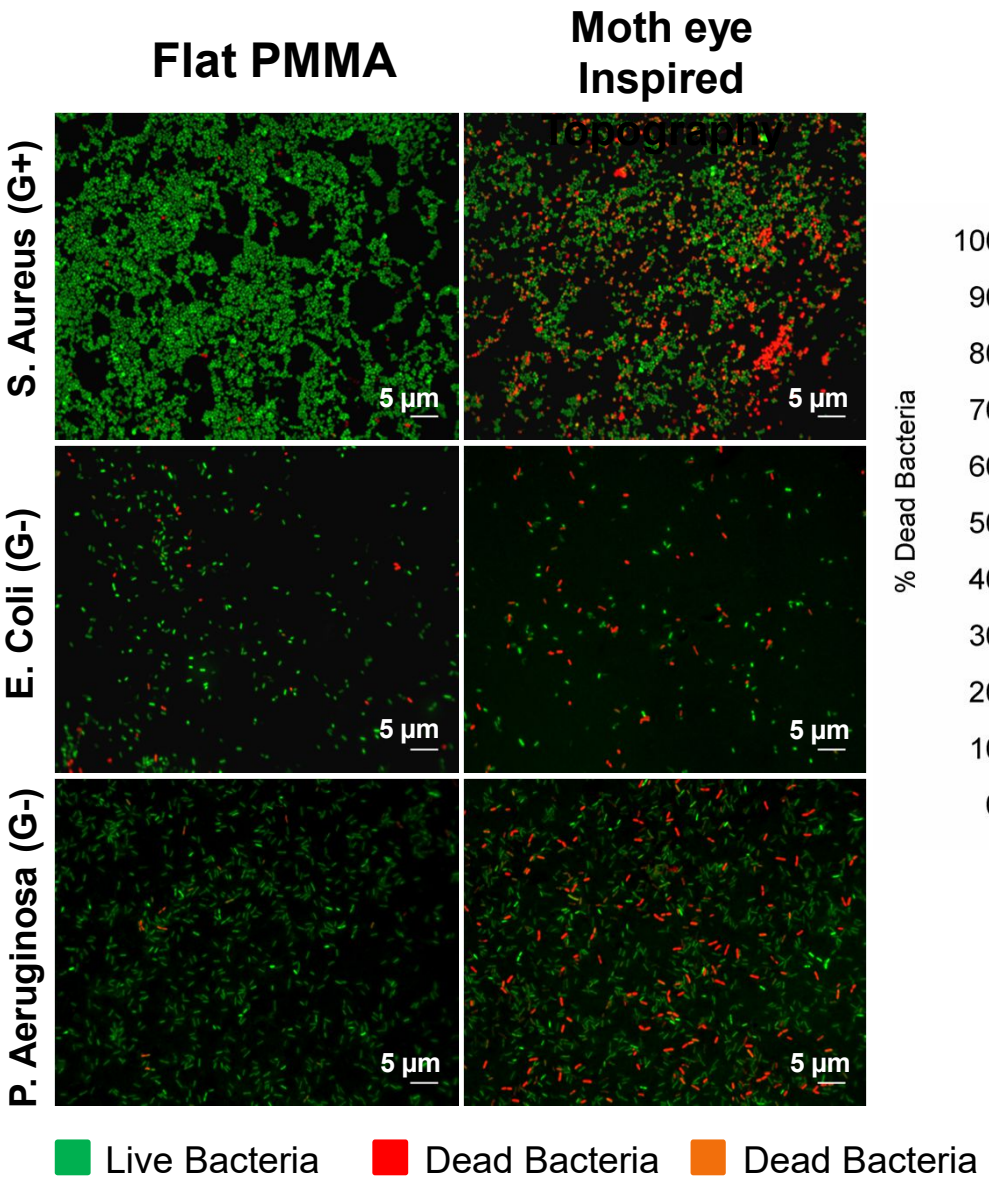
Cell Proliferation

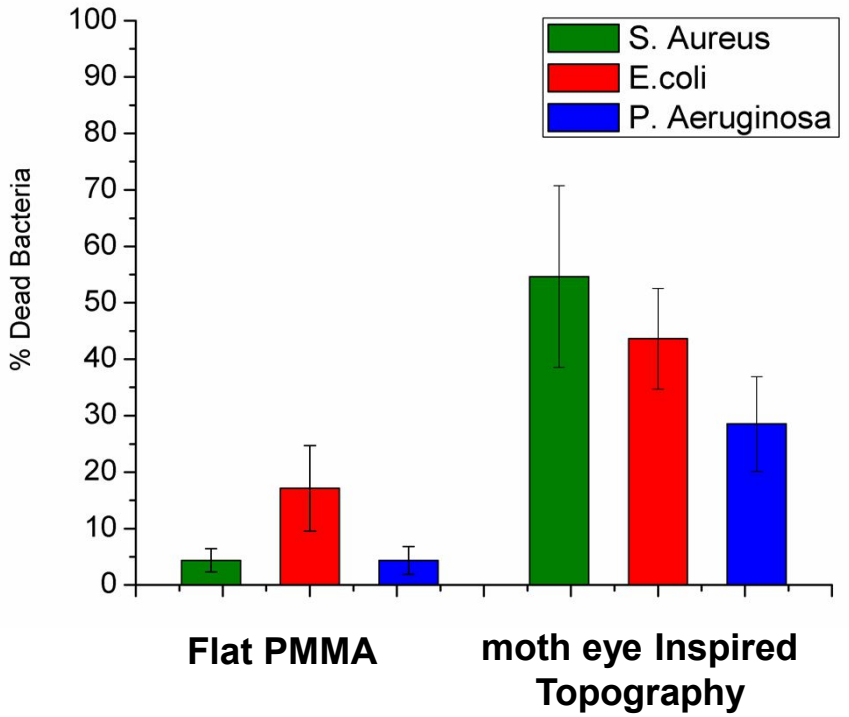


Cell Morphology



Bactericidal Efficacy of Moth Eye Topography





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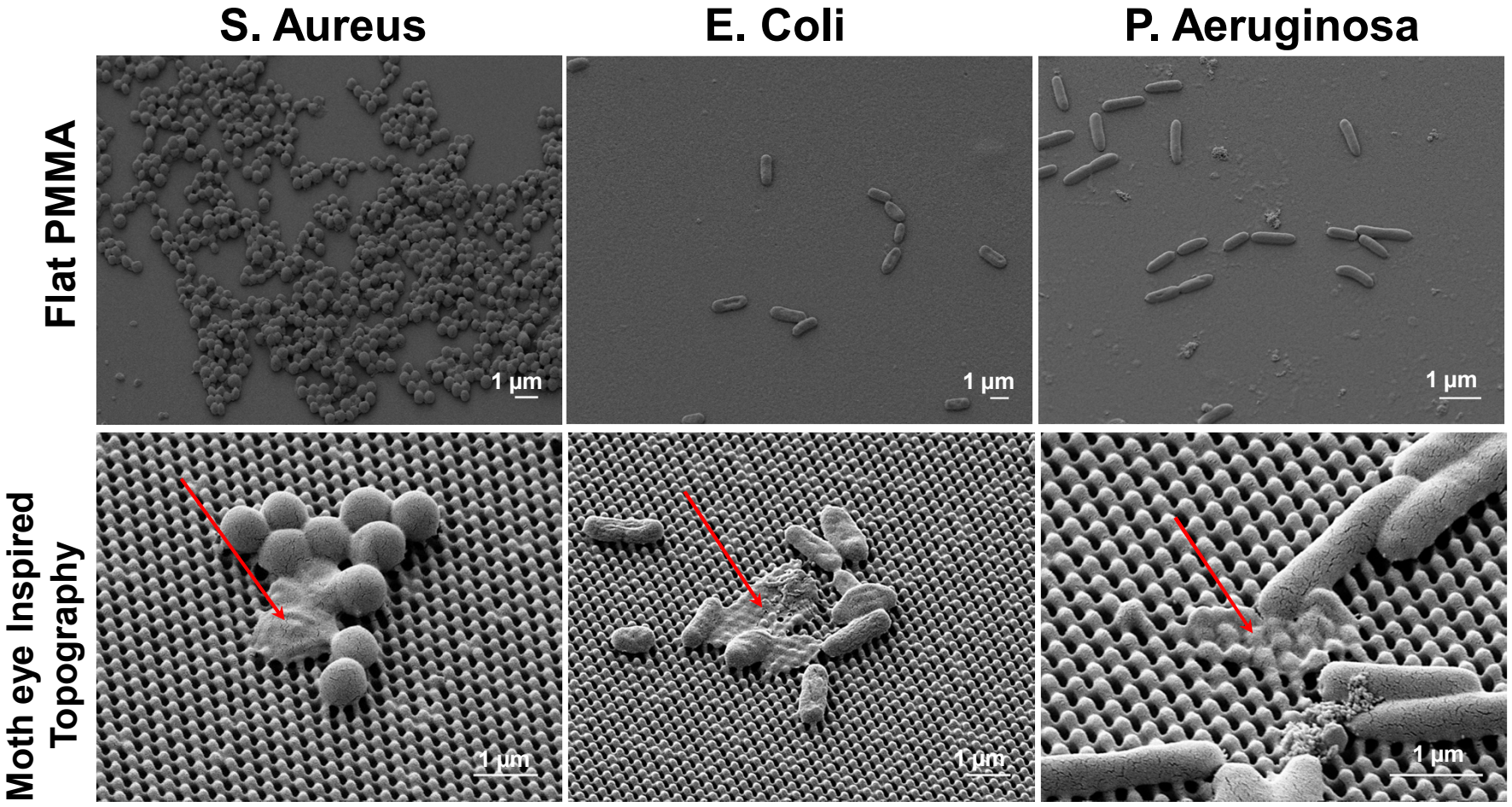
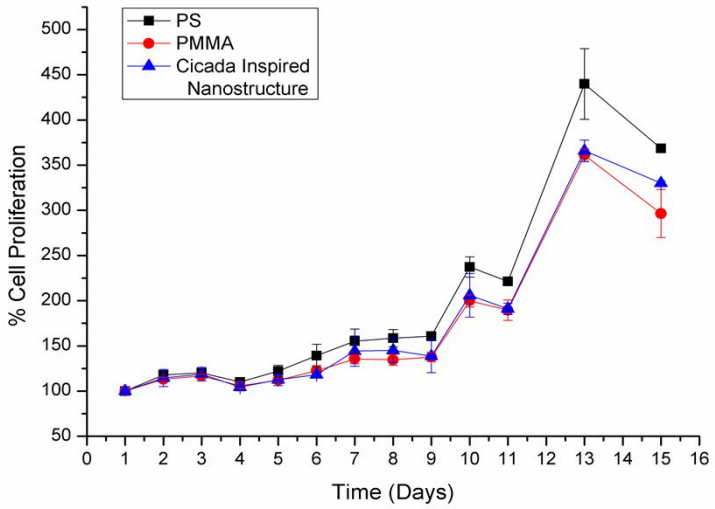
Moth Eye Bactericidal Effect

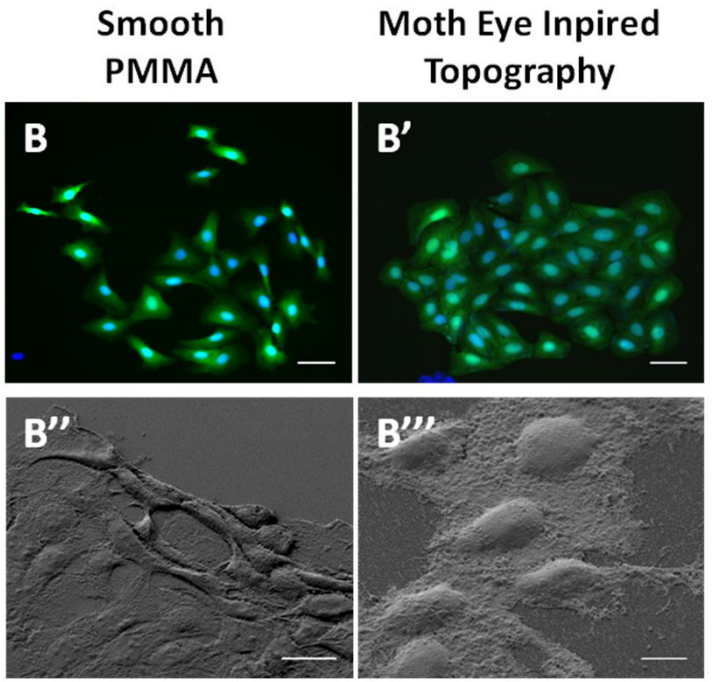


“Mechanical rupture – membrane stretching to optimize adhesion”

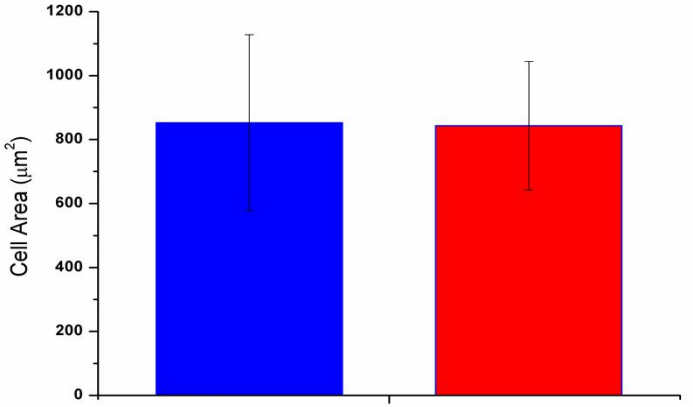
Biocompatibility of Moth Eye Topography

Cell Proliferation- HaCaT cells

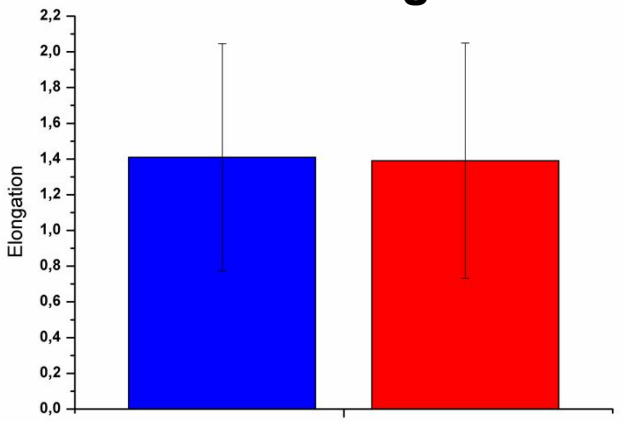




Cell Spreading

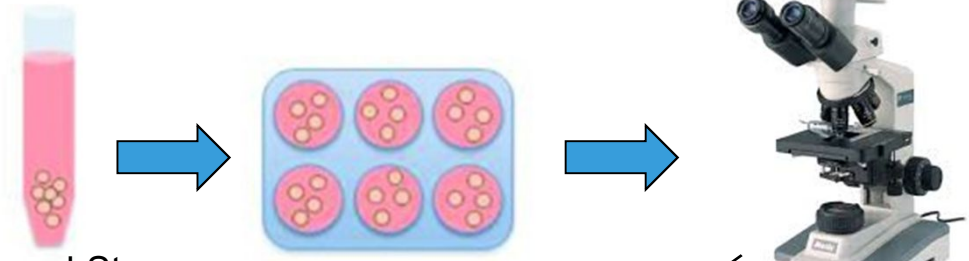


Cell Elongation



Cell Instructive Patterned Topographies

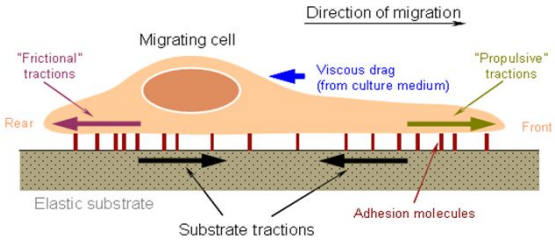
Experimental Setup



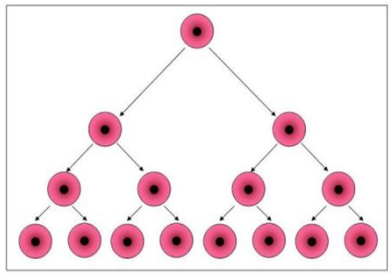
Neural Stem Cell suspension

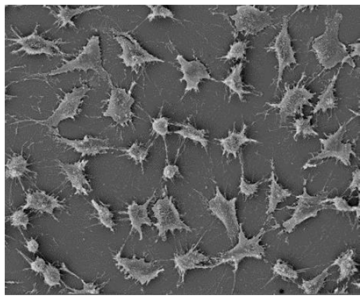
Cell cultured over nano and micropillars surfaces

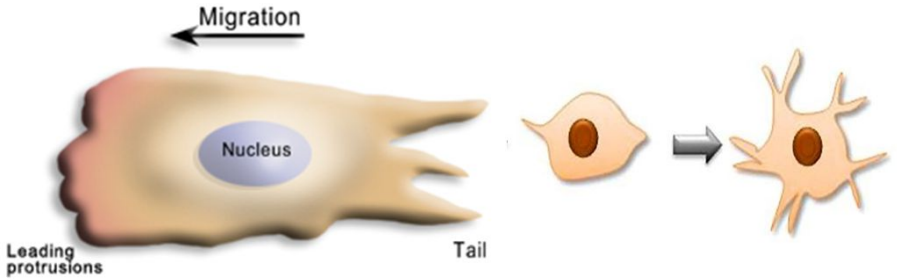
Traction Force



Proliferation Morphology Migration Differentiation

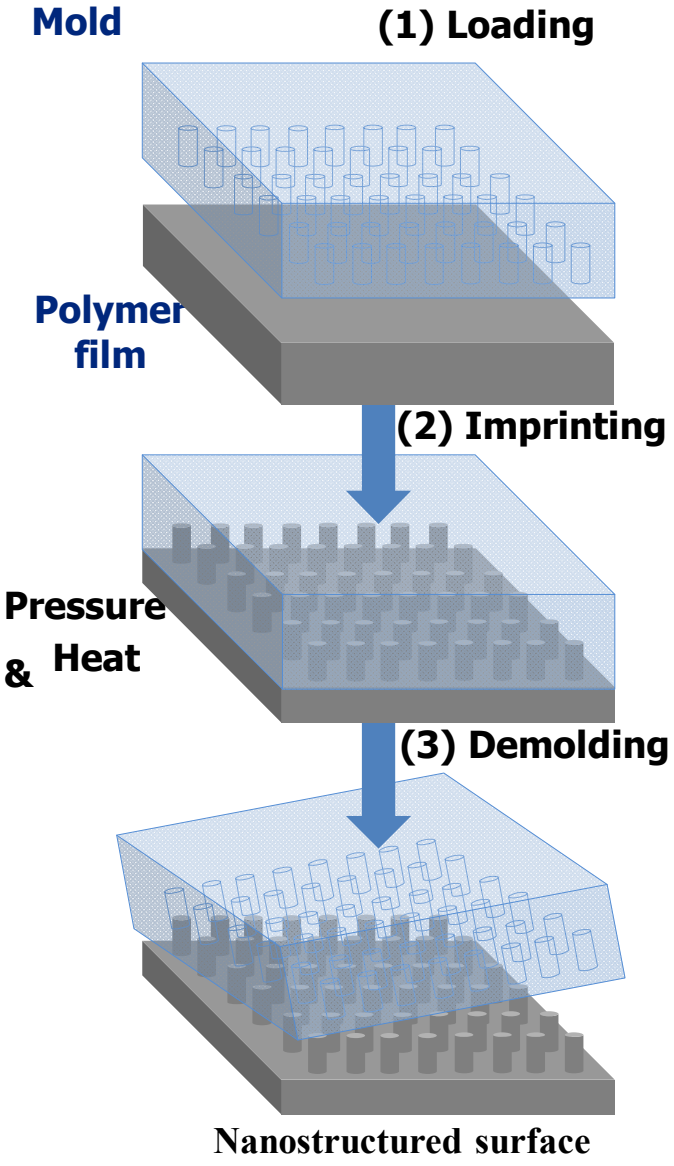




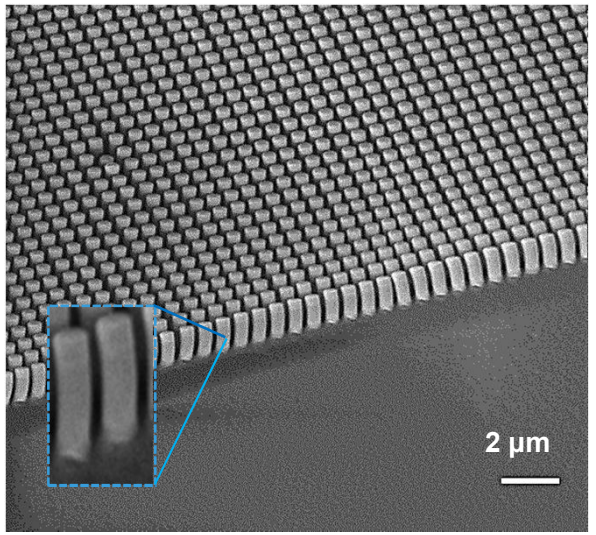


Polymer Nanoimprinting (NIL)

Replication technique: high fidelity, high resolution, low cost, scalable nanofabrication

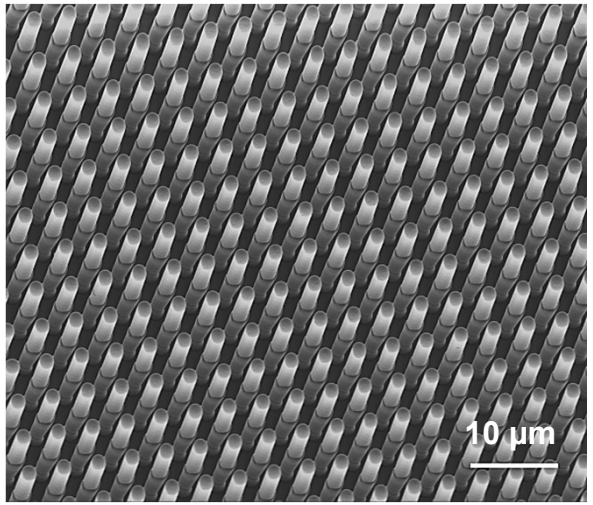


500 nm pillars



Diameter 500 nm
Height 2 µm
Interpillar Gap 500 nm
Aspect Ratio 4

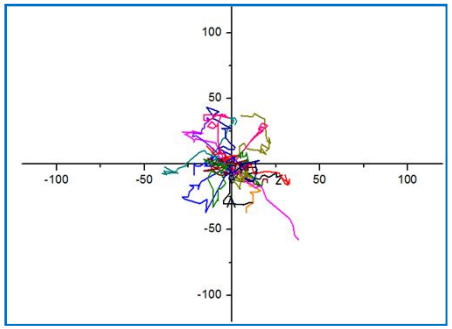
2 µm pillars

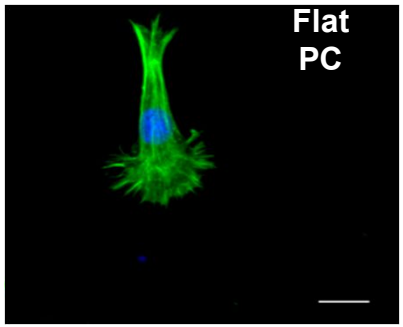


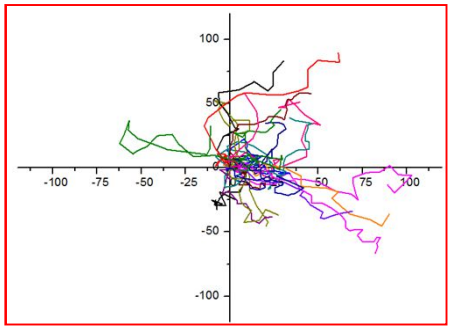
Diameter 2 µm
Height 10 µm
Interpillar Gap 2 µ
Aspect Ratio 5

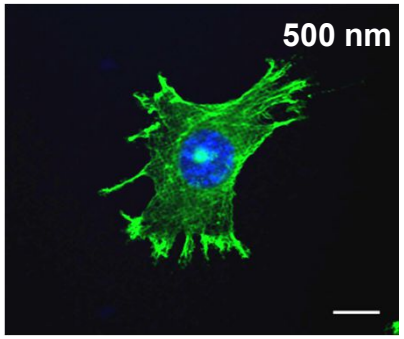
Cell Directional Migration

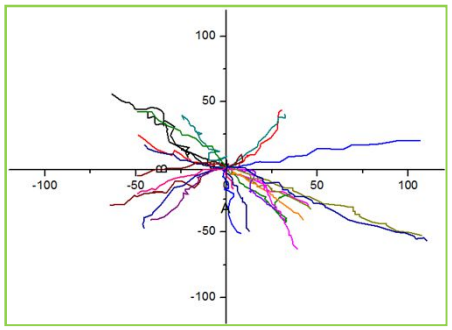
Windrose plots of ell trajectories

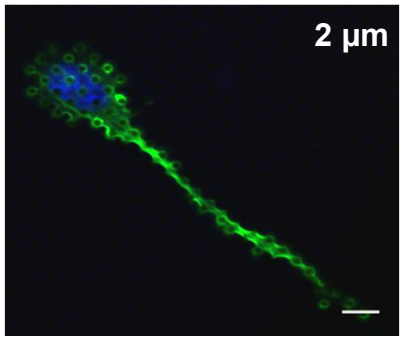


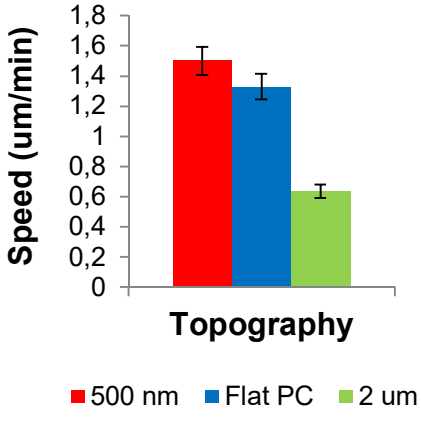


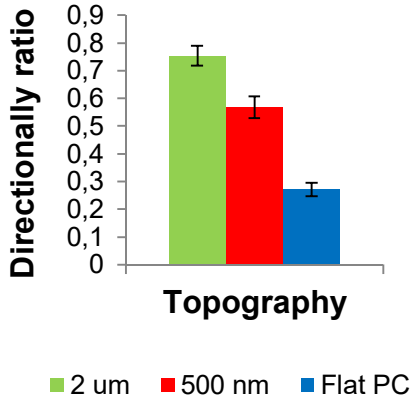


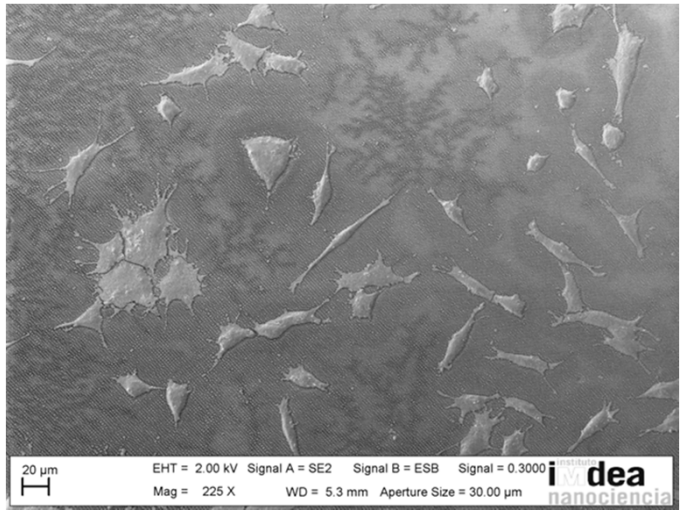




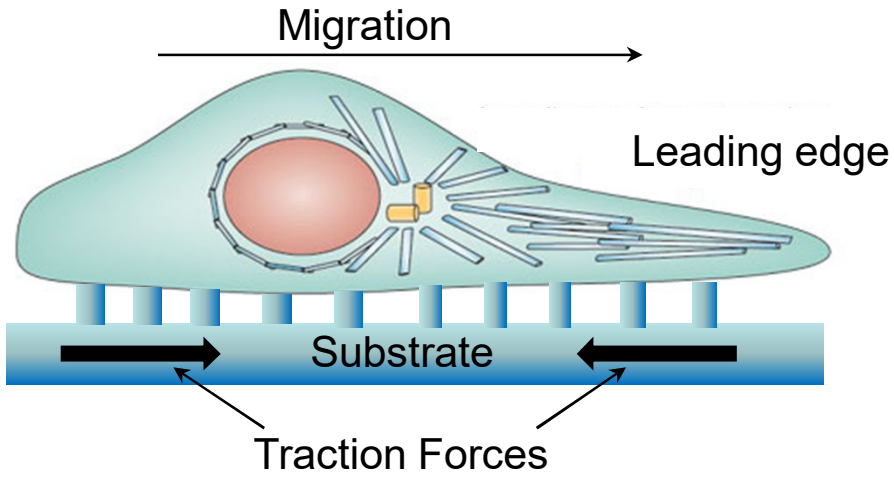








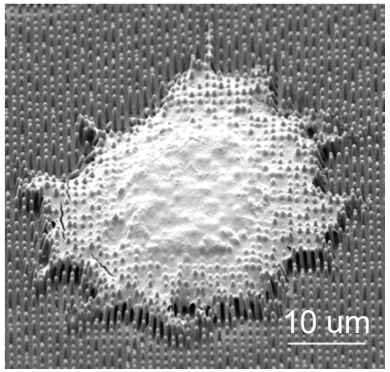
Cell Traction Force



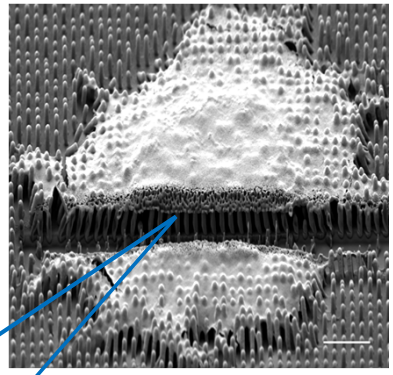
Hooke's Law

F= kΔx

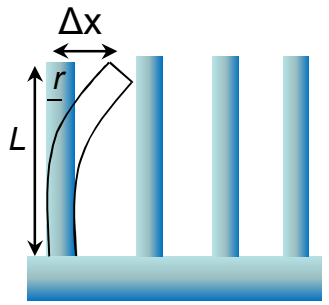
$$k = \frac{3}{4}\pi E \frac{r^4}{l^3}$$

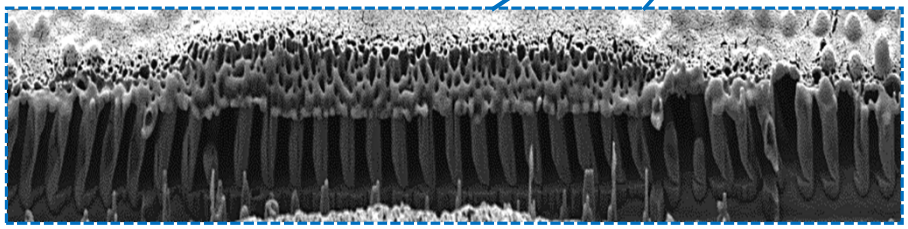


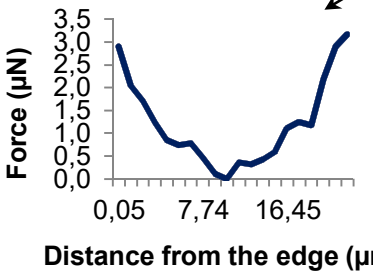
FIB-SEM Visualization

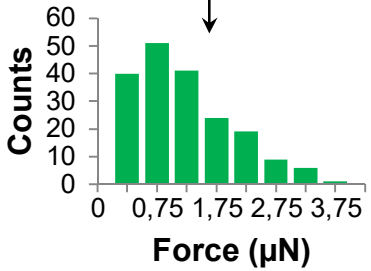


Bending angle measurement



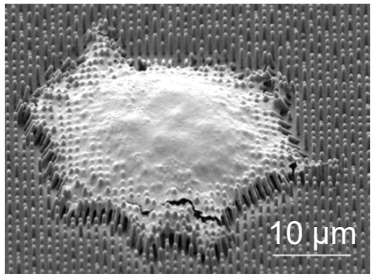




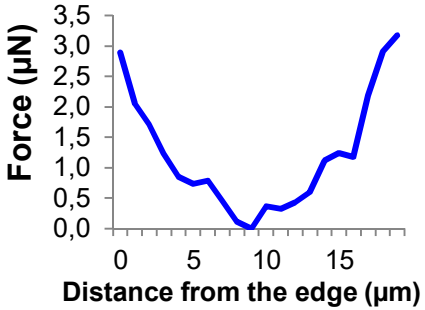


Cell Traction Force

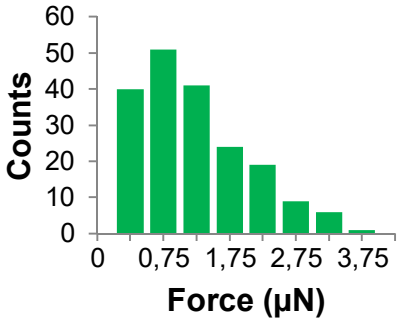
No Migration



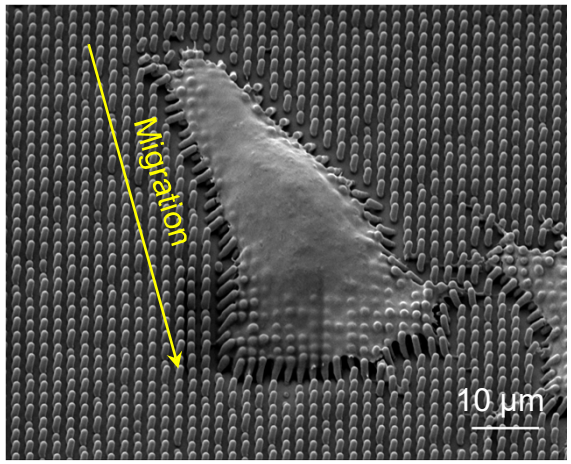
Single cell force profile



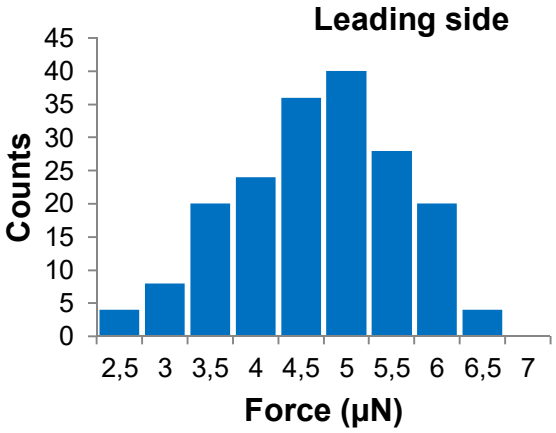
Mean force value



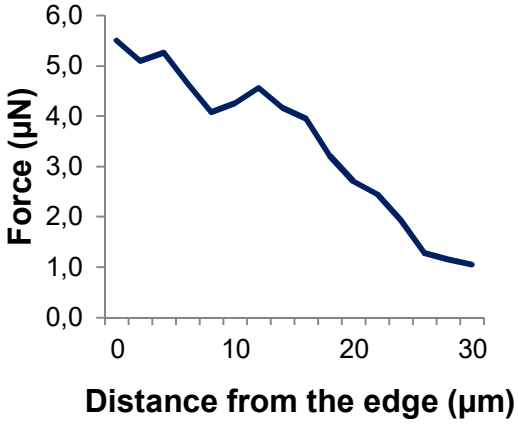
Migration

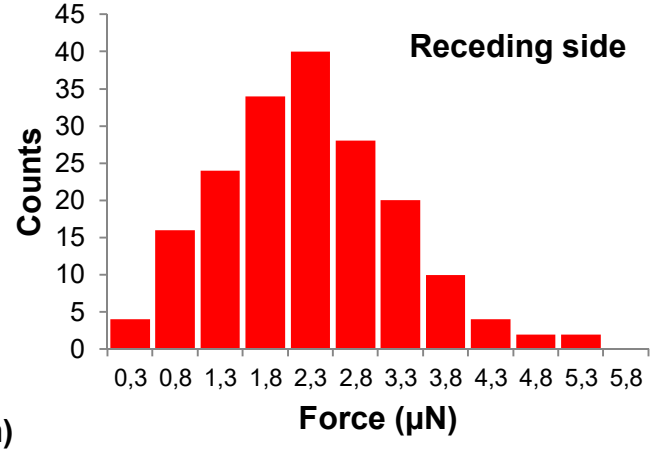


Mean force value

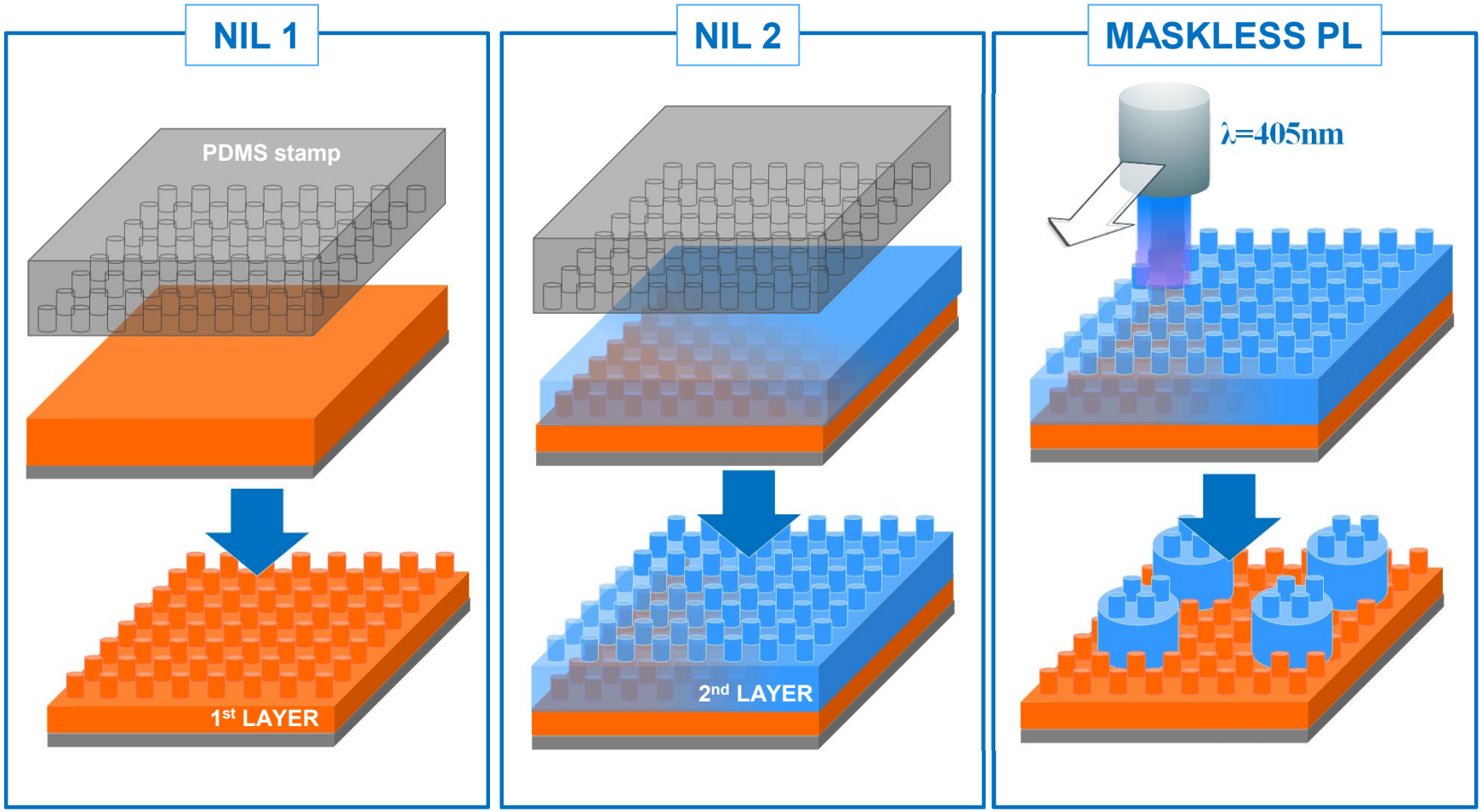


Single cell force profile





Novel fabrication procedure: NIL + PL



NIL: Nanoimprint Lithography ; PL: Photolithography

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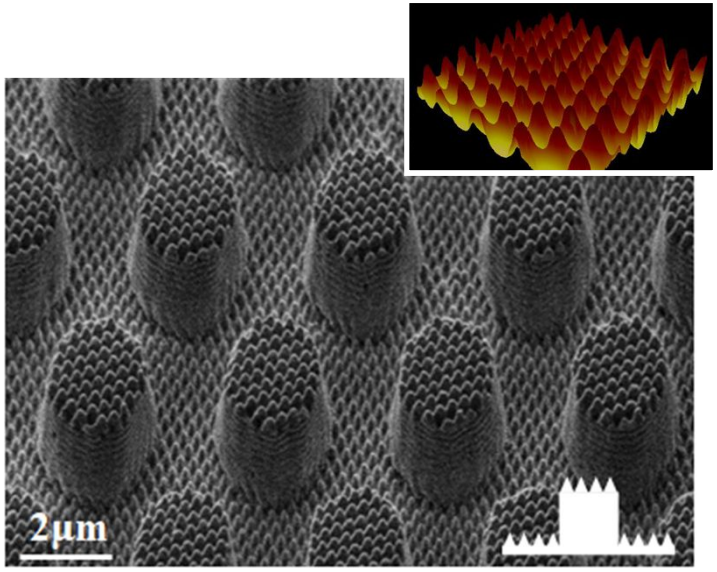
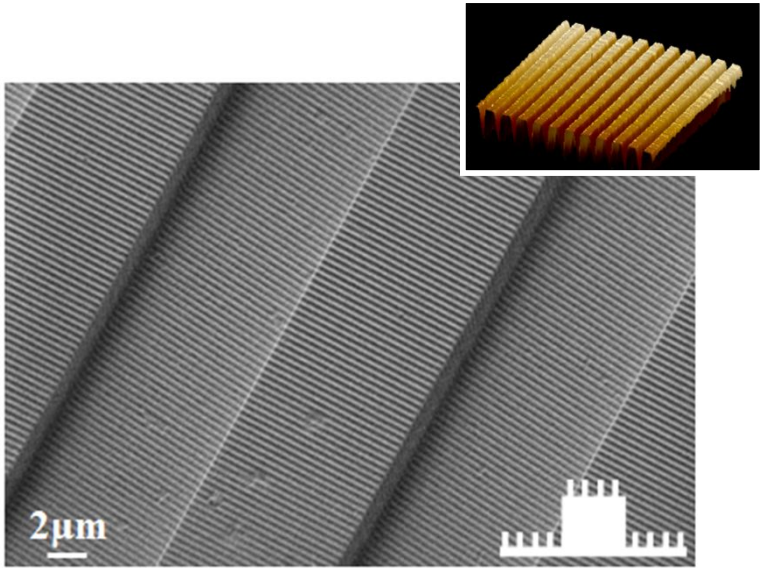
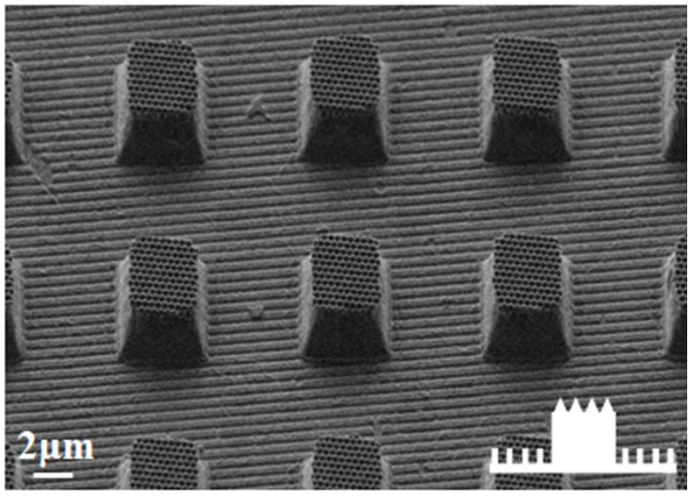
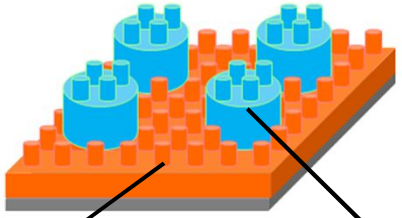
1ST LAYER: THERMOPLASTIC









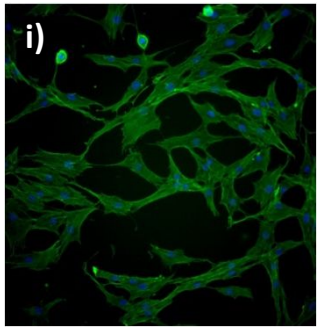
PMMA-A4
T_g=98-106ºC
T_{NIL}=170ºC
P_{NIL}=30bar
t=5min

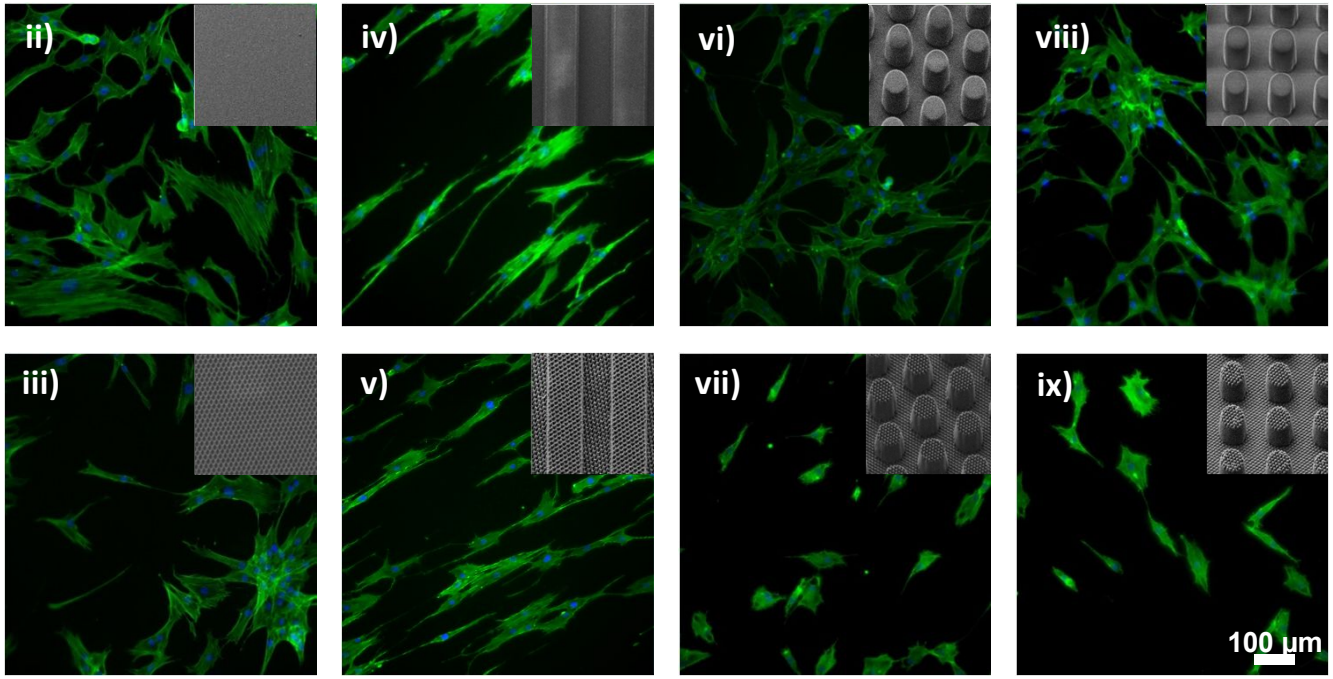
AZ1512
S.C: 2000rpm, 1min
T_{NIL}=100ºC
P_{NIL}=30bar
t=5min

Mesenchymal stem cells (iAdMSC)
Attachment and cell morphology

PDMS Micro- topographies

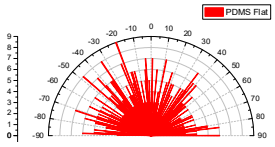
TCP -control

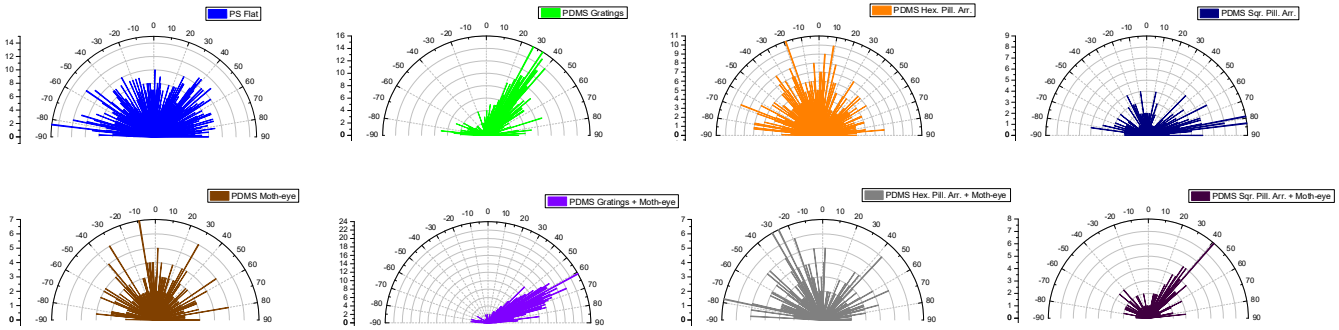




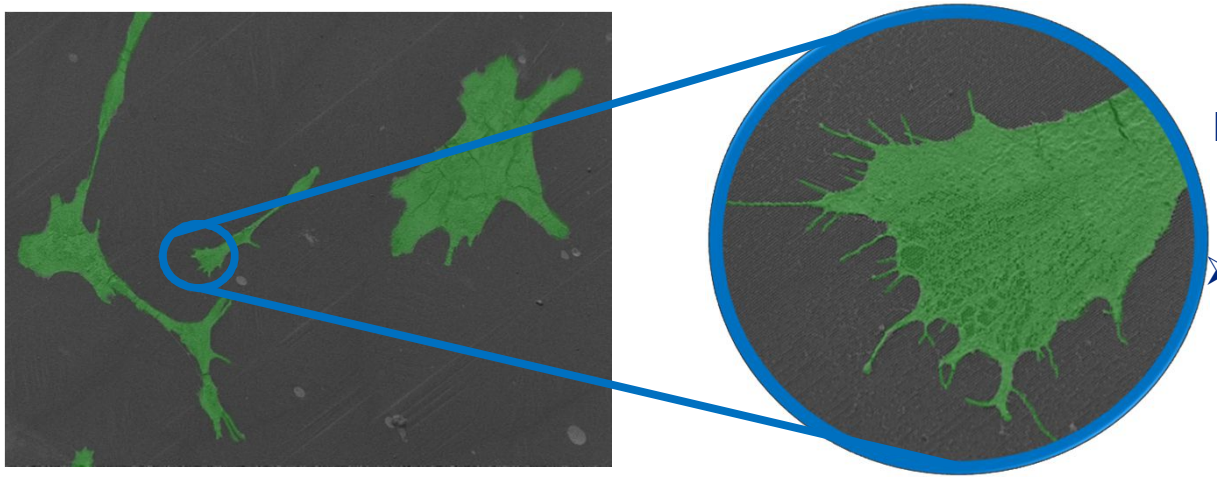
PDMS Hierarchical topographies

Orientation & spreading





MSC morphology on moth-eye & moth-eye hierarchies

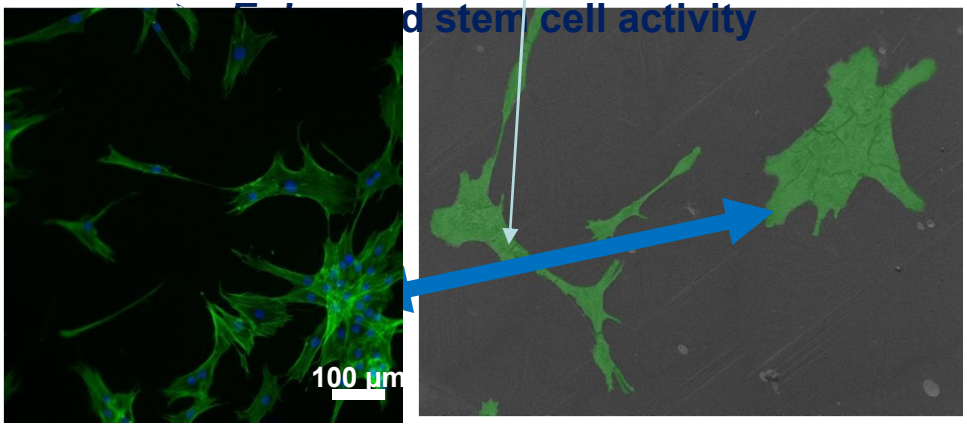


Increased number of lateral lamellipodia & filopodia

➢ Active random migration

Cell clusters' formation, increased cell-to-cell contact

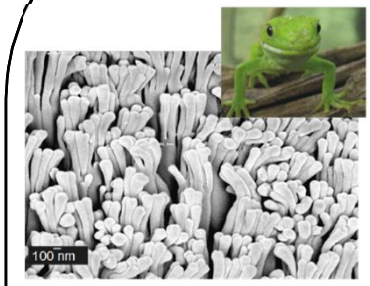
➢ Enhanced stem cell activity



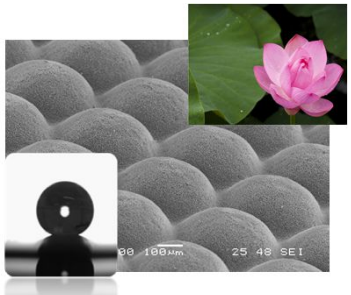
Osteogenic differentiation / Alizarin Red staining

Summary

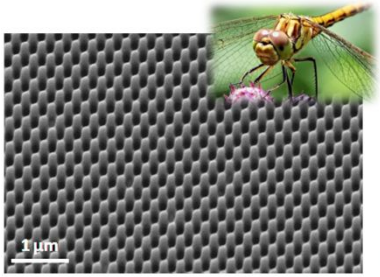
•Polymer micro/nano imprinting



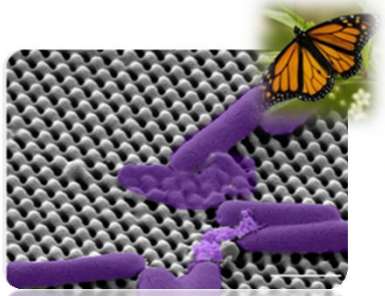
Gecko like dry adhesives



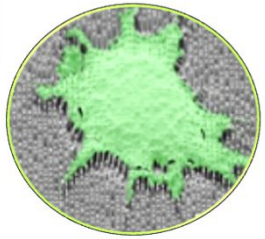
Superhydrophobic,self cleaning



Anti-reflective surfaces



Bactericidal surfaces



Cell substrates

❖Patterning is a valuable tool to exploit the functionality of materials into new applications . Design is key to achieve specific functions.

❖Structuring imparts function by physical means without the need for chemical modification. Lower developmental cost.

❖ Patterning -using replication (NIL) is a suitable methodology for **sustainable product development / nanomanufacturing**

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Daniel Granados

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Miguel Monclus

Audrey Ho
Emma van Luong
Low Hong Yee