CNRC·NRC

Institut des
matériaux industriels

Those slides summarized several research projects I carried out at National Research Council (NRC) during 2003-2008

Nanostructure Fabrication by Nanoimprint Lithography and its Applications

Bo Cui

CNRC-Industrial Materials Institute

Conseil national
de recherches Canada

National Research
Council Canada

Canada

CNRC·NRC
Institut des matériaux industriels

Outline

Part I: Introduction

What is nano? Why nano? How to reach nano?
Micro and nano-fabrication: lithography, etching, thin film deposition
One example of nanofabrication

Part II: Nanoimprint lithography (NIL) (hot embossing)

Hot embossing of several materials

- Polystyrene (biocompatible)
- Poly(lactic-co-glycolic acid) (biodegradable)
- MEH-PPV (semiconducting polymer for plastic solar cell)
- Metal (pulsed laser melting)

Replication of 100nm to mm-scale features by thermal NIL

Part III: Plasmonic chemical/biosensors based on metallic nanostructures

Introduction to plasmon
DNA hybridization detection by surface plasmon resonance (SPR)
Surface enhanced Raman scattering (SERS)

- Raman scattering and SERS fundamentals
- Fabrication of nano-prism array as SERS active substrates
- SERS detection of R6G molecules and peptides
- Fabrication of nano-pyramid, nano-ring/crescent and nano-star (brief)

Outline

Part I: Introduction

What is nano? Why nano? How to reach nano?
Micro and nano-fabrication: lithography, etching, thin film deposition
One example of nanofabrication

Part II: Nanoimprint lithography (NIL) (hot embossing)

Hot embossing of several materials

- Polystyrene (biocompatible)
- Poly(lactic-co-glycolic acid) (biodegradable)
- MEH-PPV (semiconducting polymer for plastic solar cell)
- Metal (pulsed laser melting)

Replication of 100nm to mm-scale features by thermal NIL

Part III: Plasmonic chemical/biosensors based on metallic nanostructures

Introduction to plasmon
DNA hybridization detection by surface plasmon resonance (SPR)
Surface enhanced Raman scattering (SERS)

- Raman scattering and SERS fundamentals
- Fabrication of nano-prism array as SERS active substrates
- SERS detection of R6G molecules and peptides
- Fabrication of nano-pyramid, nano-ring/crescent and nano-star (brief)

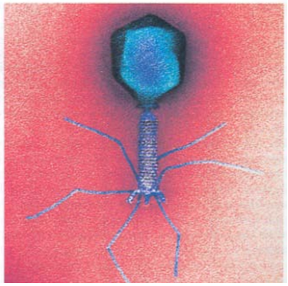
How small is nano?

Things Natural

Ant ~ 5 mm

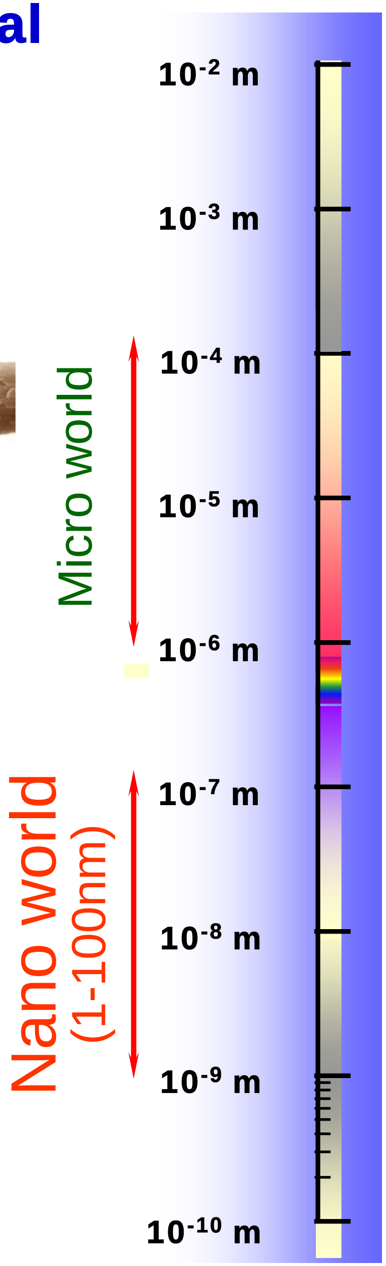
Human hair
~50 micron wide

Red blood cells
~ 2-5 micron



Virus, ~100nm

DNA ~2 nm
diameter

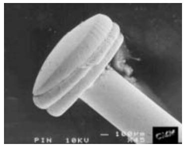


10^{-2} m
10^{-3} m
10^{-4} m
10^{-5} m
10^{-6} m
10^{-7} m
10^{-8} m
10^{-9} m
10^{-10} m

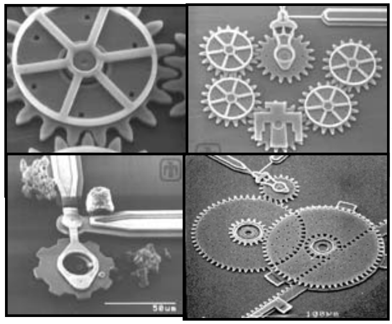
Micro world

Nano world
(1-100nm)

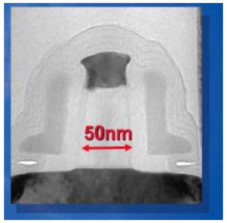
Things Manmade



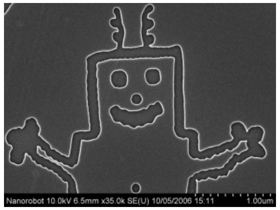
Head of a pin 1-2 mm



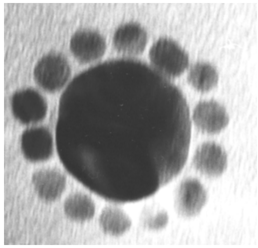
MicroElectroMechanical
Systems (MEMS)
10 -100 micron wide



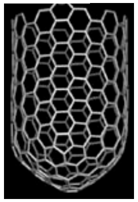
Intel transistor



Nanorobot



Au nanoparticles
13 nm & 50 nm



Carbon nanotube
~2 nm diameter

Adapted from office of Basic Energy Sciences Office of Science

Why go to nano?

L: length

- Integrated circuit: faster, more function, lower power consumption
- Data storage: higher capacity ($\propto 1/L^2$), 1Tbits/in^2 – 25nm×25nm/bit
- Semiconductor: quantum confined phenomena (quantum dots/wells…)
- Magnetism: single domain formation at

  L<magnetic domain wall thickness, superparamagnetism
- Photonics: new phenomena at $L<\lambda$

  photonic crystal, negative refractive index, near field optics,

  plasmonics
- Biomedical: DNA sorting (nanofluidics), drug delivery (nanoparticles)
- Chemistry: higher surface area

  higher reactivity for catalyst, higher sensitivity for chemical sensors

How to reach nano?

Bottom up (chemical): assemble small building blocks (atoms…) into larger structures
chemical synthesis, self assembly
nanoparticle, nanowire, nanotube…
low cost, high resolution (~few nm), 3D (sphere)

Top down (engineering): modify large object to give smaller features
lithography, thin film deposition, etching
expensive, precise control of size/shape and positioning

Top down approach: three components
Lithography: generate pattern in a material *called resist*
photolithography, electron-beam lithography, nanoimprint lithography
Thin film deposition (growth): spin coating, chemical vapor deposition, molecular beam epitaxy, sputtering, evaporation, electroplating
Etching (removal): reactive ion etching, ion beam etching, wet chemical etching, polishing

→Semiconductor industry uses top down approach

Lithographies: a comparison

Photolithography: *duplicate* pattern on the photo-mask into photo-resist

fast, low resolution (~λ), standard for micro-fabrication

Electron beam lithography: *generate* pattern by serial writing into a resist
slow (1 wafer/day), high resolution (~10nm)

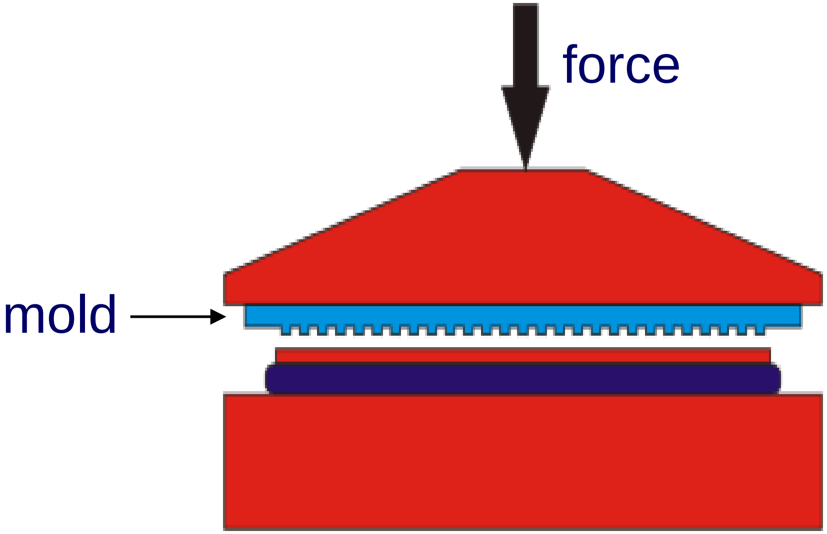
Nanoimprint lithography: *duplicate* mold pattern into a polymer resist

fast, high resolution (2nm), low cost

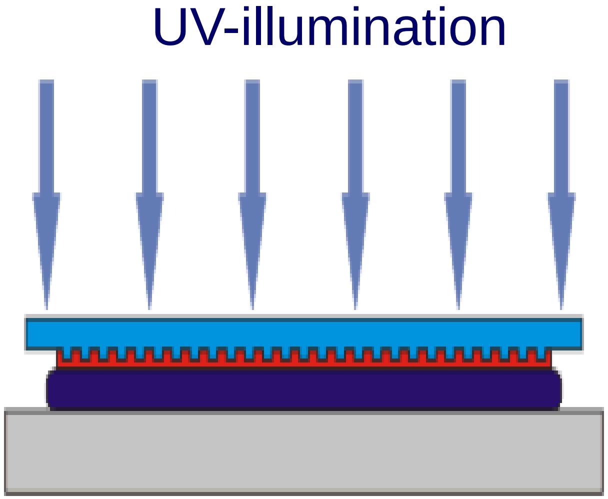
→NIL is the choice for nanoscale patterning over large surface area

Nanoimprint lithography (NIL)

Thermal NIL (hot embossing lithography)



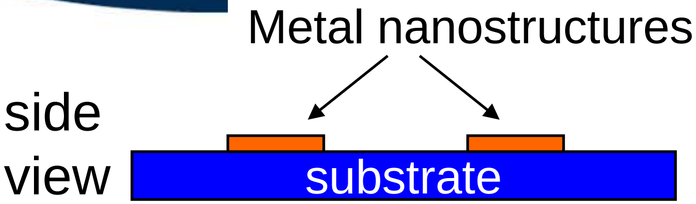
UV-curable NIL



- Rigid resist at room temperature (RT).
- Softened and patterned at high T.
- De-emboss at low temperature.
- Simple and low cost resist polymers, for general applications.

- Soft liquid resist, patterned at RT
- Hardened by UV-induced polymerization
- No thermal cycle, targeted for semiconductor industry requiring accurate alignment

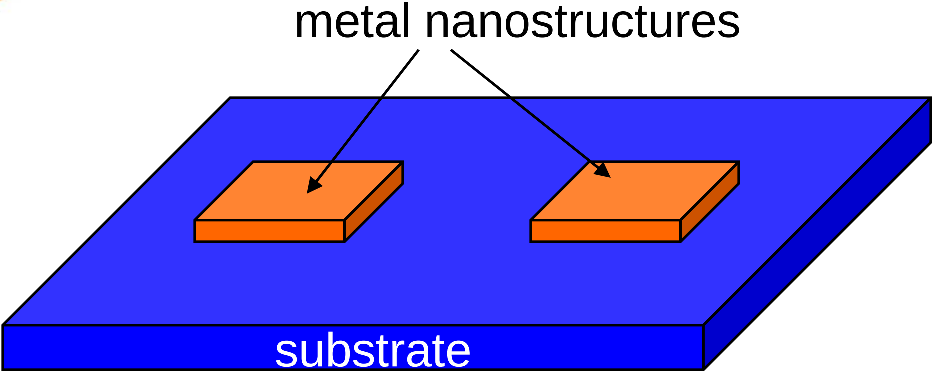
Nanofabrication: one example



Metal nanostructures

side view

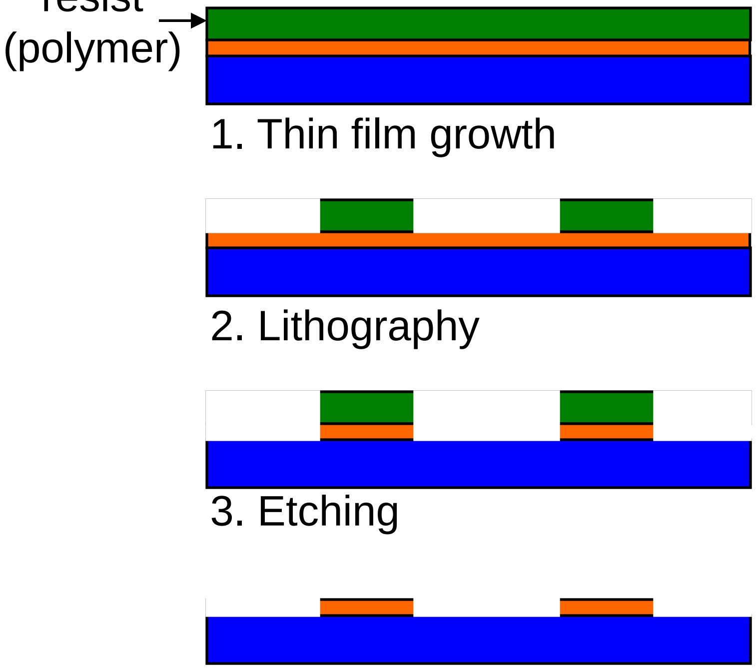
substrate



metal nanostructures

substrate

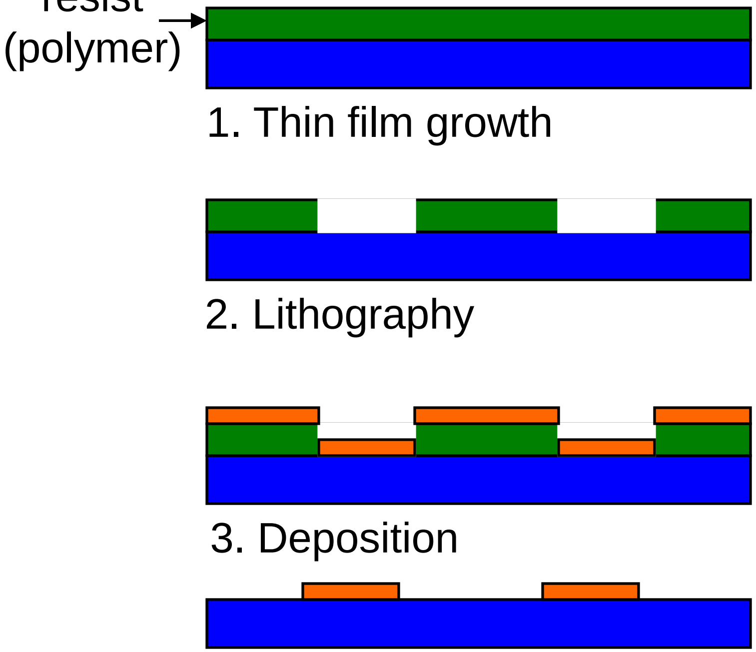
Direct etch process



resist (polymer)

1. Thin film growth
2. Lithography
3. Etching
4. Etching (dissolve resist)

Liftoff process

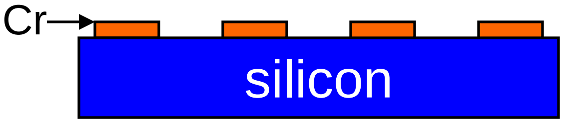


resist (polymer)

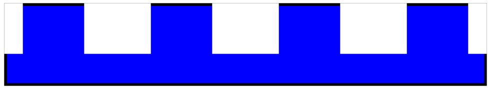
1. Thin film growth
2. Lithography
3. Deposition
4. Etching (dissolve resist)

→3-5 steps to pattern each layer, computer chip has >15 layers

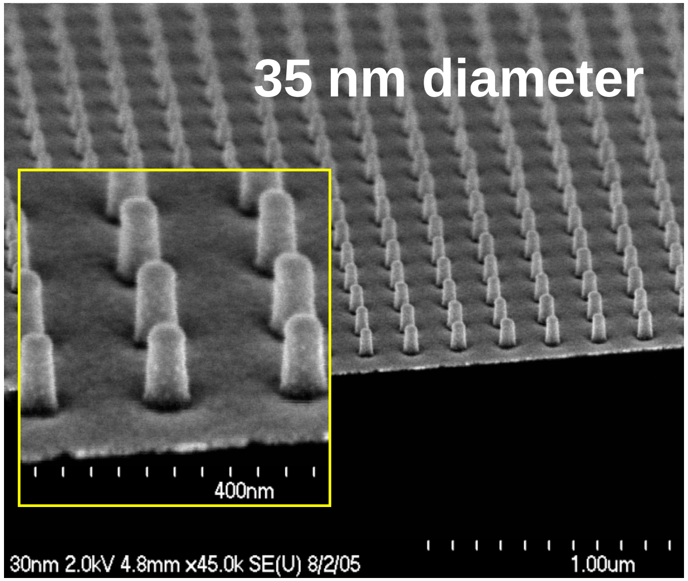
One more step: 200nm period pillar array with various diameters

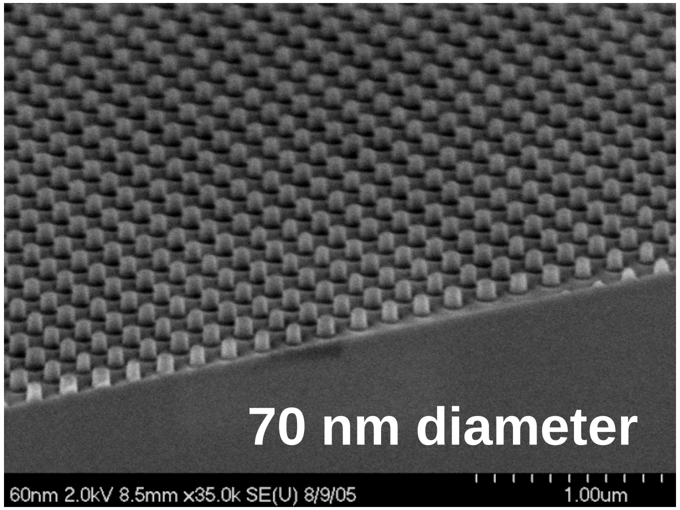


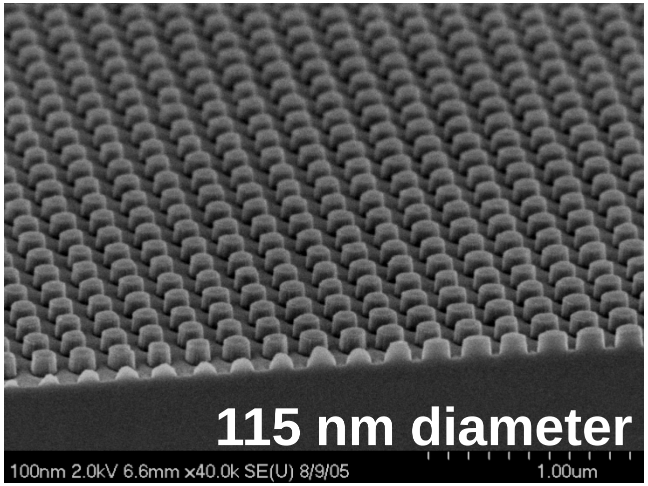
1. Cr dots by liftoff



2. RIE silicon and remove Cr
(RIE: reactive ion etching)


35 nm diameter

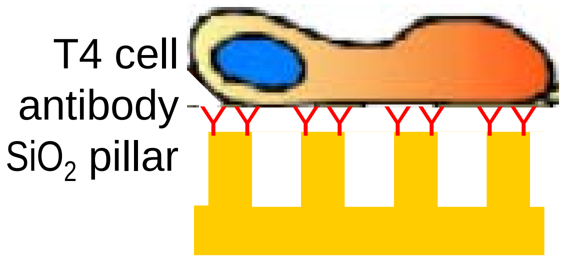

70 nm diameter

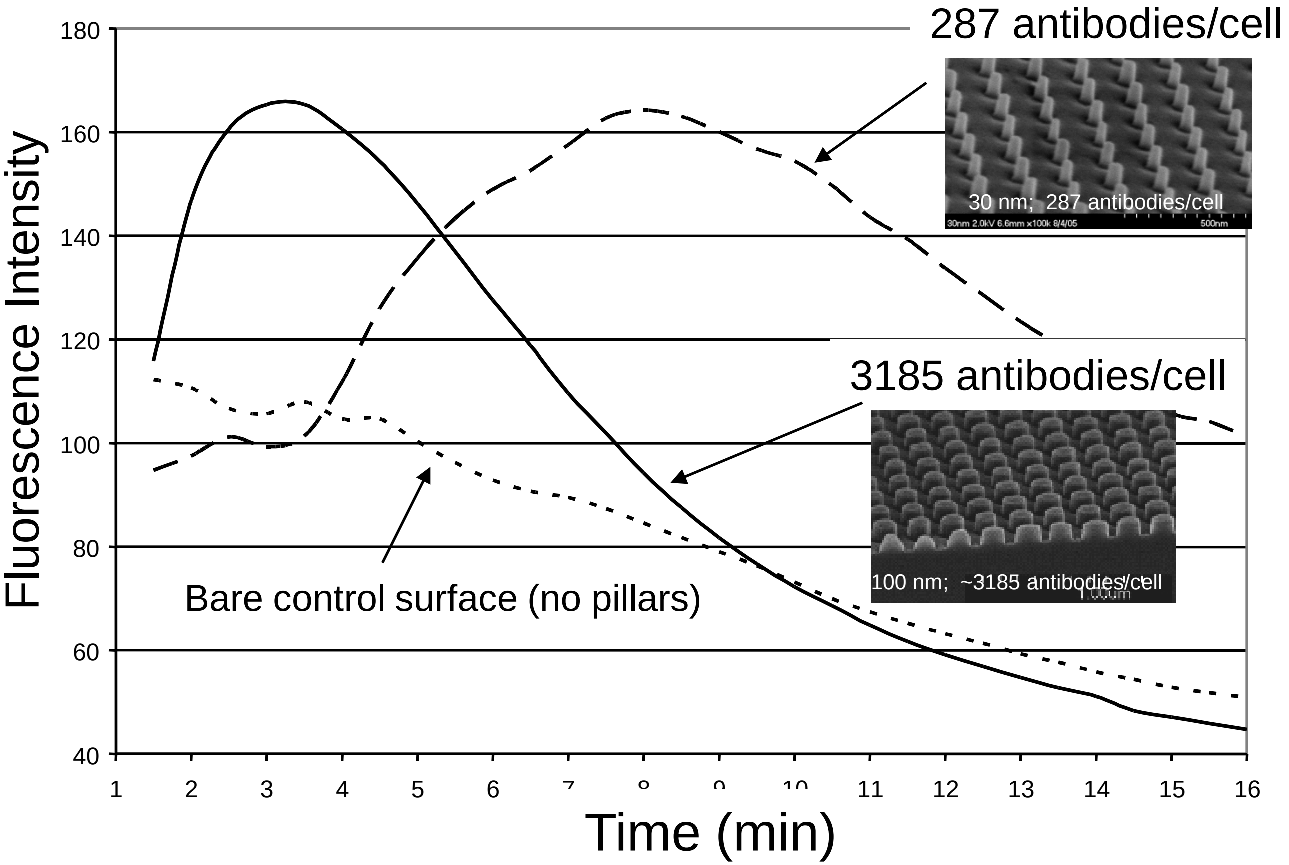

115 nm diameter

Application: cell-antibody interaction

For a fixed pitch of 200nm

# of antibody a cell interacts ∝ pillar surface area ∝ $(\text{diameter})^2$





Goal: study how many antibody molecules are required to activate a cell.
Activation represented by the upward slope of the fluorescence curve.

→More antibodies, shorter cell activation time

Collaboration with MIT/Northeastern University (ongoing)

Summary for Part I

1. Nano-science studies the length range 1nm-100nm
2. New physics and applications appear at nanoscale, or just better performance
3. Two approaches for arriving at nano: “bottom up” and “top down”
4. Three components for “top down” approach: lithography, thin film deposition and etching.
5. Nanoimprint lithography is a molding process having high throughput and high resolution.

Outline

Part I: Introduction

What is nano? Why nano? How to reach nano?
Micro and nano-fabrication: lithography, etching, thin film deposition
One example of nanofabrication

Part II: Nanoimprint lithography (NIL) (hot embossing)

Hot embossing of several materials

- Polystyrene (biocompatible)
- Poly(lactic-co-glycolic acid) (biodegradable)
- MEH-PPV (semiconducting polymer for plastic solar cell)
- Metal (pulsed laser melting)

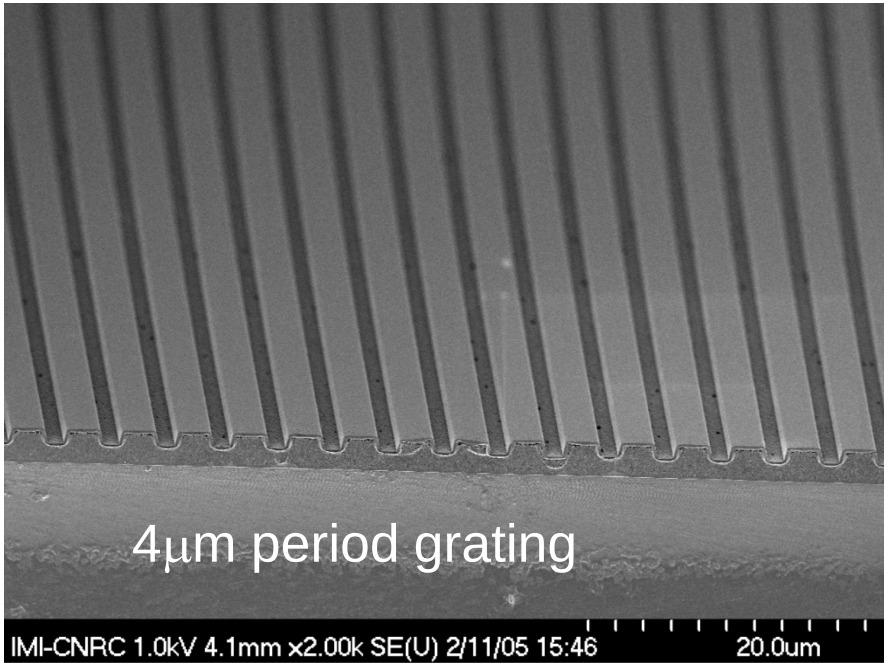
Replication of 100nm to mm-scale features by thermal NIL

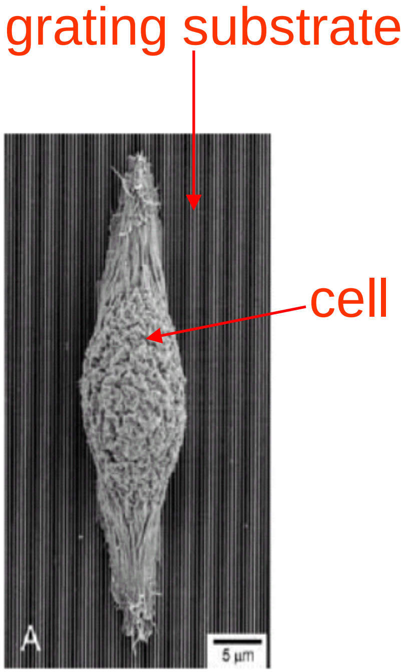
Part III: Plasmonic chemical/biosensors based on metallic nanostructures

Introduction to plasmon
DNA hybridization detection by surface plasmon resonance (SPR)
Surface enhanced Raman scattering (SERS)

- Raman scattering and SERS fundamentals
- Fabrication of nano-prism array as SERS active substrates
- SERS detection of R6G molecules and peptides
- Fabrication of nano-pyramid, nano-ring/crescent and nano-star (brief)

Hot embossing of polystyrene (biocompatible)





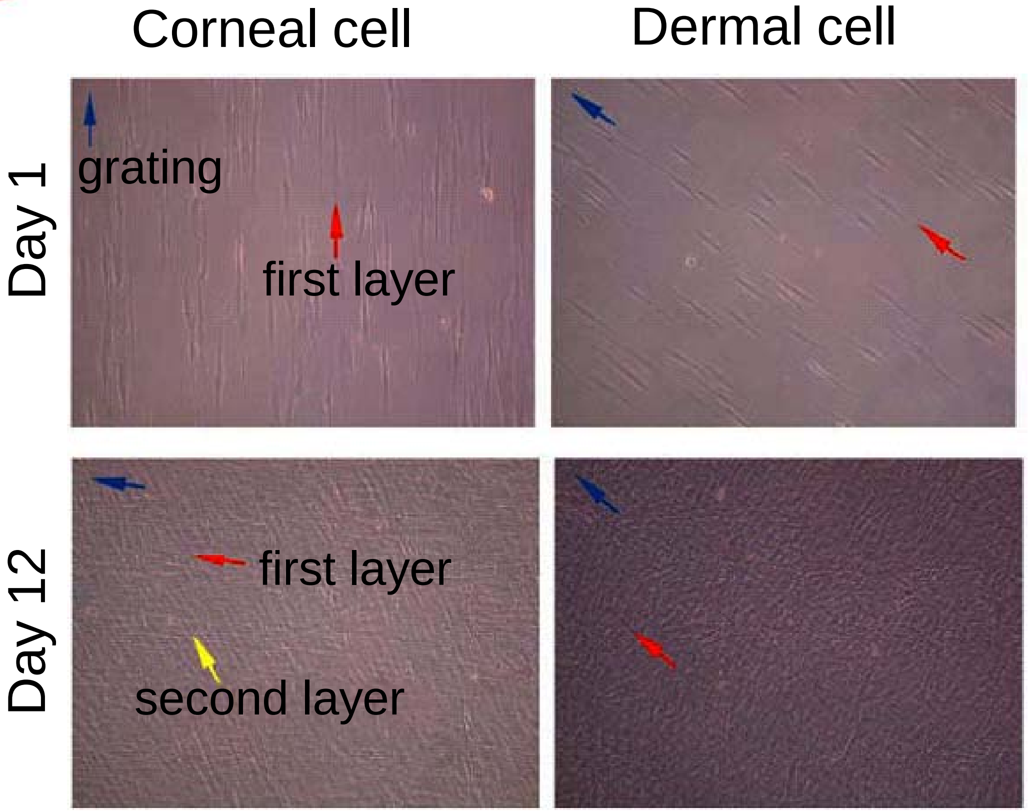
Journal of Cell Science 116 (10)

Application: contact guidance of cell growth

- Definition: anisotropic topographic features induce cells to align along the direction of the anisotropy.
- Importance: in tissue engineering, if tissue is to be repaired, the new cells must be aligned and positioned correctly.

Collaboration with LOEX of Laval University

Corneal and dermal cell growth



- First layer: both cells aligned with the grating (as expected).
- Second layer:

  Corneal cells - oriented at 60° relative to first layer, as in a native cornea

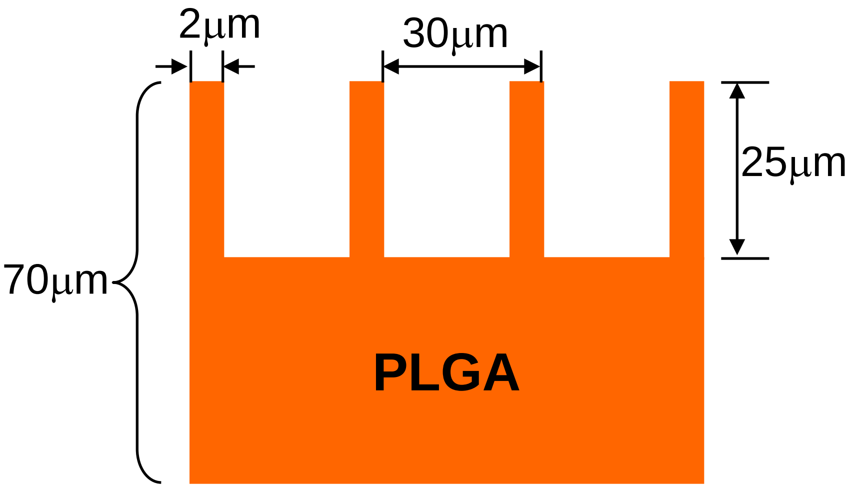
  Dermal cells - no orientation

Guillemette, Cui… Nature Methods, to be submitted

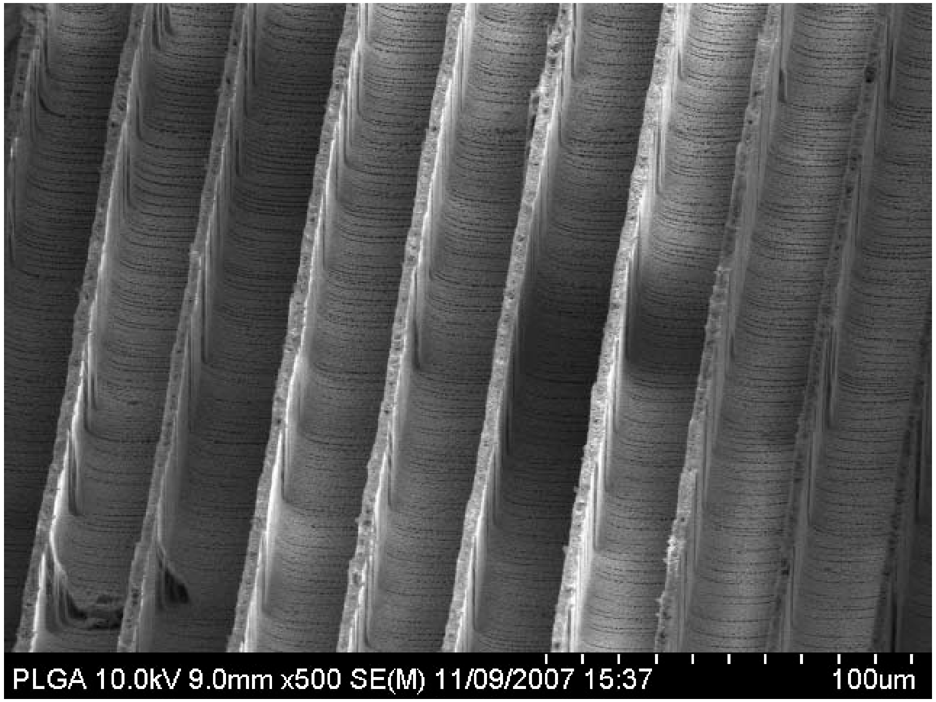
Hot embossing of PLGA

(poly(lactic-co-glycolic acid))

(biodegradable, biocompatible)



Aspect ratio: >10:1



SEM image of 30μm period PLGA grating
(SEM: scanning electron microscopy)

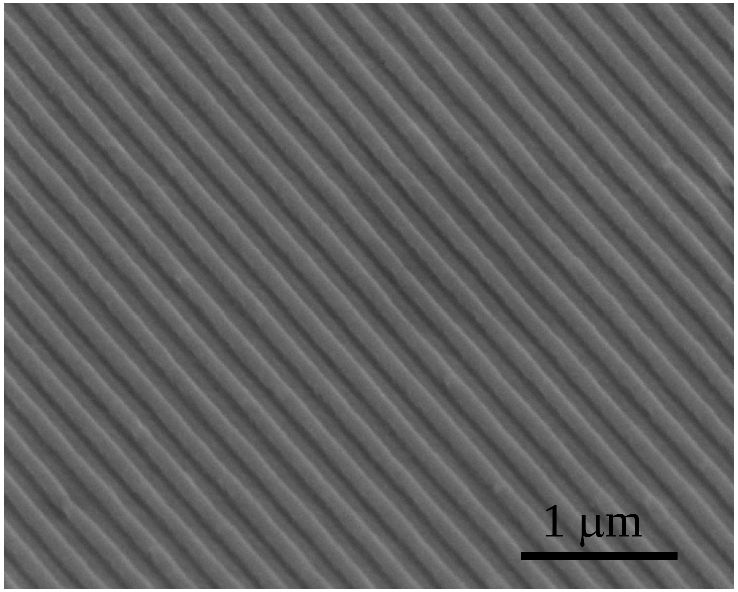
Application:

<u>Brain repair</u>: grow neuron cells on PLGA gratings and transplant it into brain. The support PLGA will disappear in 1-2 months (as it is biodegradable).

Collaboration with NRC-Institute for Biological Sciences

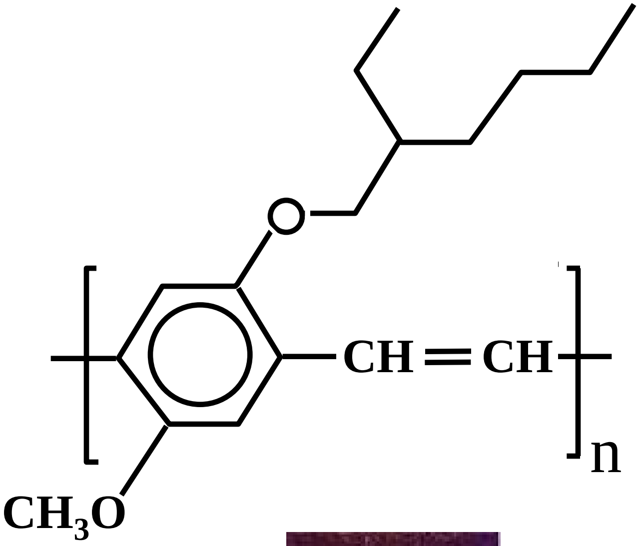
Hot embossing of semiconducting polymers

SEM image of 200nm period MEH-PPV grating



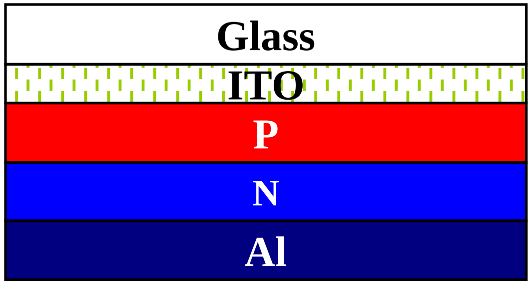
MEH-PPV T_g=65°C.
Hot embossing at 120°C and 20bar.
MEH-PPV spun on a PEDOT/ITO/glass.

MEH-PPV

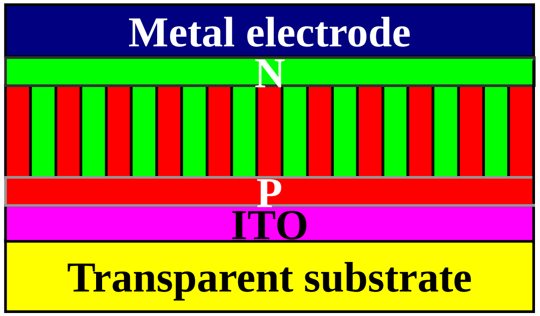


Collaboration with Organic Vision Inc. and McGill University

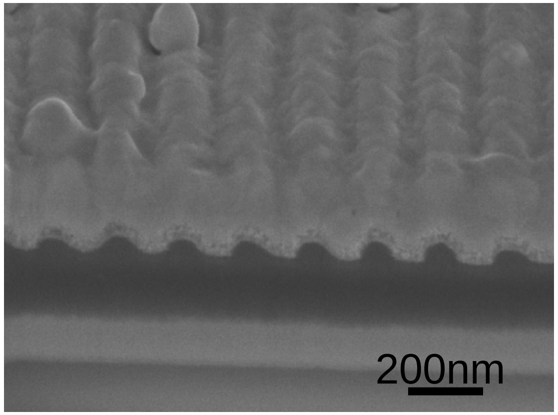
Application: nanostructured plastic solar cell



Classic planar p-n junction, low junction area, low efficiency



Nanostructured junction, high junction area, high efficiency

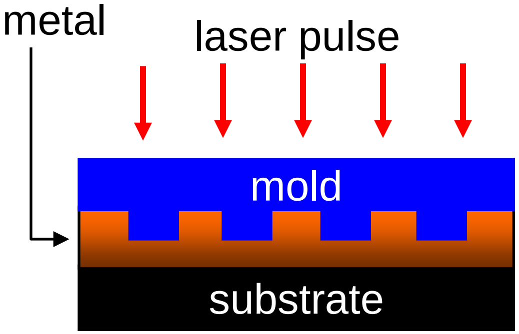


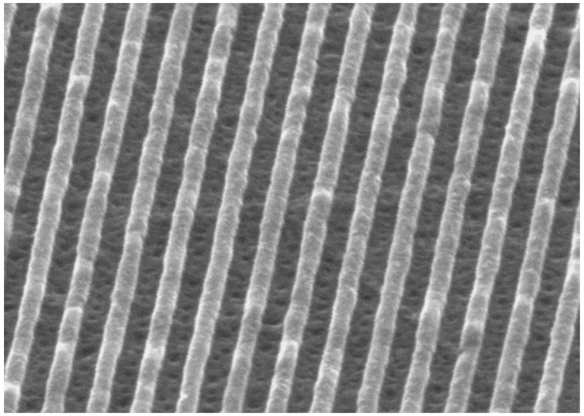
Layers: glass/ITO/PEDOT/MEH-PPV(p)/Alq3(n)/Al

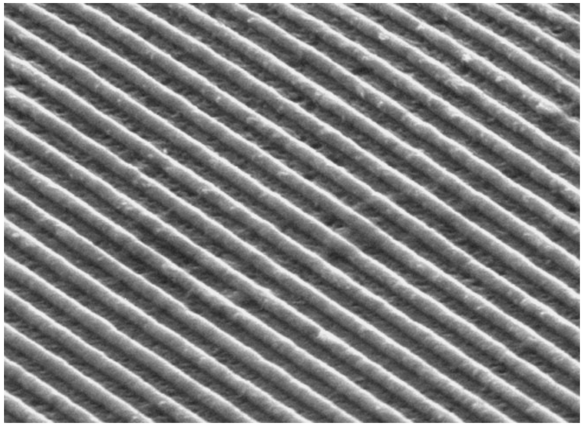
- Plastic solar cells: flexible, light weight, tunable electrical properties, and potential lower fabrication cost.
- Limitation: low energy conversion efficiency due to low carrier mobility.
- Method to increase efficiency: increase the interface area by nano-patterning the p-n junction.

Cui…, NNT, 2004

"Hot embossing" of metal using pulsed laser




200nm period nickel grating


Copper grating

- XeCl pulsed excimer laser, λ=308nm, τ=20ns, 0.2-0.5J/cm^2.
- Lines rounded due to surface tension and volume shrinking upon solidification

- Metals are generally more difficult to pattern due to lack of suitable RIE process (RIE: reactive ion etching)
- Here Ni and Cu were patterned and the step took only ~100ns with minimal heating of the substrate

Cui…, manuscript in preparation

Outline

Part I: Introduction

What is nano? Why nano? How to reach nano?
Micro and nano-fabrication: lithography, etching, thin film deposition
One example of nanofabrication

Part II: Nanoimprint lithography (NIL) (hot embossing)

Hot embossing of several materials

- Polystyrene (biocompatible)
- Poly(lactic-co-glycolic acid) (biodegradable)
- MEH-PPV (semiconducting polymer for plastic solar cell)
- Metal (pulsed laser melting)

→Replication of 100nm to mm-scale features by thermal NIL

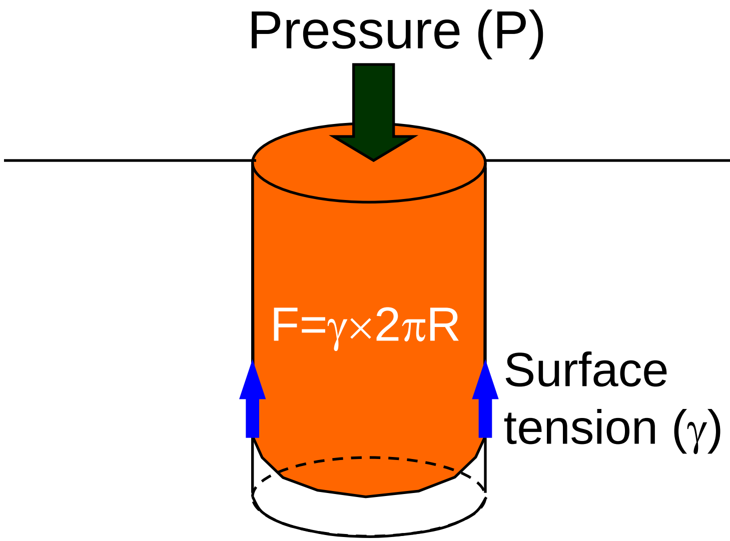
Part III: Plasmonic chemical/biosensors based on metallic nanostructures

Introduction to plasmon
DNA hybridization detection by surface plasmon resonance (SPR)
Surface enhanced Raman scattering (SERS)

- Raman scattering and SERS fundamentals
- Fabrication of nano-prism array as SERS active substrates
- SERS detection of R6G molecules and peptides
- Fabrication of nano-pyramid, nano-ring/crescent and nano-star (brief)

NIL for small features (<10nm)

Press liquid into a nano-hole



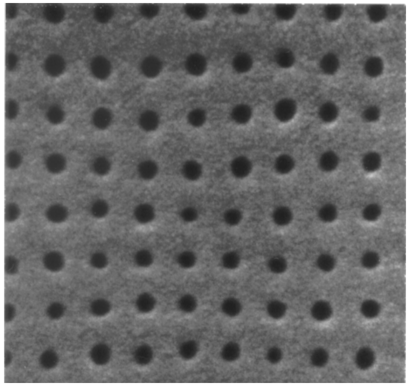
Pressure (P)

F=γ×2πR

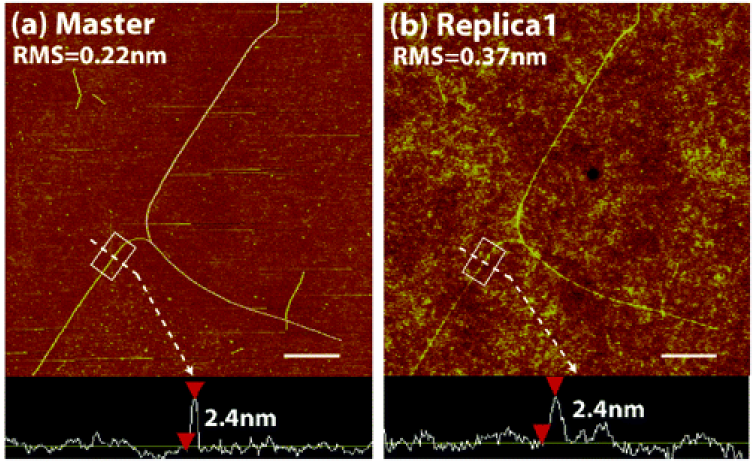
Surface tension (γ)

$$P = \frac{\gamma \times 2\pi R}{\pi R^2} = \frac{2\gamma}{R} \propto \frac{1}{R}$$

- Pressure ∝ 1/diameter.
- But for protruded mold features (pillars…), local pressure at the pillar is much higher than average - easy to imprint.



Thermal NIL into PMMA
(**10nm** pillar array mold)
Chou, J. Vac. Sci. Technol. B, 1997



UV-curable NIL, **2nm** carbon nanotube mold
Hua, Nano Lett. 2004

→NIL not difficult for nano, especially for protruded mold features

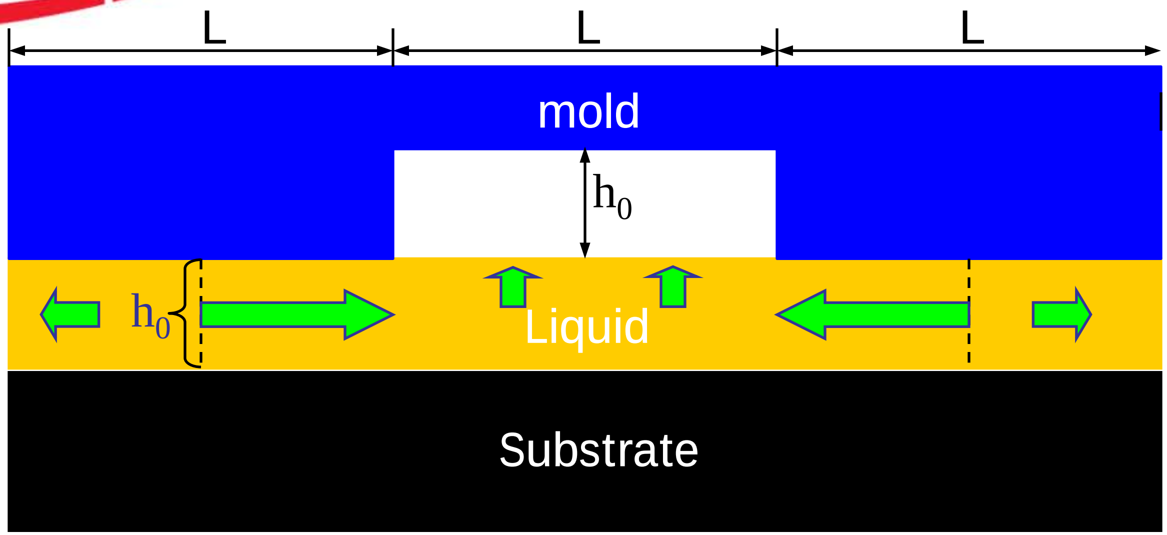
NIL for large features (>100 μm) - simultaneous pattern duplication of large and small features

- Application: large features needed to connect small ones to the outside world (electrodes…).
- Challenge: more polymer must be displaced over longer distances.
- A popular approach: two-step process - small features by NIL, large ones by photolithography.

- Previously, pattern size of 100μm duplicated by thermal NIL.
- Here, we will demonstrate pattern duplication of nm – mm features.

→More challenging to duplicate large features than small ones

Modeling of liquid flow for large features (>>pattern depth)



Assumptions: periodic mold structure (period 2L)
ignore inertial, gravitational forces and surface tension
resist film thickness = mold trench depth = h_0

$$L = \frac{2h_0}{3}\sqrt{\frac{p\tau}{\mu}} \propto \left(\frac{p\tau}{\mu}\right)^{1/2}$$

L: achievable feature size
p: pressure
τ: imprinting time
μ: viscosity
h_0: film thickness

→Achievable feature size depends on pressure, time and viscosity of molten polymer

Strategy to imprint large features (mm)

$$L \propto \left(\frac{p\tau}{\mu} \right)^{1/2} \propto \frac{1}{\sqrt{\mu}}$$

L: achievable feature size
p: pressure
τ: melting time
μ: viscosity

For PMMA at T>Tg=105°C (glass transition temperature)

$$\boxed{\log \mu = n \log M_w - \frac{12.21(T - T_g)}{70.1 + (T - T_g)} + const}$$

M_w: molecular weight
n=1 for $M_w < M_C$, un-entangled molecules
n=3.4 for $M_w > M_C$, entangled molecules

Viscosity for PMMA (M_c=30kg/mol)
a) 12 kg/mol, 200°C b) 12 kg/mol,150°C c) 120 kg/mol, 200°C

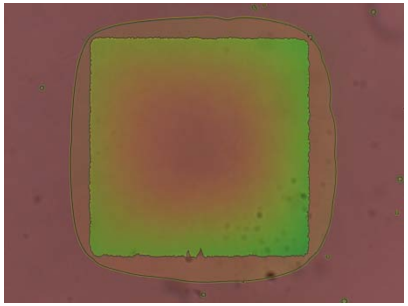
$\mu_a : \mu_b : \mu_c = 1:126:278$

→ Use low molecular weight PMMA and imprint at high temperature

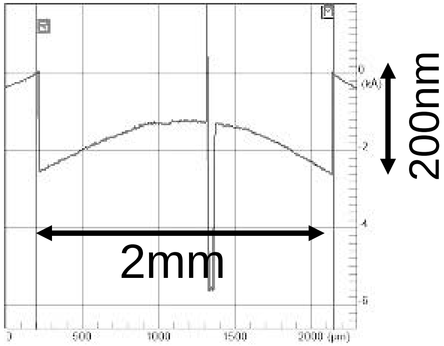
Strategy to imprint large features (mm)

Square (mm) imprinted into PMMA

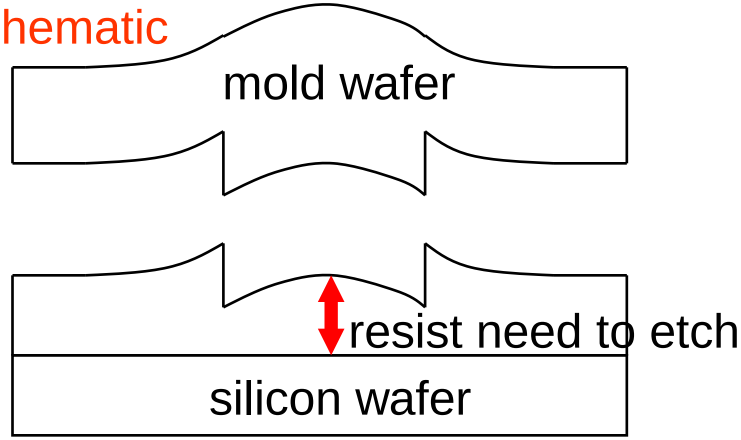
Optical image



Profile

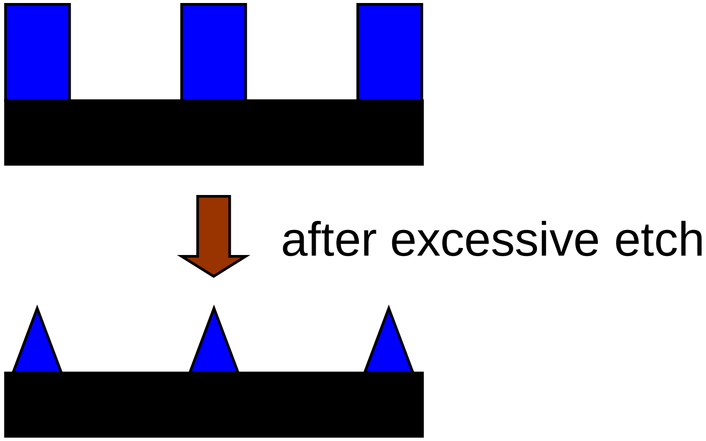


Schematic



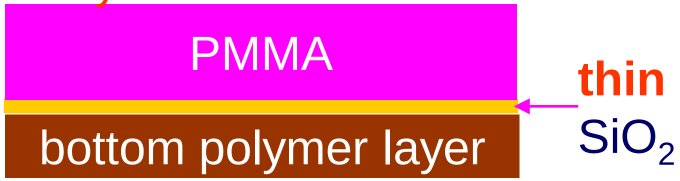
Need excessive etch to remove the **thick** resist at the square center

But for nanoscale features…



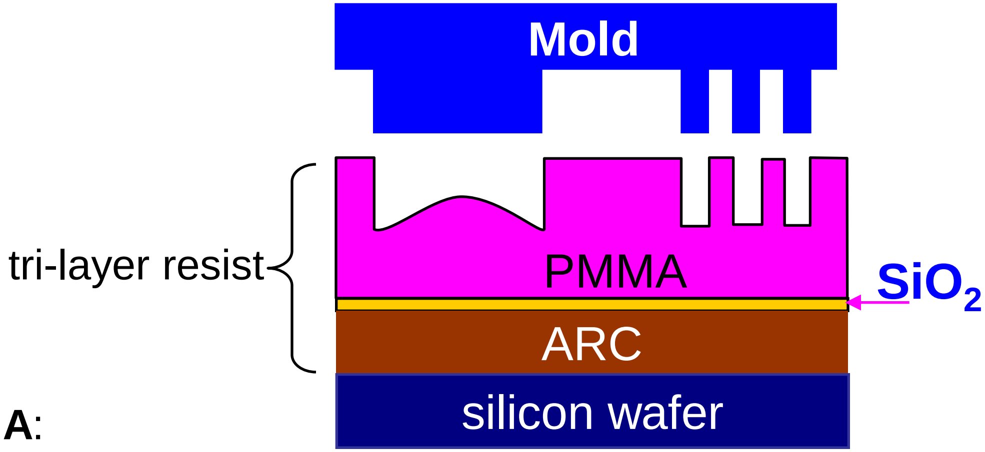
Such a profile makes liftoff difficult.
Solution: use tri-layer resist system

tri-layer resist

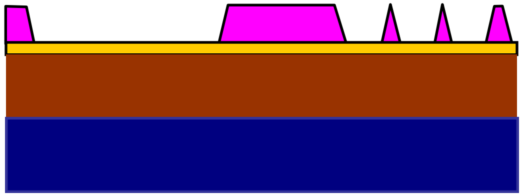


→ Need excessive resist etch and tri-layer resist for large features

Fabrication process flow



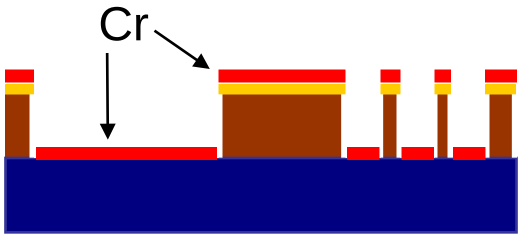
1. Imprint



2. RIE PMMA (excessive etch)

3. RIE SiO_2 (CHF_3 gas)

4. RIE ARC (O_2 gas, etch little SiO_2)



5. Evaporate Cr

6. Liftoff Cr (dissolve ARC)

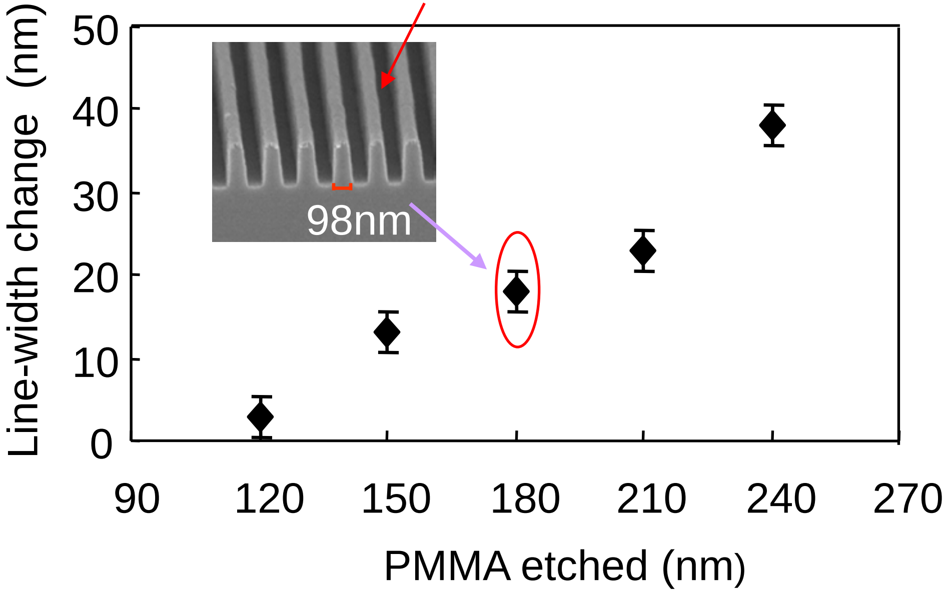
7. RIE Si (etch little Cr)

PMMA: Polymethyl methacrylate.
ARC: Anti-reflection coating, cross-linked polymer.
RIE: Reactive ion etching

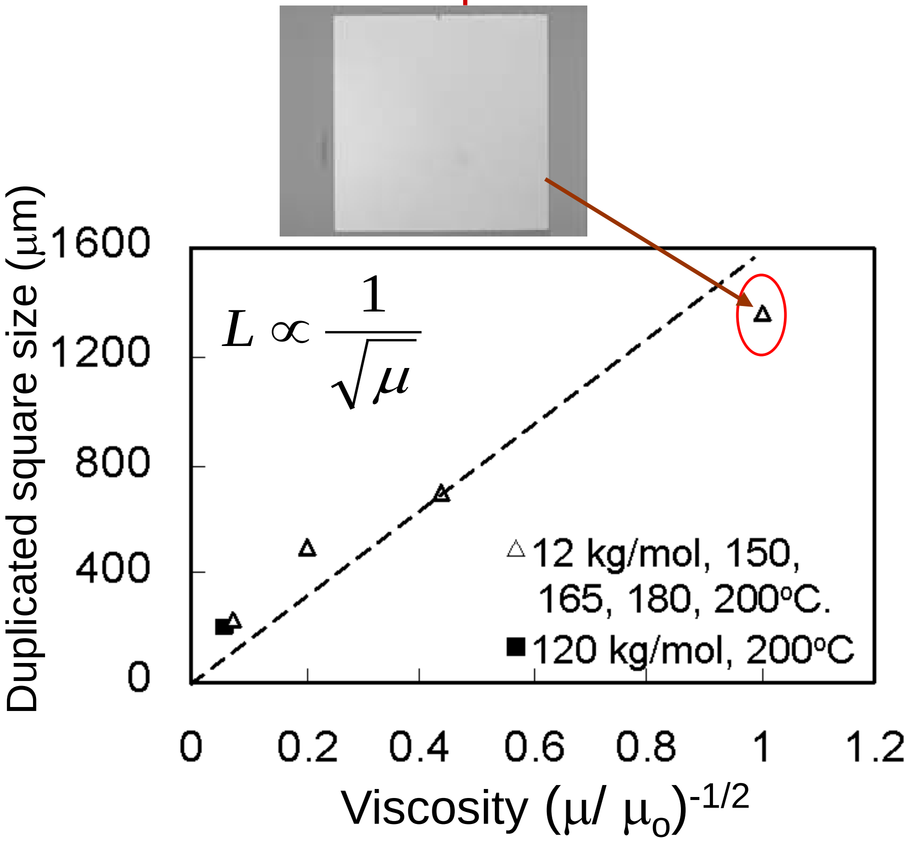
→Fabrication is liftoff process using tri-layer resist plus etching

Result of pattern duplication of nano-grating and mm-square

Line-width in the mold is 80nm
Line-width in the duplicated pattern is 98nm



1.3mm square



→For small features, line-width increased by ~18nm (acceptable).

→For large features, 1.3mm squares faithfully duplicated (one order higher than previously achieved).

Cui…, Microelectronic Engineering, 2006

Summary for Part II

1. Hot embossing can pattern various functional polymer materials: biocompatible, biodegradable, semiconducting
2. It is not so difficult for NIL to achieve high resolution (<5nm)
3. It is more challenging to pattern large features (>100μm)
4. We have demonstrated simultaneous pattern duplication of nm to mm-scale feature

Outline

Part I: Introduction

- What is nano? Why nano? How to reach nano?
- Micro and nano-fabrication: lithography, etching, thin film deposition
- One example of nanofabrication

Part II: Nanoimprint lithography (NIL) (hot embossing)

- Hot embossing of several materials
  - Polystyrene (biocompatible)
  - Poly(lactic-co-glycolic acid) (biodegradable)
  - MEH-PPV (semiconducting polymer for plastic solar cell)
  - Metal (pulsed laser melting)
- Replication of 100nm to mm-scale features by thermal NIL

Part III: Plasmonic chemical/biosensors based on metallic nanostructures

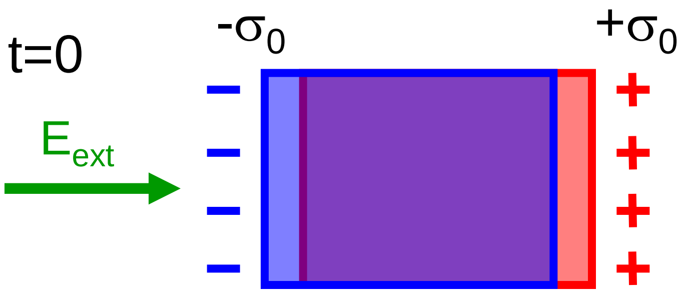
- Introduction to plasmon
- DNA hybridization detection by surface plasmon resonance (SPR)
- Surface enhanced Raman scattering (SERS)
  - Raman scattering and SERS fundamentals
  - Fabrication of nano-prism array as SERS active substrates
  - SERS detection of R6G molecules and peptides
  - Fabrication of nano-pyramid, nano-ring/crescent and nano-star (brief)

Plasmon: “bulk”, surface, localized

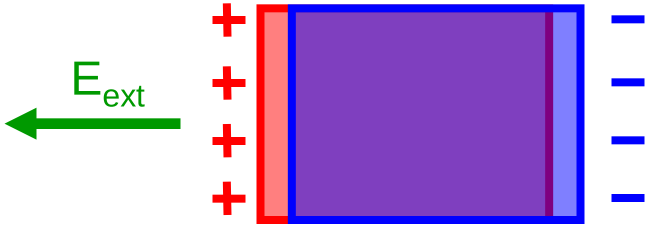
Plasmon: *collective* oscillation of free electrons
(has nothing to do with *plasma* TV (ionized gas))

$$E_{ext} = E_0 e^{i\omega \cdot t} \qquad \sigma = \sigma_0 e^{i\omega \cdot t}$$

t=0



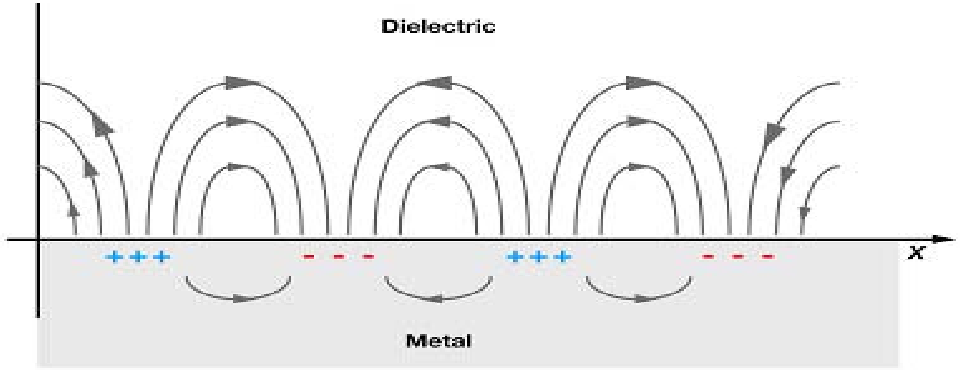
t=T/2=π/ω (half period)



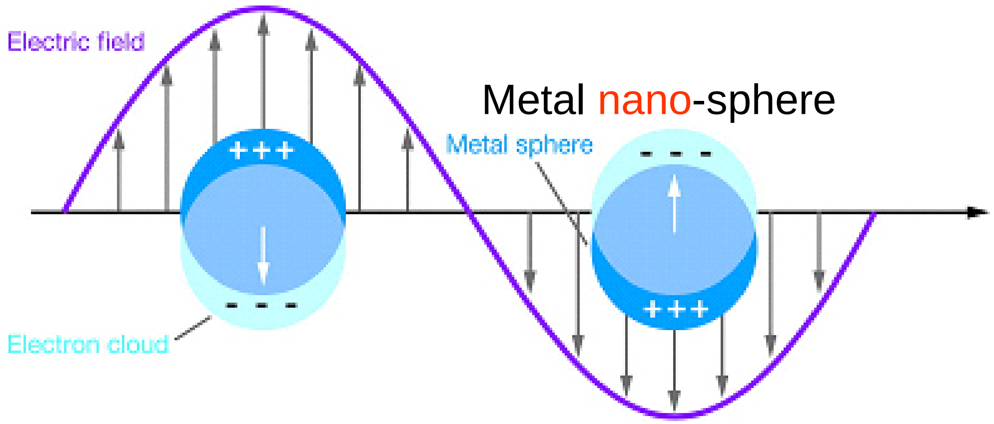
$$\omega_p^2 = \frac{4\pi n e^2}{m}$$

~ frequency of visible light

Surface plasmon: plasmon confined to (metal) surface



Localized surface plasmon: plasmon confined to (metal) nano-structures



Metal nano-sphere

Annu. Rev. Phys. Chem 2007

Lycurgus Cup of the 4th Century

Green = Reflected Light

Red = Transmitted Light

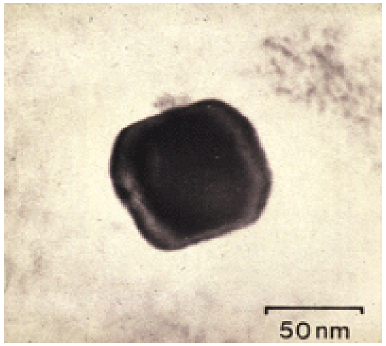


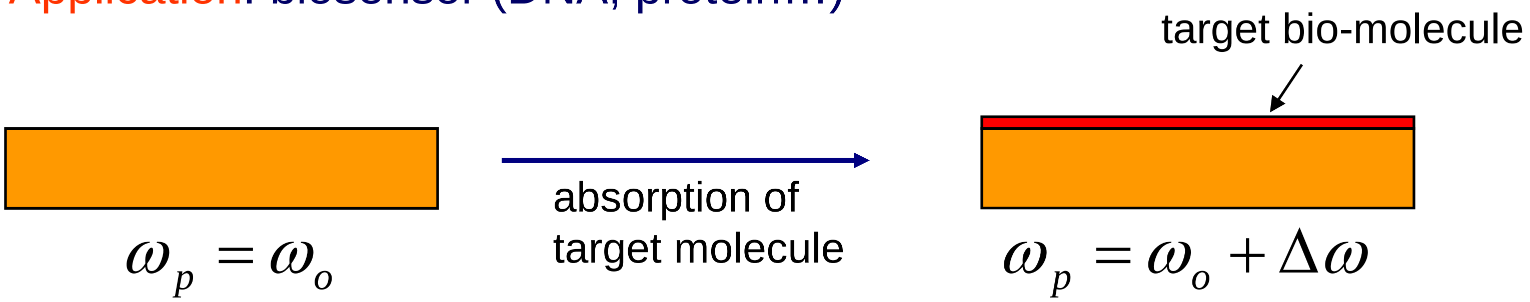
Image of Ag/Au nanoparticle in the Lycurgus cup

Color is due to *resonant* absorption of light, which excites localized surface plasmon when ω(light)$\approx\omega$(plasmon)

The British Museum. http://www.thebritishmuseum.ac.uk/ (March 2004)

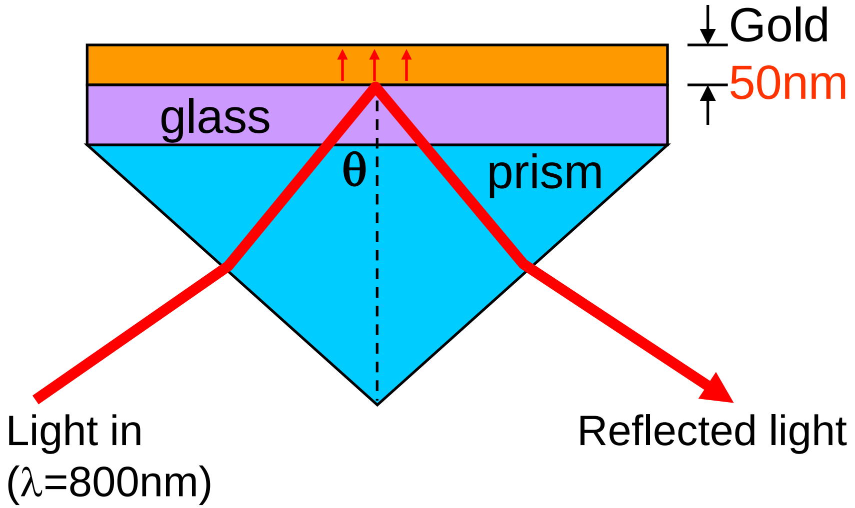
Surface plasmon resonance (SPR) biosensor

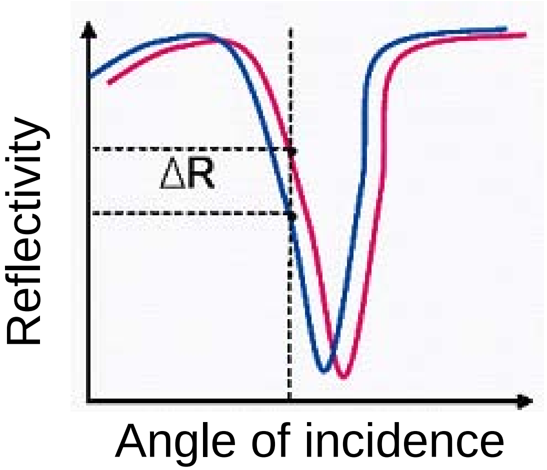
SPR: excitation of surface plasmon by light
Plasmon frequency is very sensitive to changes on metal surface
Application: biosensor (DNA, protein…)



$$\omega_p = \omega_o$$

$$\omega_p = \omega_o + \Delta\omega$$

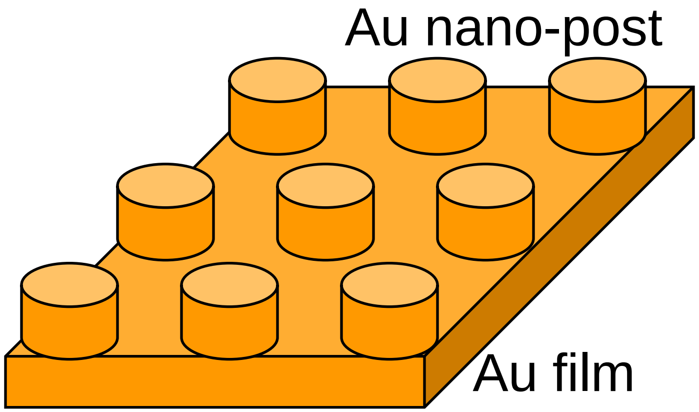




- Excitation of surface plasmon by *evanescent* wave
- Resonant absorption occurs at certain angle θ

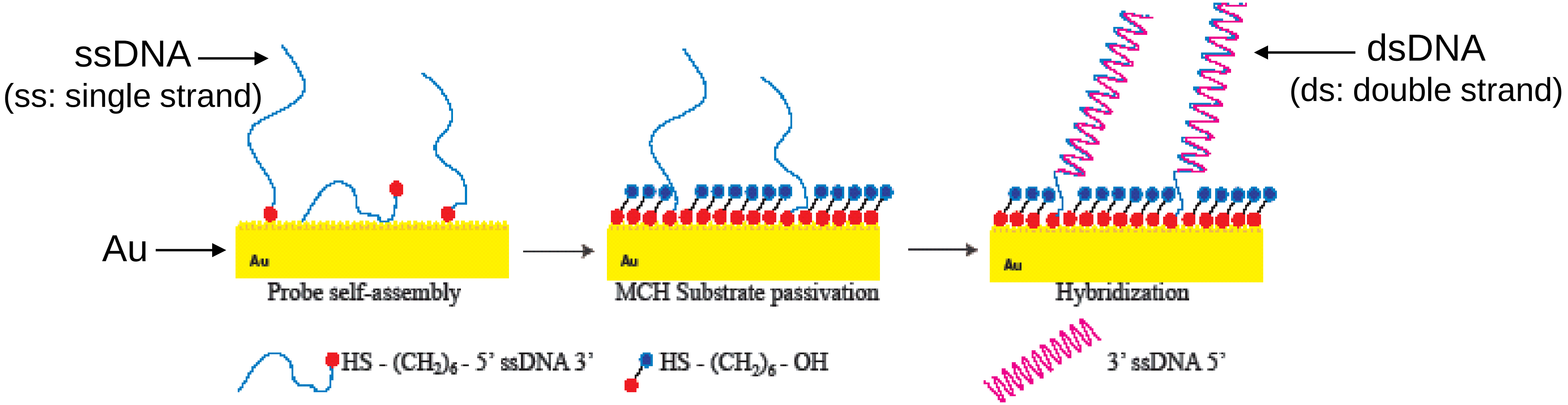
→ SPR sensor detects change in thickness/refractive index on metal surface

Enhanced DNA hybridization detection by SPR on periodic Au nano-post array



Au nano-posts increase sensitivity by:

1. Coupling between localized (from nano-posts) and propagating (from underlying continuous film) surface plasmon.
2. Increasing the surface area for DNA binding.

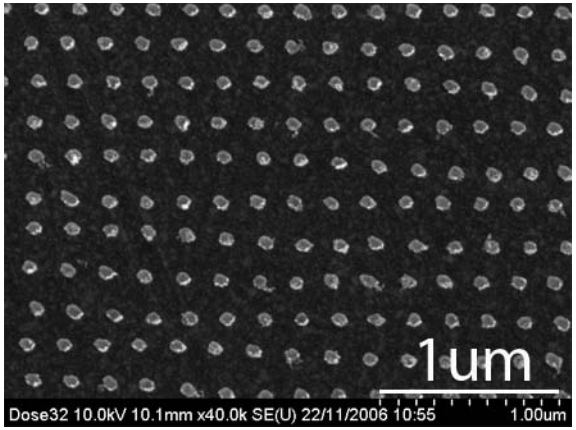


DNA hybridization leads to a change in -

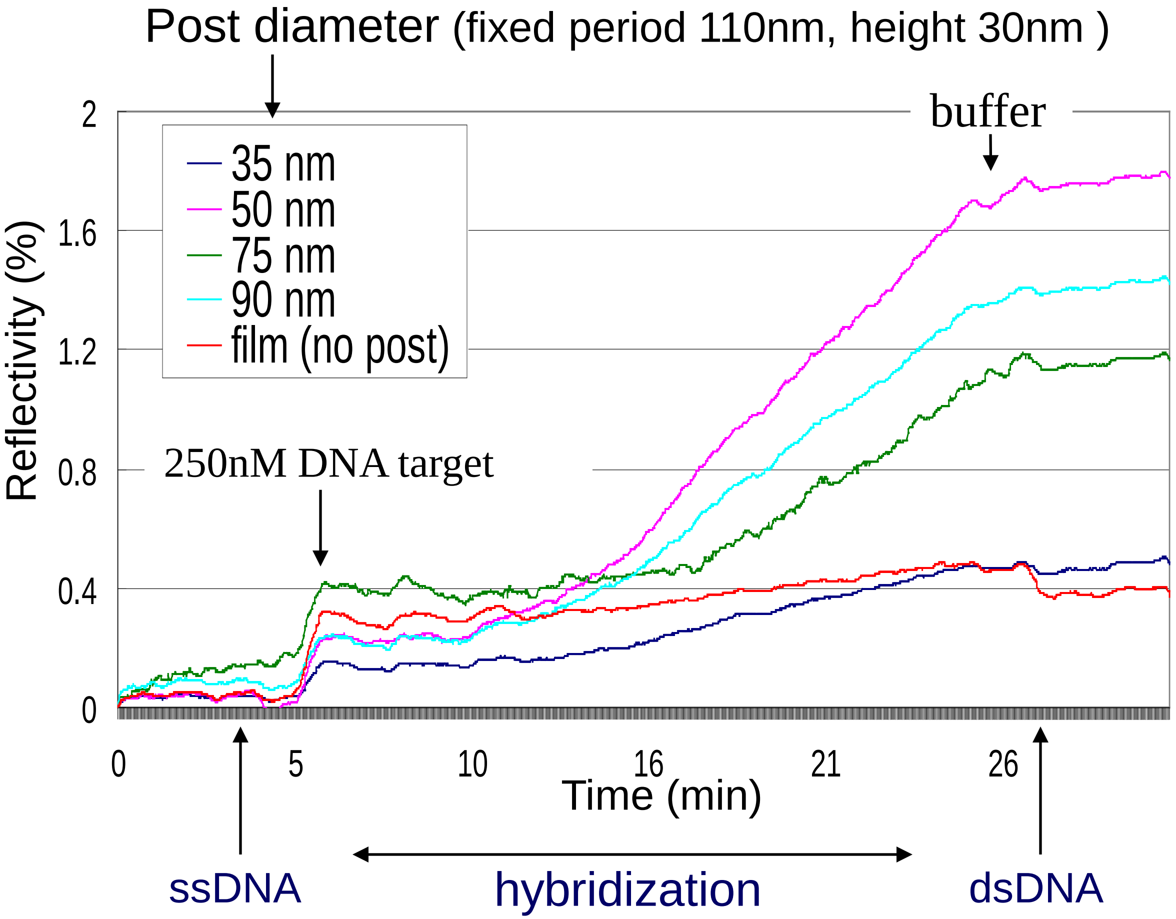
- refractive index by 5%
- thickness by 3.5nm

Collaboration with McGill University

Enhanced SPR detection of DNA hybridization



SEM image of Au nano-post array on 20nm flat Au film



→ Sensitivity was enhanced by 5× when post diameter = 50nm

Malic, Cui… Optics Letters, 2007

Outline

Part I: Introduction

What is nano? Why nano? How to reach nano?
Micro and nano-fabrication: lithography, etching, thin film deposition
One example of nanofabrication

Part II: Nanoimprint lithography (NIL) (hot embossing)

Hot embossing of several materials

- Polystyrene (biocompatible)
- Poly(lactic-co-glycolic acid) (biodegradable)
- MEH-PPV (semiconducting polymer for plastic solar cell)
- Metal (pulsed laser melting)

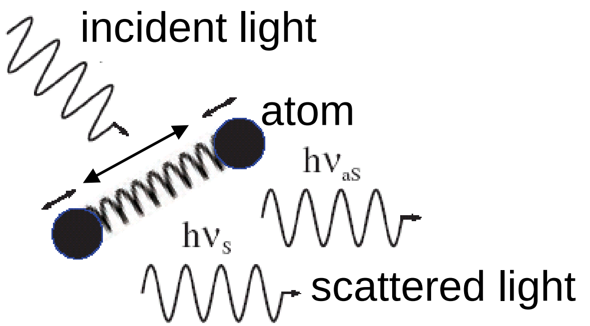
Replication of 100nm to mm-scale features by thermal NIL

Part III: Plasmonic chemical/biosensors based on metallic nanostructures

Introduction to plasmon
DNA hybridization detection by surface plasmon resonance (SPR)
→**Surface enhanced Raman scattering (SERS)**

- Raman scattering and SERS fundamentals
- Fabrication of nano-prism array as SERS active substrates
- SERS detection of R6G molecules and peptides
- Fabrication of nano-pyramid, nano-ring/crescent and nano-star (brief)

SERS (surface enhanced Raman spectroscopy) fundamentals



$$\nu(photon) = \nu_0 \pm \nu(phonon)$$

Molecular vibration:

- Molecular vibrational energy quantized (phonon).
- Its frequency lies in infrared (IR) spectral range.
- IR spectroscopy is used to identity a material. (strong absorption when ν(photon)=ν(phonon))

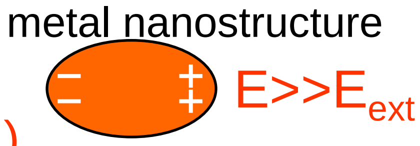
Raman scattering:

- *Inelastic* light scattering from a sample with a shift in frequency by the energy of its characteristic molecular vibrations (phonon).
- It detects *symmetric* vibration, which complements IR spectroscopy.
- The vibration information is transferred from IR to visible, where brighter sources and more efficient detectors are available.

SERS effect: enormous enhancement (up to 10^{12}) of Raman scattering when a molecule is adsorbed on *nanostructured* metallic surface.

This arises from two main mechanisms -

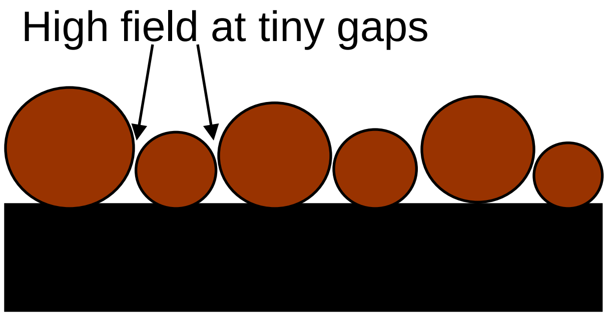
- Electromagnetic effect (dominant): *localized* surface plasmon resonance. (Raman intensity $\propto E^4$)
- Chemical effect: electronic coupling between molecule and metal.



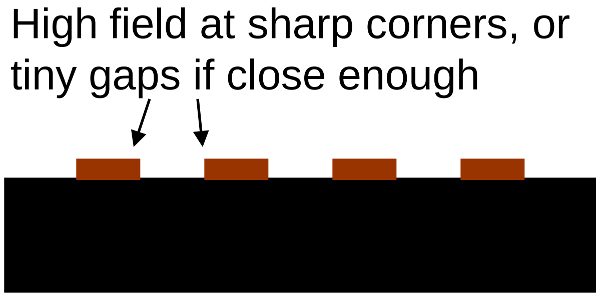
SERS advantages, approaches to generate SERS-active surfaces

Advantage of SERS: (3 “S”)

- Sensitivity - high, single molecule detection demonstrated
- Selectivity - high, fingerprint of each type of molecule
- Speed - high, few seconds



Metallic particles
(chemical synthesis)



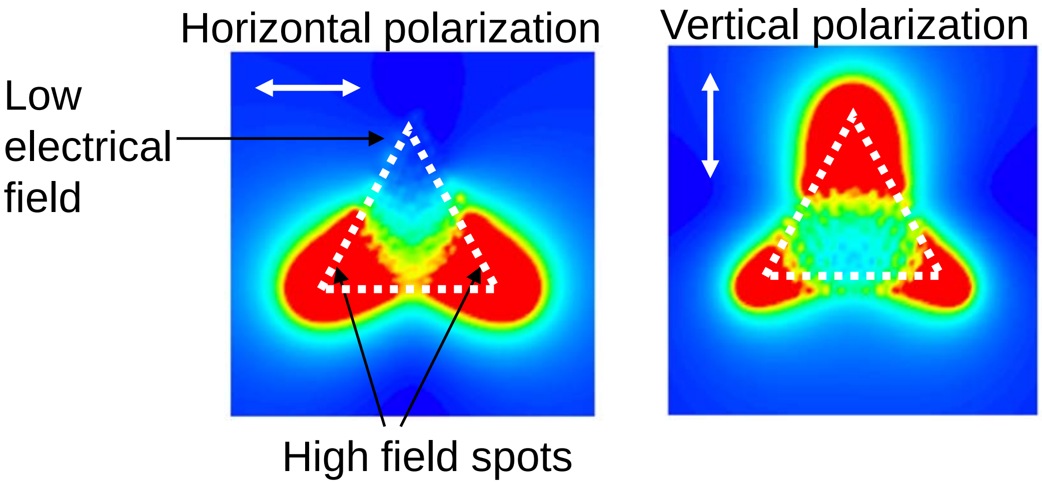
Metal nanostructure

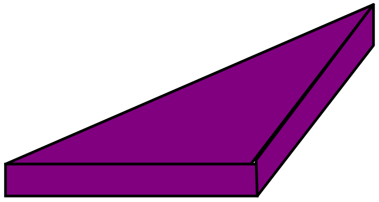
→Nanofabricated metal structures - tunable resonant wavelength, homogeneous size/shape, more reproducible and reliable SERS detection

One example: nanoprism
(triangular nanostructure)

Motivation:

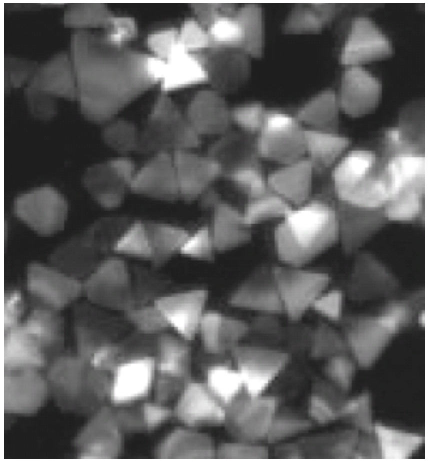
- Localized surface plasmon resonance can be tuned systematically by varying the size, shape and height of the nanoprism.
- Sharp corners of the nanoprism lead to a strong local electromagnetic field enhancement.





Previous fabrication method:

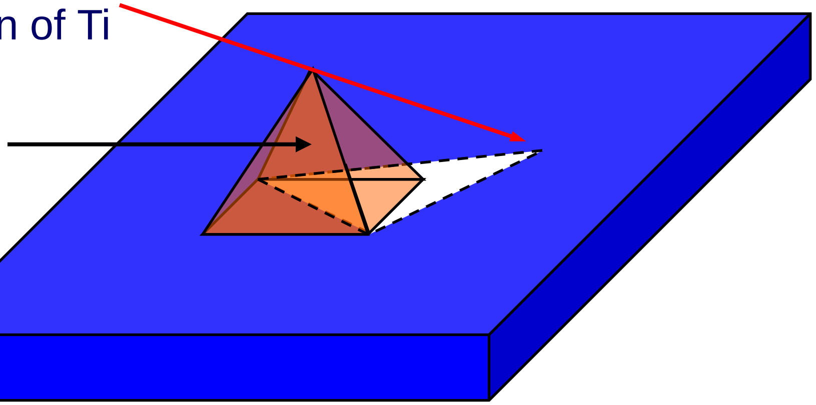
- Chemical approach: reduction of metal salts (difficult).
- Light-induced aggregation of small nanoparticle seeds (low yield and none-homogeneous)



Jin, Science, 294, 1901(2001)

→Nanoprism: tune plasmon resonance, enhance local electrical field

Fabrication principle



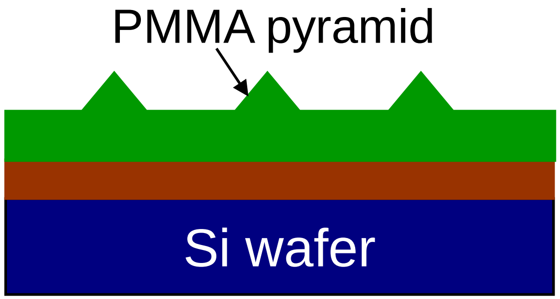
Direction of angle evaporation of Ti

PMMA pyramid by NIL with a mold having inverse-pyramid-shaped hole

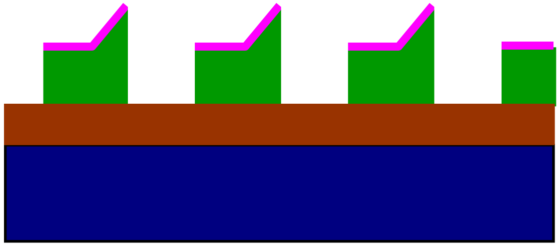
PMMA: Polymethyl methacrylate

NIL: Nanoimprint lithography

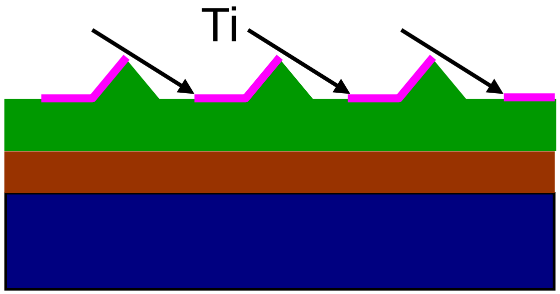
RIE: Reactive ion etching



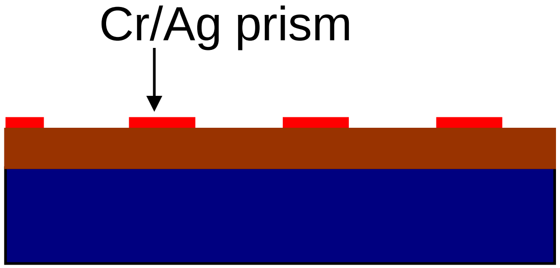
1. NIL into PMMA



3. RIE PMMA



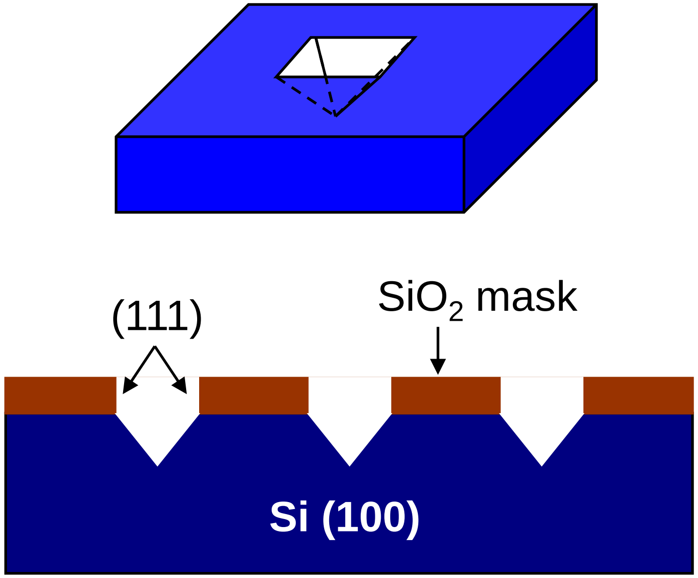
2. Evaporate Ti at large angle



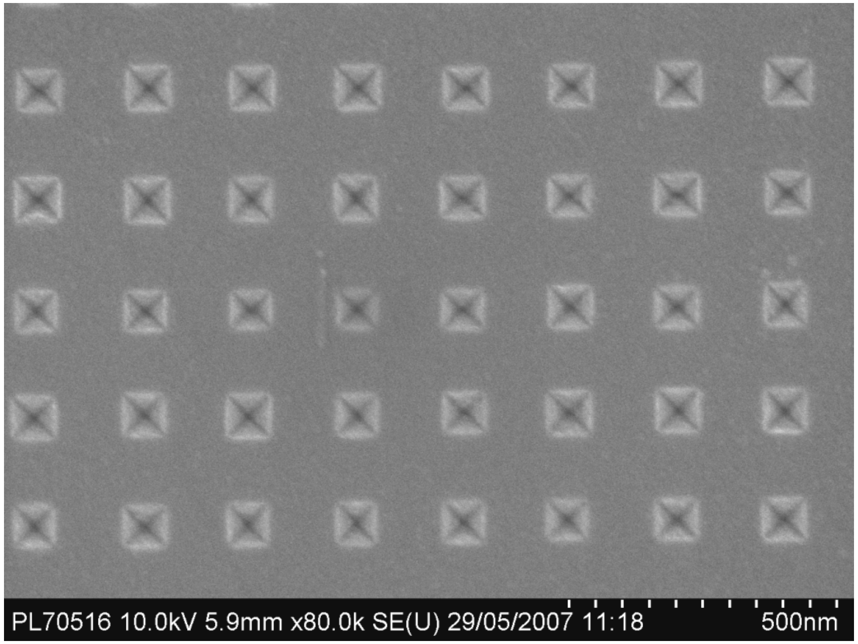
4. Evaporate and liftoff metal

→Again, it is a liftoff process

Fabrication of mold with inverse-pyramid-shaped hole array



KOH etch Si (111) direction 100 times slower than other crystalline planes. So etching will “stop” at (111) crystalline plane, forming an inverse-pyramid-shaped hole.

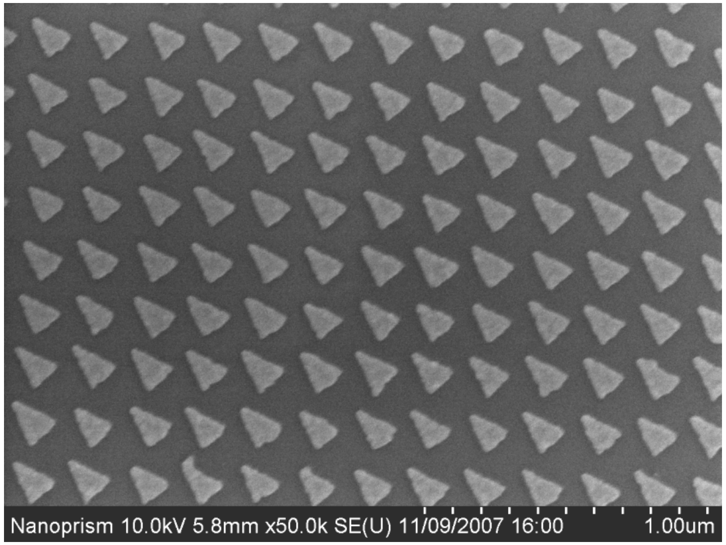


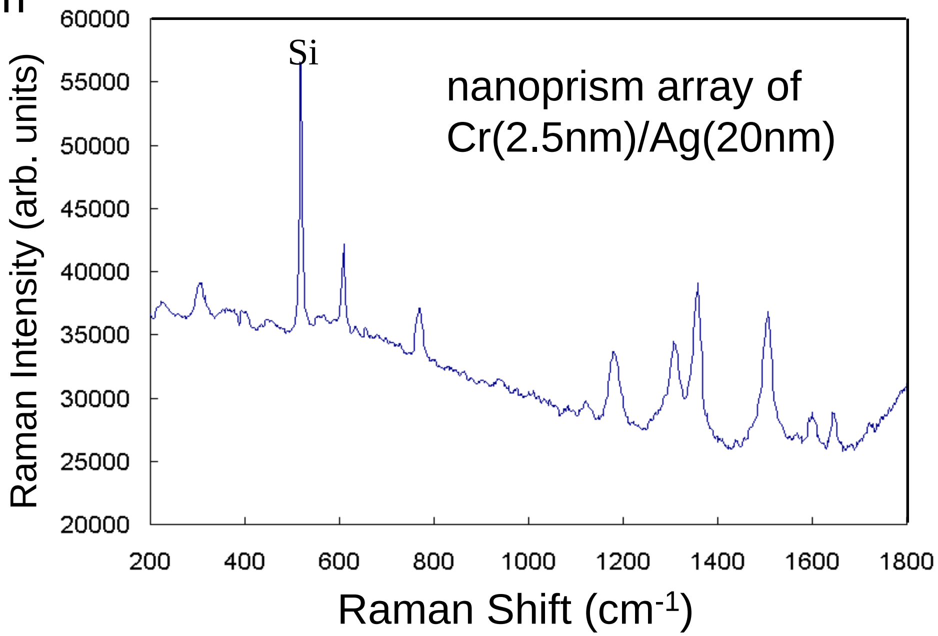
SEM image of the mold
(SEM: scanning electron microscopy)

→KOH etching of *crystalline* Si is anisotropic

SERS detection of rhodamine 6G (R6G) molecule

SEM image of 200nm period nanoprism





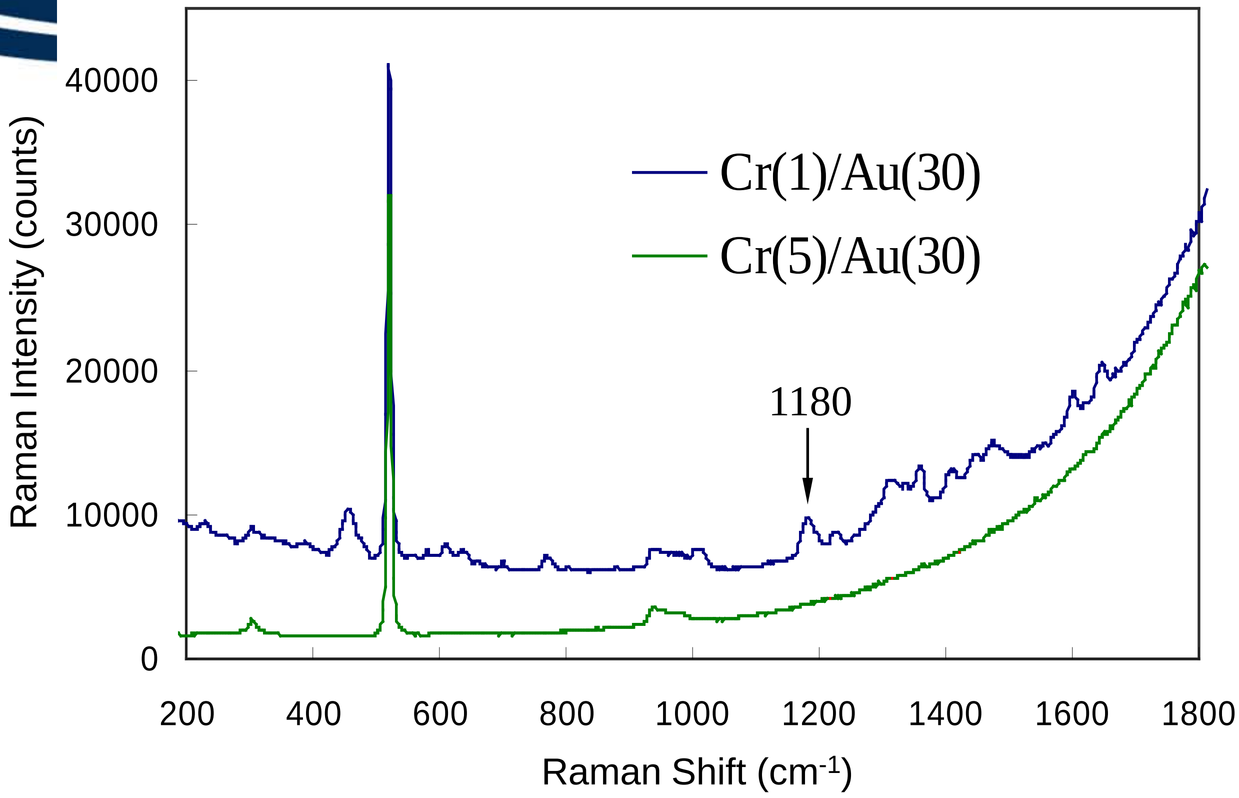
Raman measurement:

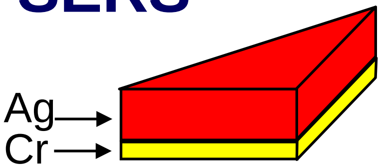
excitation laser λ=785nm, power 0.16mW/mm^2, beam spot size 25-30μm, collection time 3sec.

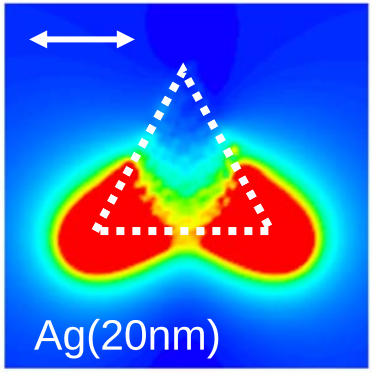
→Raman signal from ~monolayer R6G is nearly comparable to that from *bulk* silicon

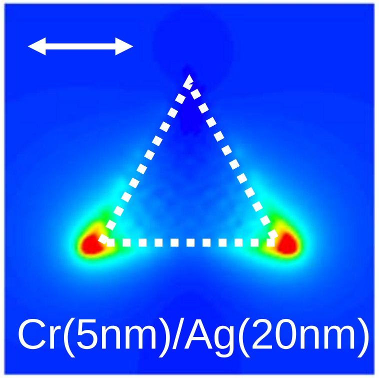
Cui…, Nanotechnology, 2008

Effect of Cr (adhesion layer) on SERS









Why Cr is detrimental to SERS?

Electric permittivity $\varepsilon = \varepsilon_1 + i\, \varepsilon_2$

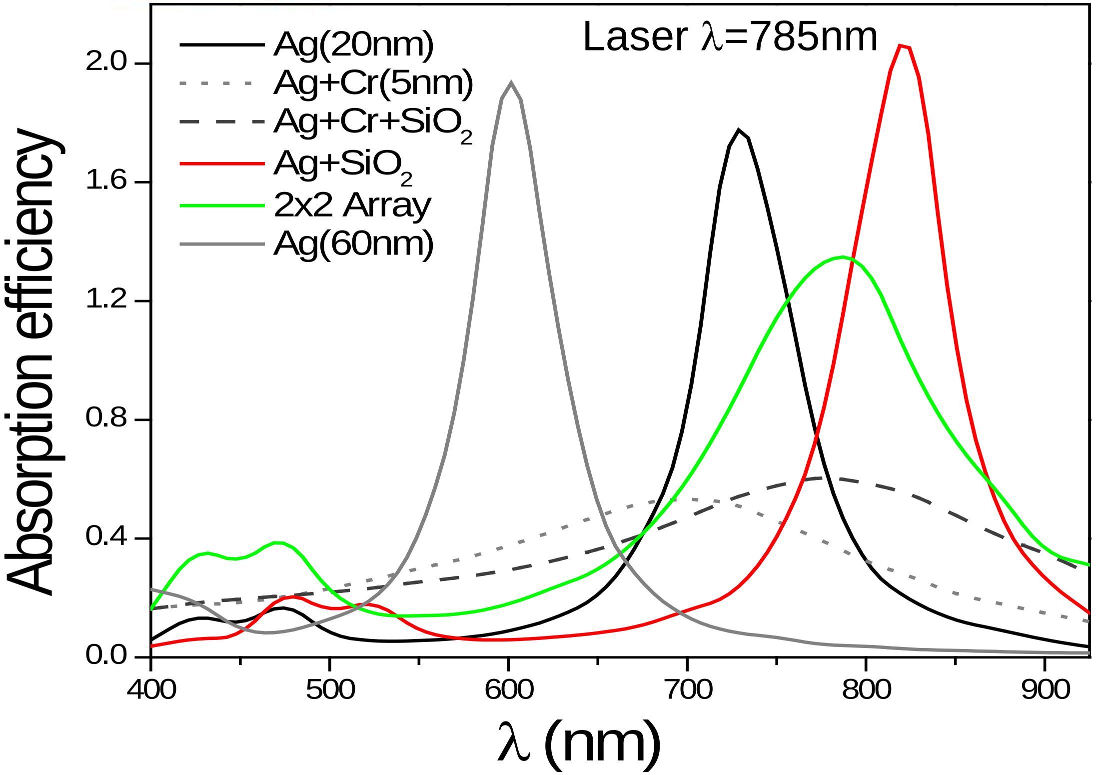
Strong SERS requires large ε_1 (strong charge oscillation) and small ε_2 (low loss)

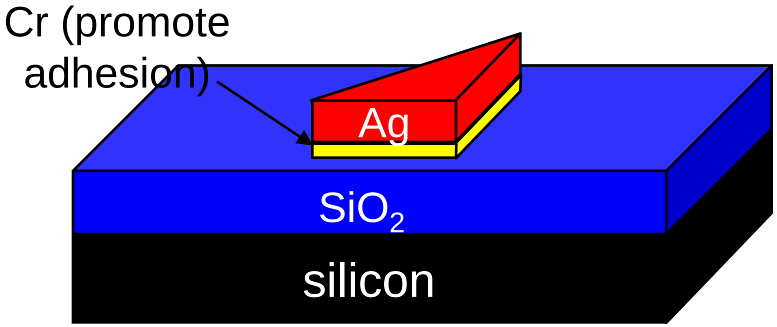
But at λ=800 nm $\varepsilon_1(Cr)/\varepsilon_1(Ag)=1/20$ $\varepsilon_2(Cr)/\varepsilon_2(Ag)=50/1$

→Keep Cr adhesion layer as thin as possible (1nm)

Numerical calculation by discrete dipole approximation

(to optimize nanoprism dimension)





- For single Ag nanoprism, λ_{res}~720nm.
- Cr decreases absorption efficiency.
- SiO$_2$ substrate red-shift λ_{res} by 100nm.
- Thicker Ag decreases λ_{res}
- 2×2 array has higher λ_{res}

Discrete Dipole Approximation (DDA):

- It computes scattering of light by wavelength-scale structures.
- The structure is represented by an array of dipoles located in a regular cubic lattice.
- Advantage: only the domain of interest (the metal nanostructure) is discretized.

SERS detection of bio-molecules

Challenges:

Bio-molecules compose of similar repeating units (base for DNA, amino acid for protein), hence their Raman spectra are very similar

Solution:

- Attach a tag molecule to the bio-molecule, but no longer label-free
- Collect large number of spectra and do regression date analysis

Application:

Detection of drug (e.g. recombinant proteins) abuse in sports (doping).

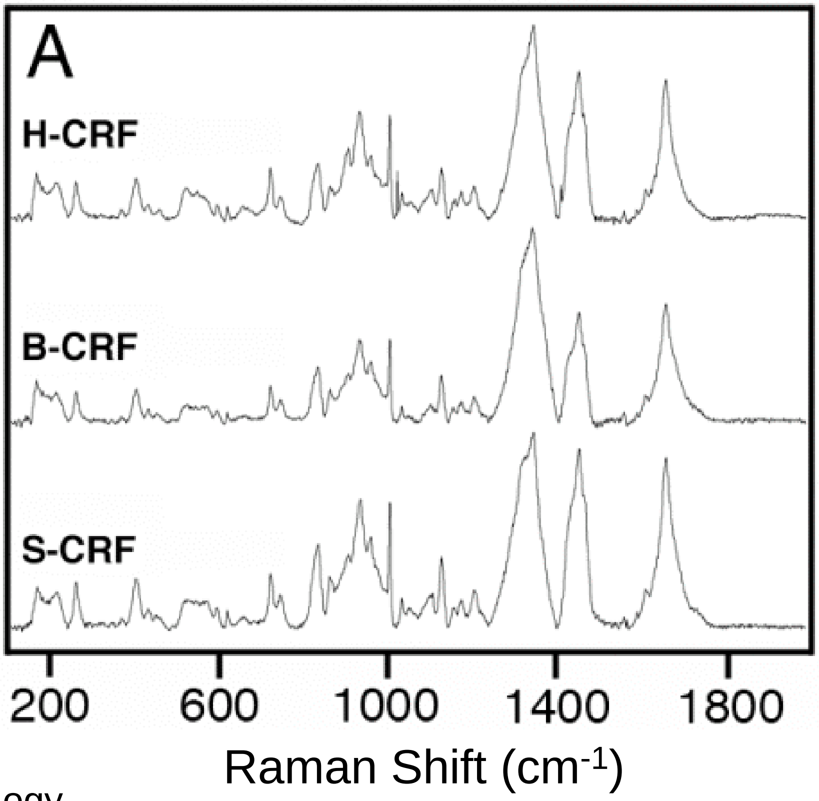
H-CRF: SQEPPISLDLTFHLLREVLEM AR A E QLAQQAH S NRKL ME I I

B-CRF: SQEPPISLDLTFHLLREVLEM TK A D QLAQQAH N NRKL LD I A

S-CRF: SQEPPISLDLTFHLLREVLEM TK A D QLAQQAH S NRKL LD I A

H: Human; B: Bovine; S: Sheep;

CRF: Corticotropin releasing factors



Collaboration with NRC – National Institute for Nanotechnology

Regression Data Analysis

Collected 798 spectra per sample

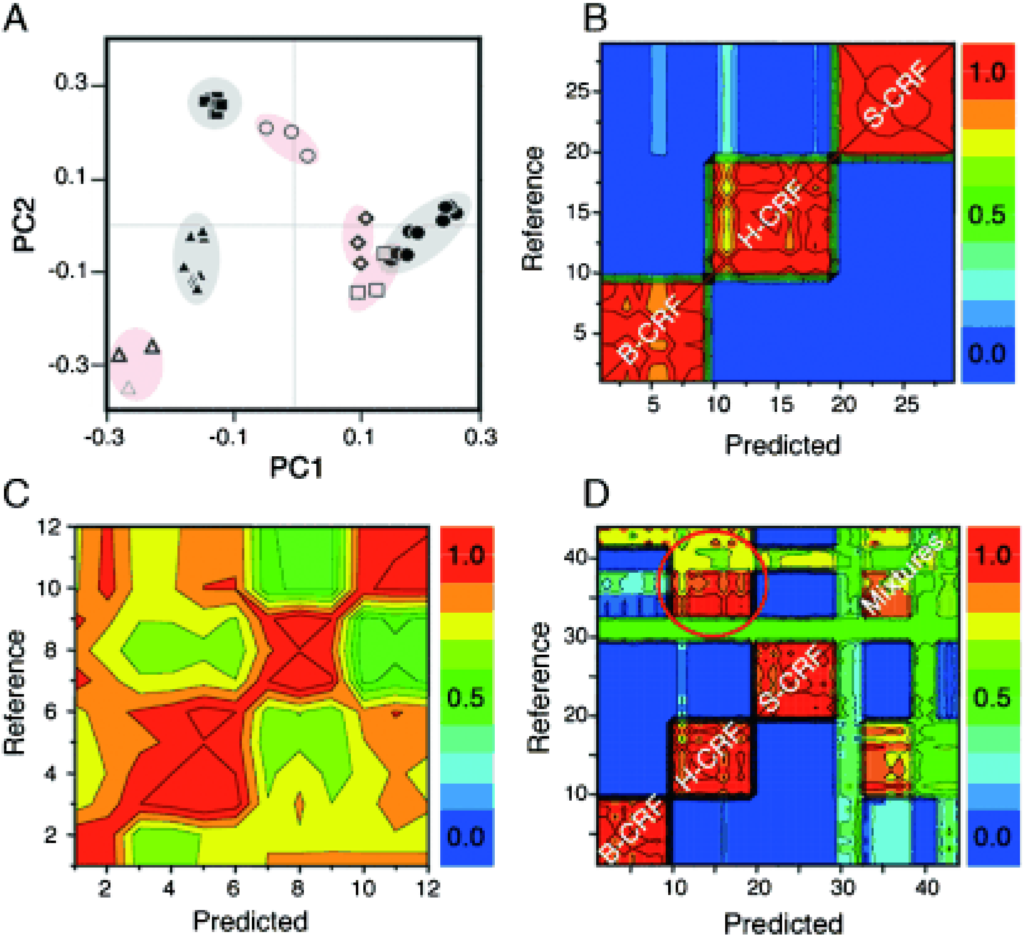
Partial least-squares regression

A. Score plot representing the first two principal components.

B. Contour plot showing the correlation for the three CRFs.

C. Contour plot for their mixtures ("contaminated" samples).

D. Contour plot for the three CRFs and their 12 mixtures (B+C).



→ SERS can distinguish bio-molecules, but need collect large number of spectra

Alvarez-Puebla, Cui… ChemMedChem, 2007

Outline

Part I: Introduction

What is nano? Why nano? How to reach nano?

Micro and nano-fabrication: lithography, etching, thin film deposition

One example of nanofabrication

Part II: Nanoimprint lithography (NIL) (hot embossing)

Hot embossing of several materials

- Polystyrene (biocompatible)
- Poly(lactic-co-glycolic acid) (biodegradable)
- MEH-PPV (semiconducting polymer for plastic solar cell)
- Metal (pulsed laser melting)

Replication of 100nm to mm-scale features by thermal NIL

Part III: Plasmonic chemical/biosensors based on metallic nanostructures

Introduction to plasmon

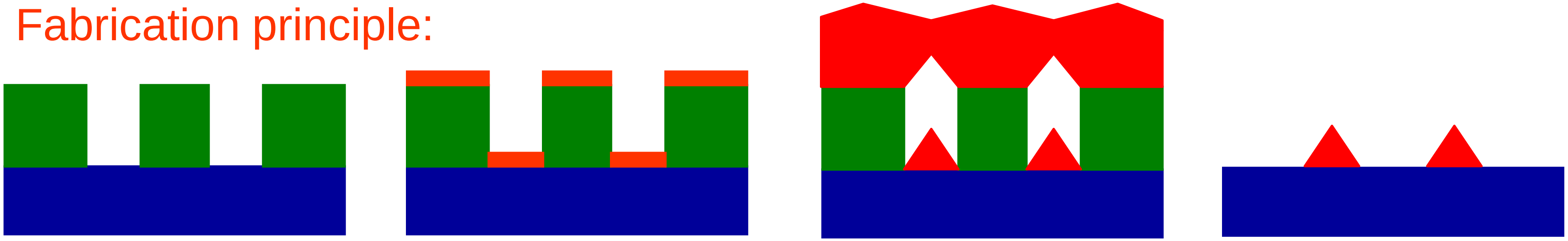
DNA hybridization detection by surface plasmon resonance (SPR)

Surface enhanced Raman scattering (SERS)

- Raman scattering and SERS fundamentals
- Fabrication of nano-prism array as SERS active substrates
- SERS detection of R6G molecules and peptides
- Fabrication of nano-pyramid, nano-ring/crescent and nano-star (brief)

Other types of nanostructures fabricated by NIL: nano-pyramid

Fabrication principle:

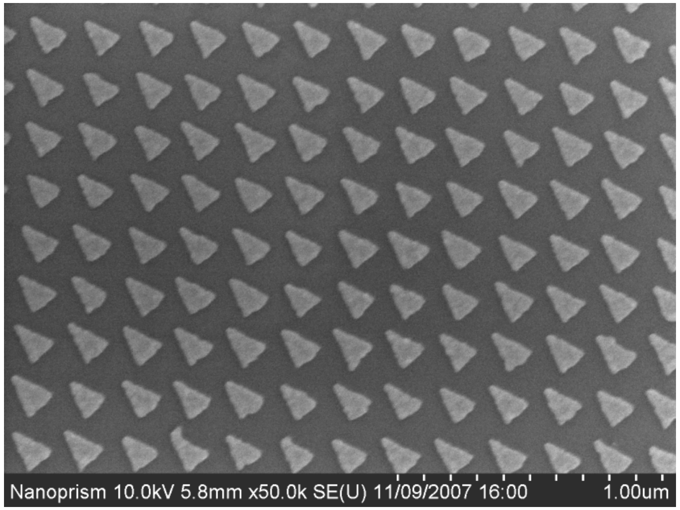


1. Triangular hole array

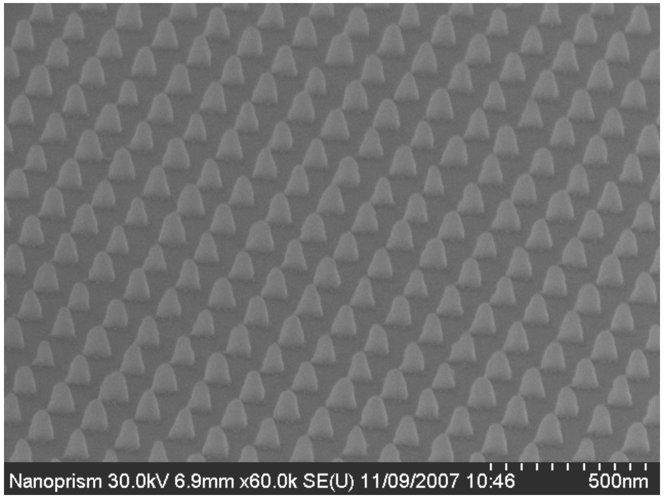
2. Deposit **thin** film

3. Deposit **thick** film
Opening close-up gradually due to lateral deposition

3. Liftoff



Nano-prism (2D)

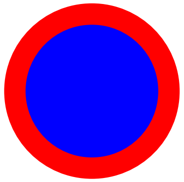


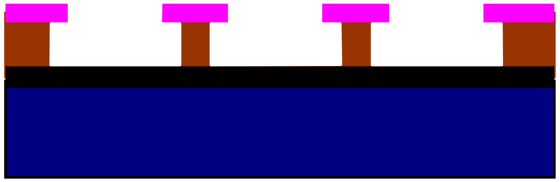
Nano-pyramid (3D)

Nano-ring and nano-crescent

Fabrication principle:

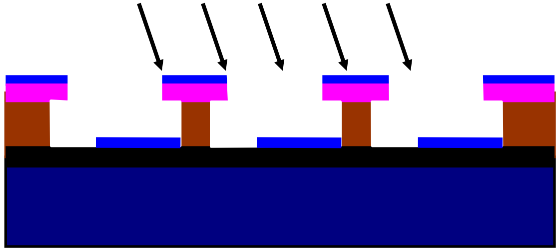
Nanoring (red) defined by edge of nanodisk (blue)





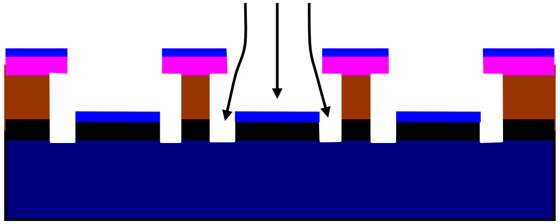
1. Hole array with large undercut

Cr deposition at an angle

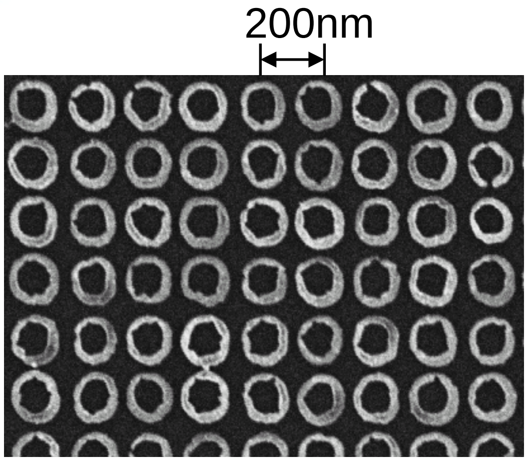


2. Deposit Cr to cover hole bottom

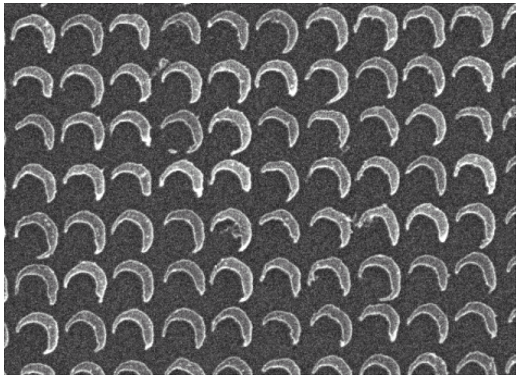
Reactive gas



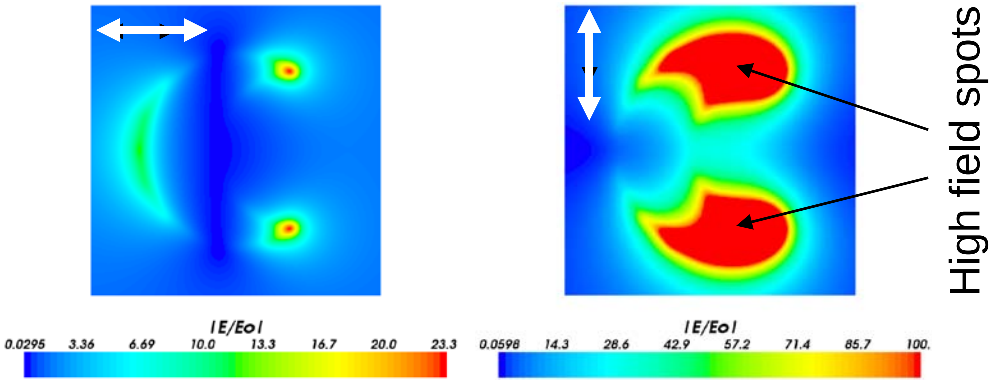
3. RIE with lateral etch



Nano-ring



Nano-crescent

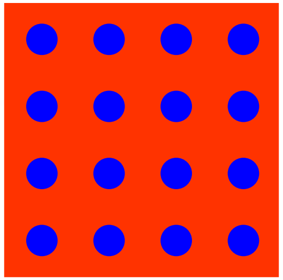


Near field for nano-crescent

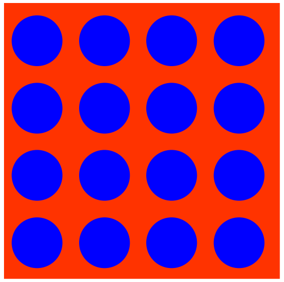
Cui…, Microelectronic Engineering 2007; Li, Cui…Nanotechnology 2008

Nano-star array

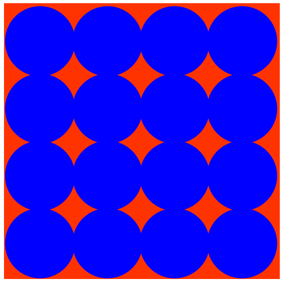
Fabrication principle:



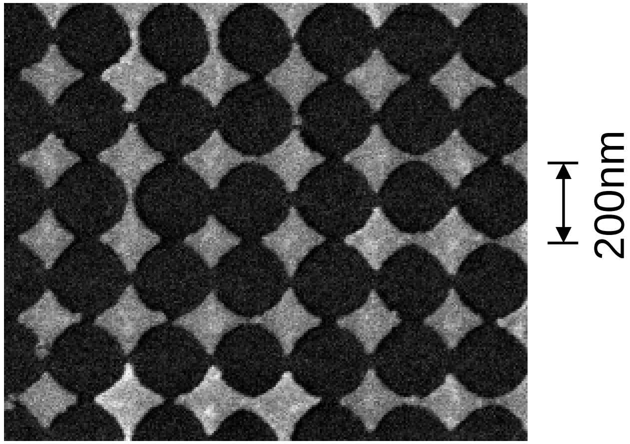
1. Nano-hole array (**blue color**)

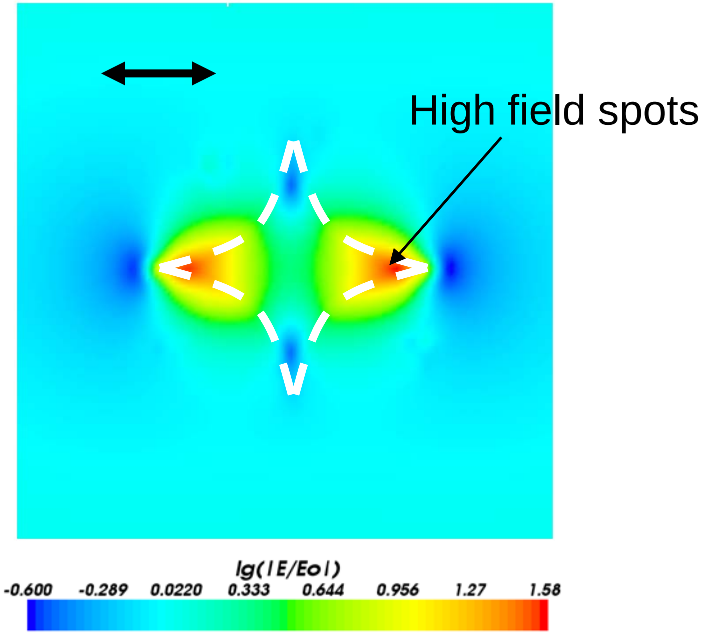


2. Enlarge holes due to lateral etching



3. Nano-stars (**red color**) formed when adjacent holes touch each other





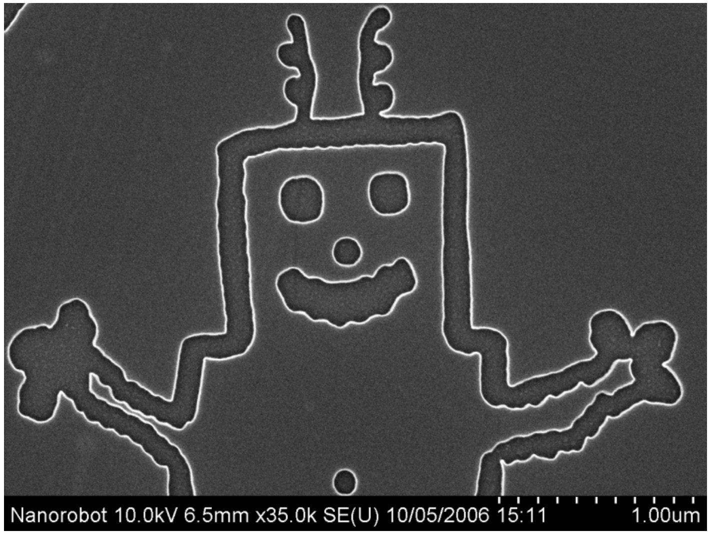
High field spots

Cui… SPIE 2008

Summary for Part III

1. Plasmon is collective oscillation of free electrons
2. Three types of plasmon: bulk, surface and localized
3. Surface plasmon resonance can be used for biosensors
4. We achieved 5× higher SPR sensitivity by patterning Au nano-post array on a flat Au film
5. SERS is an enormous enhancement of Raman scattering when a molecule is adsorbed on a nanostructured metallic surface
6. Using nanoimprint lithography, we fabricated arrays of nano-prism, nano-pyramid, nano-ring/crescent and nano-star.
7. We demonstrated SERS detection of R6G molecules, as well as peptides classification.

Acknowledgement



CNRC-IMI: Teodor Veres (group leader)

Collaborators:

- **LOEX (Laval University): M. Guillemette, FA Auger, L. Germain**
- **McGill University: L. Malic, M. Tabrizian**
- **MIT/Northeastern University: X. Cheng, S. Murthy, M. Toner**
- **NINT: R. Alvarez-Puebla, H. Fenniri**
- **Organic Vision Inc.: S. Xiao**

CNRC-NRC

Institut des
matériaux industriels

La Science à l'œuvre pour le Canada

Conseil national
de recherches Canada

National Research
Council Canada

Canada