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Large Area CoNi Stress Free Electroforming Mold for Nanoimprinting Lithography



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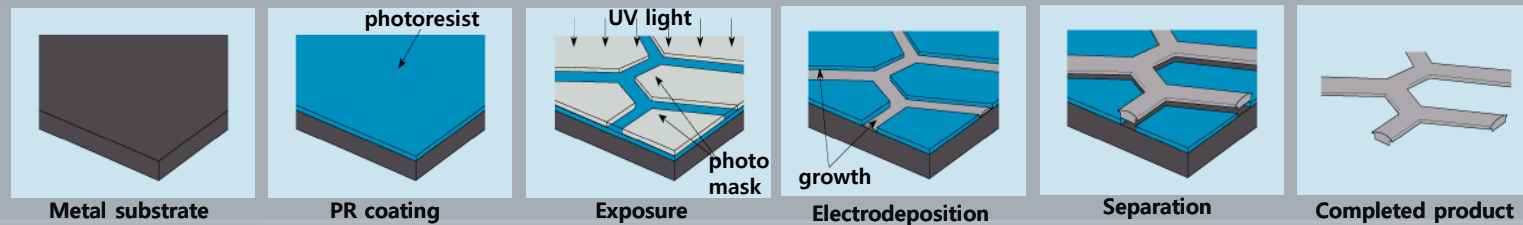
Results & Conclusions



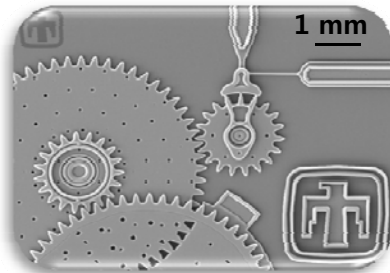
Electroforming for MEMS

❖ **Electroforming** is ... a highly specialized process of metal part fabrication using electrodeposition in a plating bath

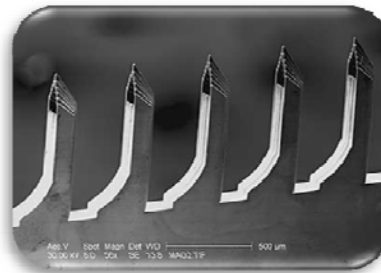
Electroforming process



Electroforming parts



< Micro gear >



< Array of micro needles >



< Micro scissor >

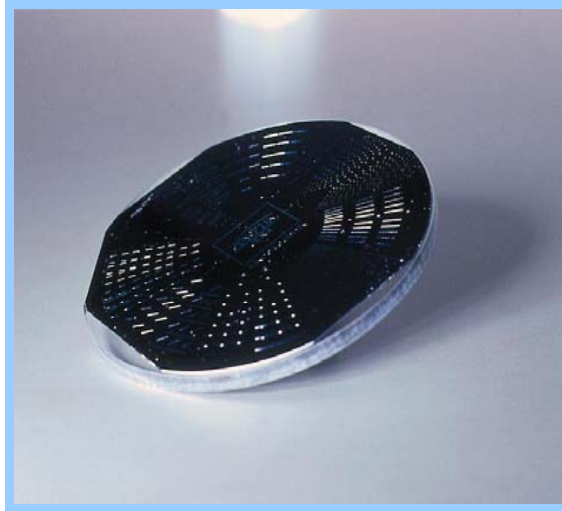
- Technically, it is a process of synthesizing a metal object by controlling the electrodeposition of metal passing through an electrolyte onto a metal seed layer.
- The miniature components for these machines often **require electrodeposition** fabrication steps

References: Sandia National Laboratories (<http://mems.sandia.gov/gallery/images/tg8.jpg>), Microfabrica Inc. (www.Microfabrica.com)

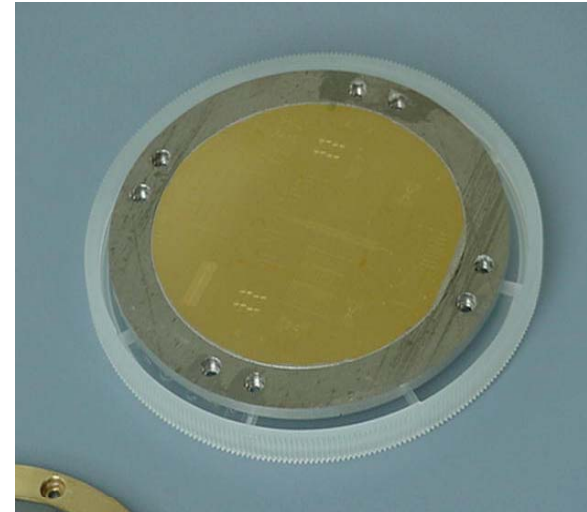


Silicon and Ni Molds

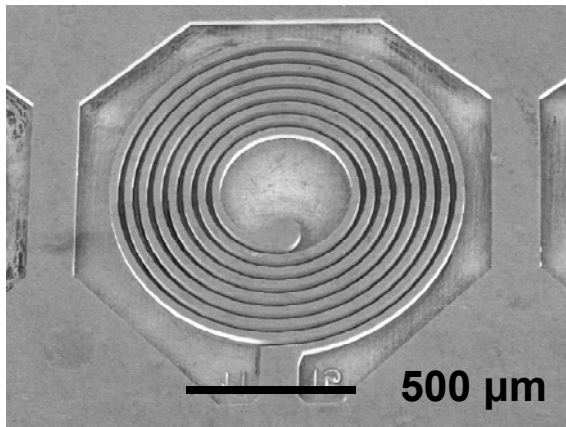
Silicon
Mold



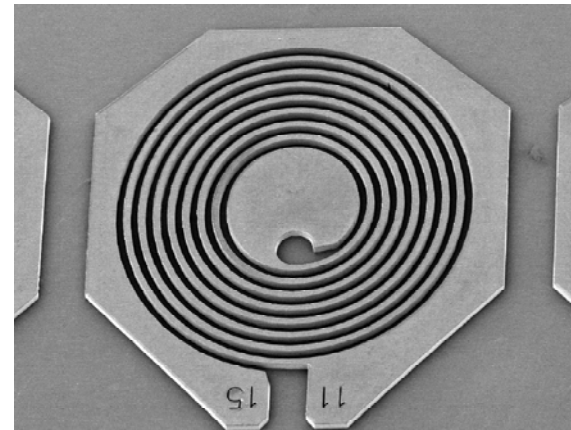
Ni Mold



Ni Mold



Polycarbonate
height : 50 μm



Source: IMM



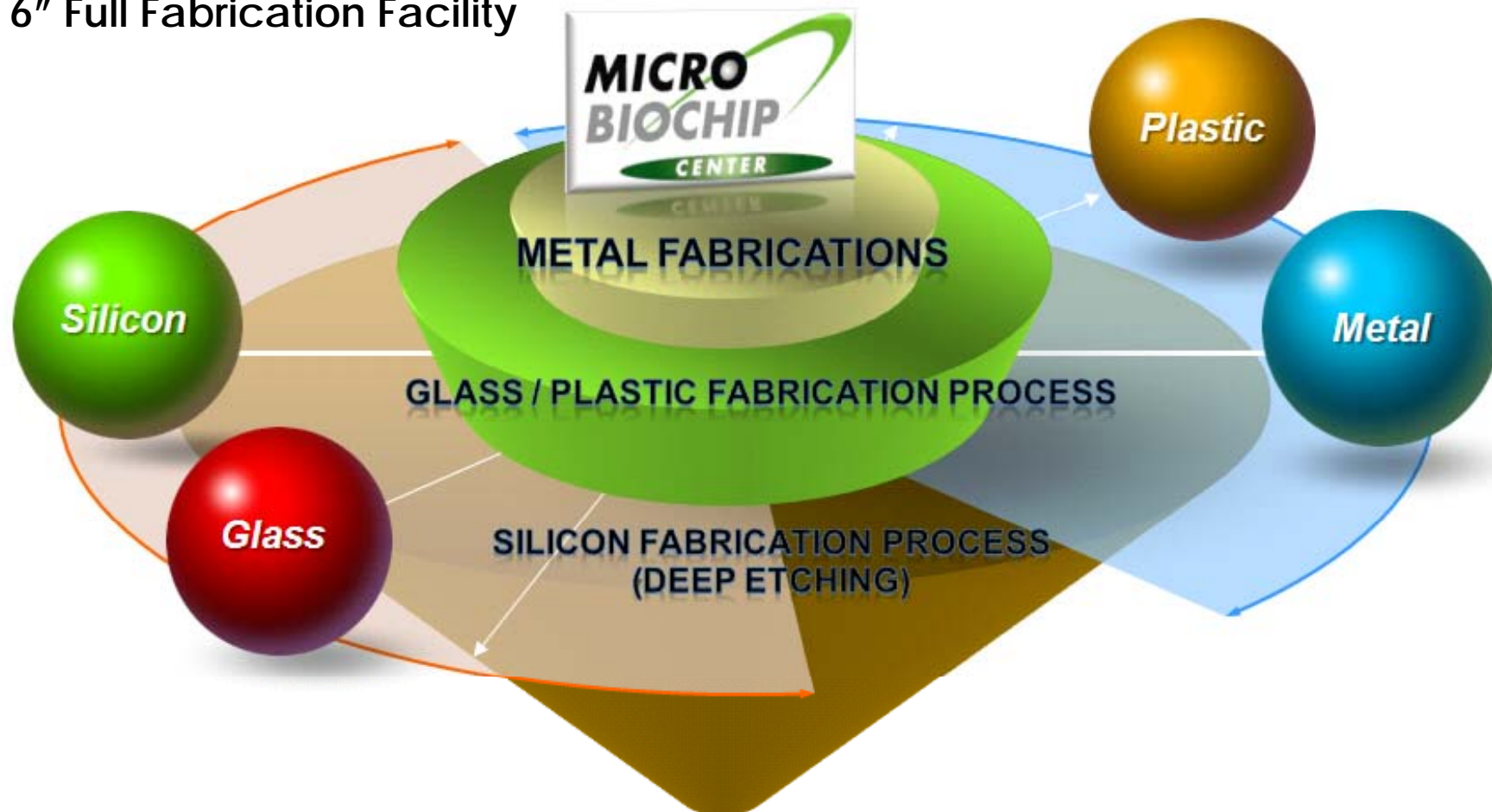
Molds

Mold Material	Advantage	Disadvantage
Silicon	<ul style="list-style-type: none">▪ Well known, traditional method▪ Easy to make▪ Relatively cheap process▪ Can manufacture fine patterns	<ul style="list-style-type: none">▪ Easy to broken▪ Needs Antistiction layer
Nickel	<ul style="list-style-type: none">▪ Long life time▪ Acceptable for mass production▪ Hard to broken	<ul style="list-style-type: none">▪ Easy to warpage during process▪ Takes long time to make▪ Relatively expensive process▪ Needs Antistiction layer▪ Hard to make thick mold
Glass	<ul style="list-style-type: none">▪ Transparency▪ Acceptable for UV imprinting▪ Can manufacture fine pattern	<ul style="list-style-type: none">▪ Easy to broken▪ Needs Antistiction layer
Plastic	<ul style="list-style-type: none">▪ Hard to broken▪ Transparency▪ Acceptable for UV imprinting▪ Relatively cheap process	<ul style="list-style-type: none">▪ Easy to deform▪ Needs Antistiction layer▪ Needs master mold



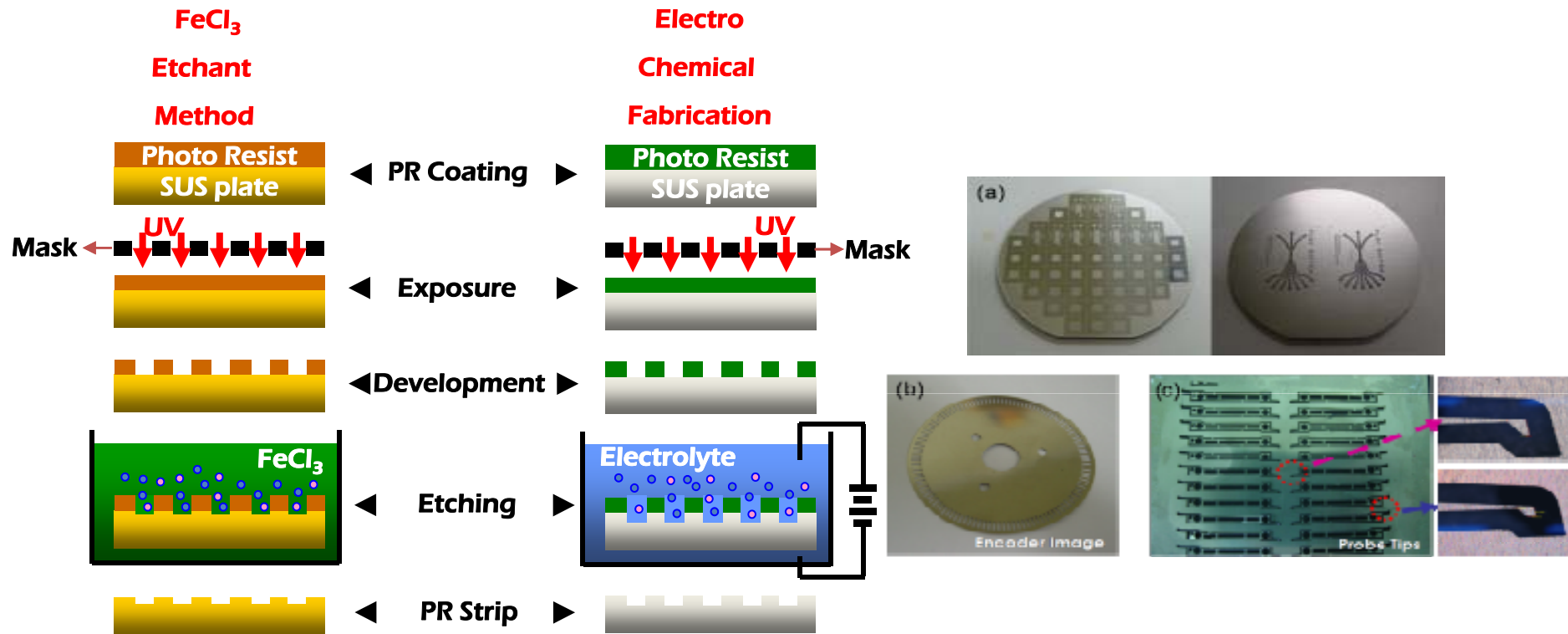
HYU MBC R & D Areas

6" Full Fabrication Facility





Electro Chemical Fabrication (ECF)

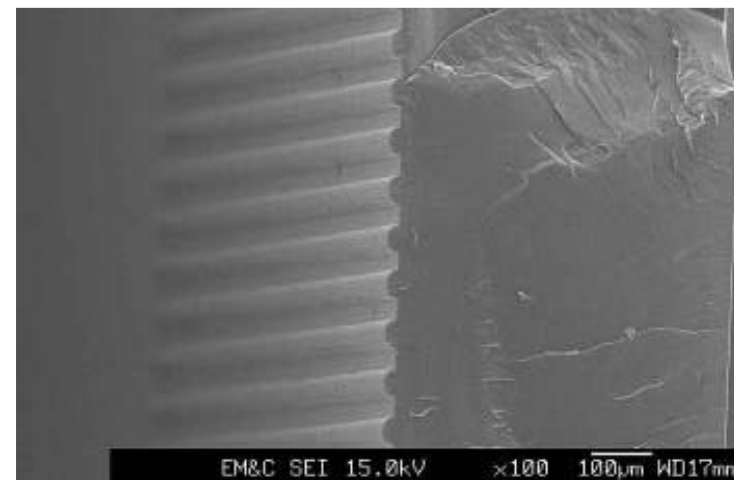
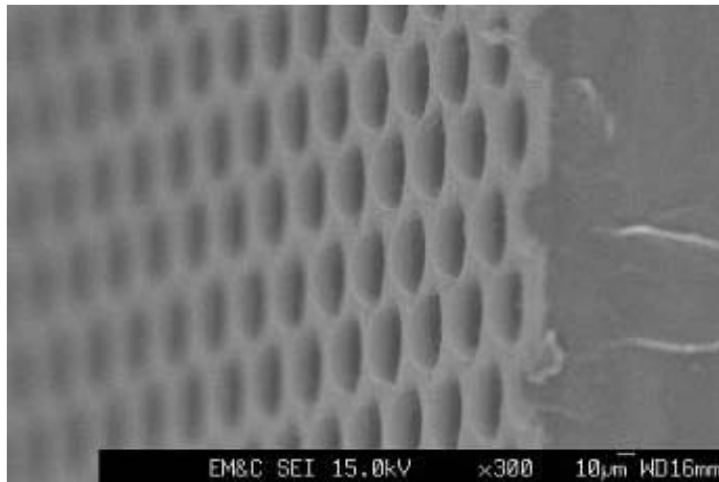
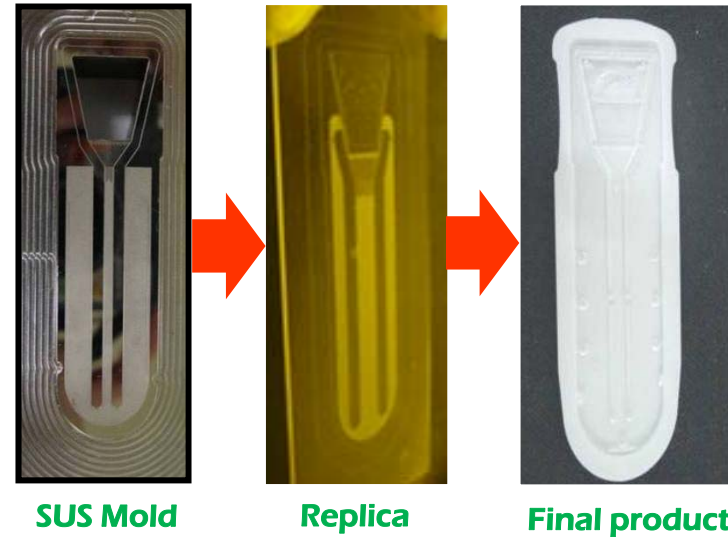
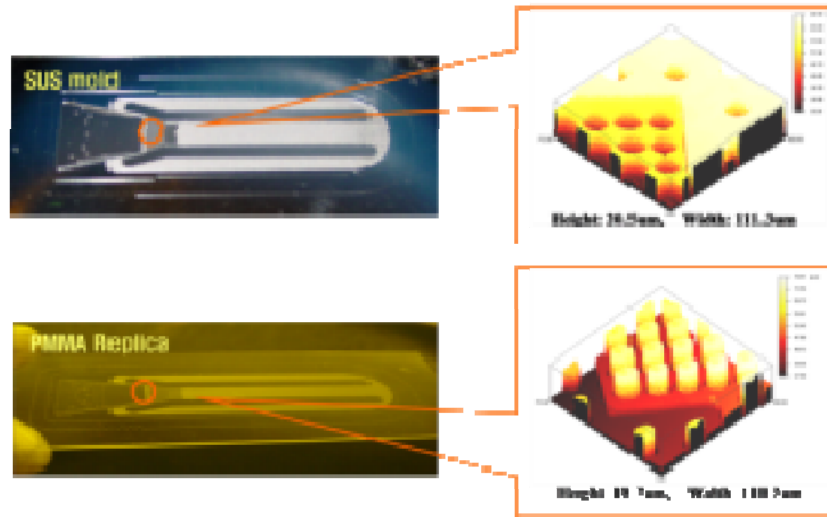


Schematic illustration of **E**lectro **C**hemical **F**abrication (ECF) process

Applications : SUS mold for biochip, encoder, probe tip → Micron
Molds for Injection molding



SUS mold with Multilayer for Biochip

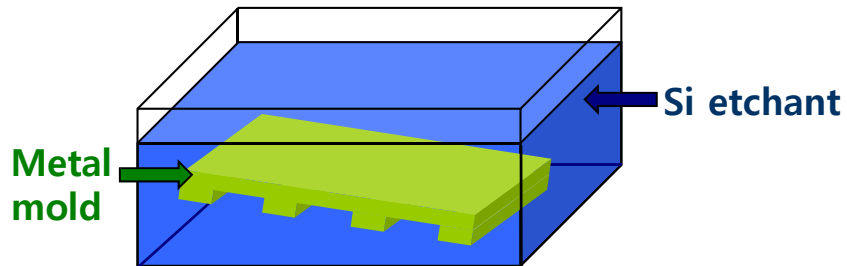




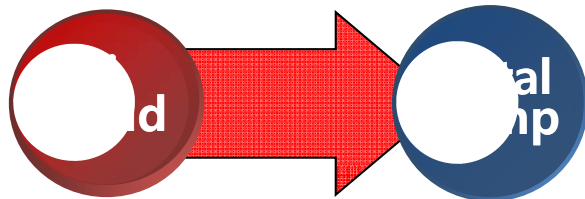
Fabrication of Ni Electroformed Mold

Si Removal by using etchant

✓ The sample is usually dipped in KOH solution to remove Si



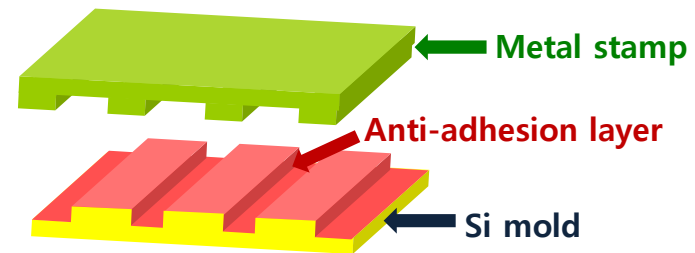
One Si mold to one metal stamp



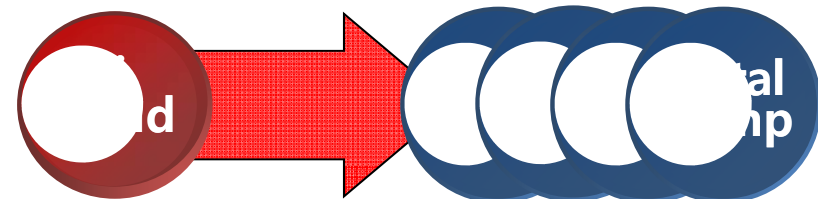
- High price of Metal mold
- Spend on long time to make a stamp
- Waste of chemicals (Si etchant)

❖ If we use this method, the consumption of Si mold is necessary to produce a metal stamp

Mold separation



One Si mold to many metal stamps



- Low price of Metal mold
- Saving time
- Easy separation

➤ we can fabricate metal stamp without the consumption of Si mother mold.

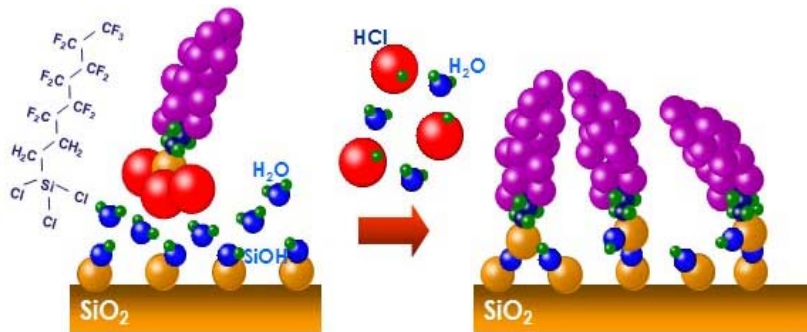


Vapor Self Assembled Monolayer (V-SAM) Deposition

Definition of Self Assembled Monolayer

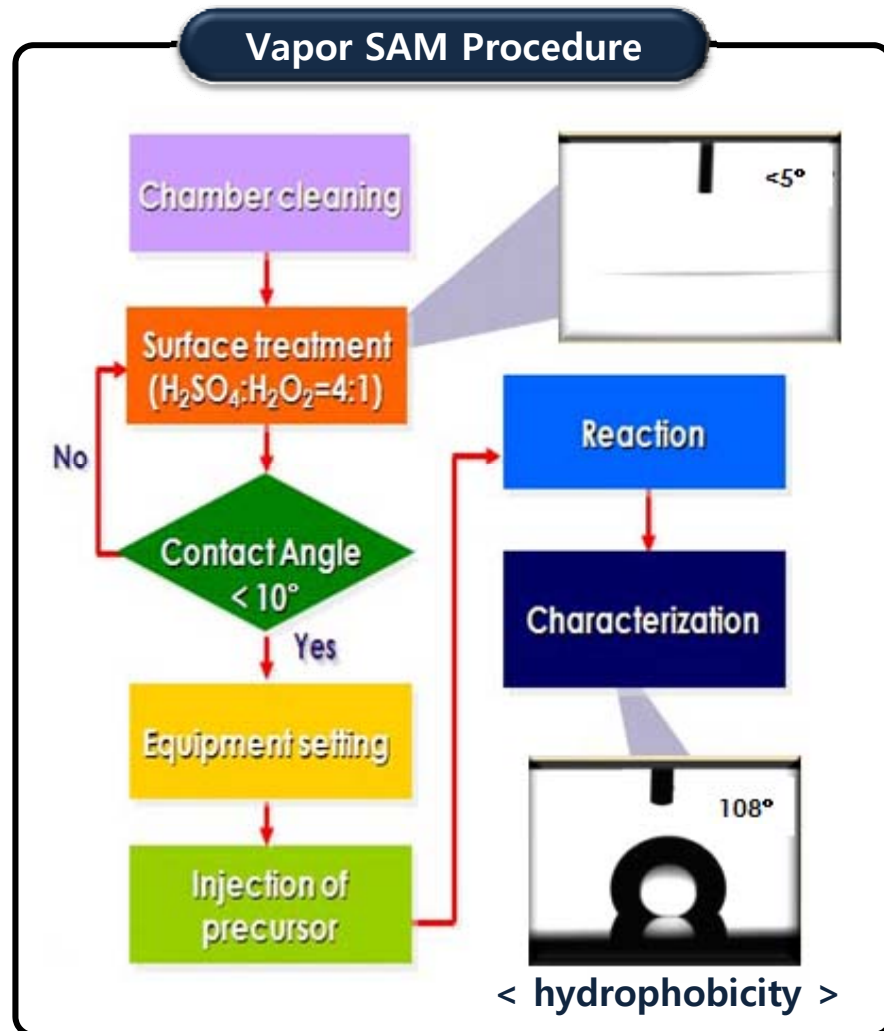
- Liquid or Vapor source reacts on the surface or interface by themselves and then the monolayer is formed.

Schematic diagram of film formation



- Precursor reacts on the surface and the monolayer is formed, and then characteristic of surface can be changed.

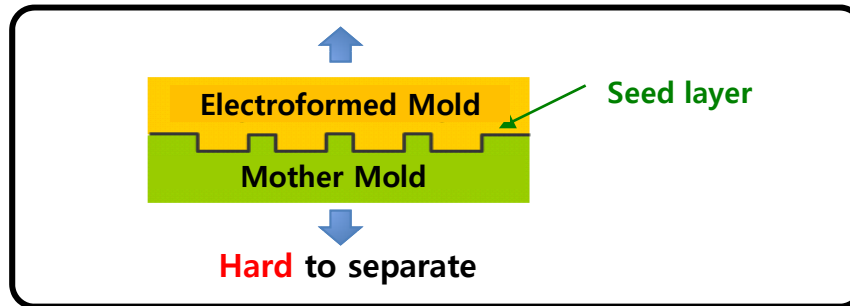
Vapor SAM Procedure



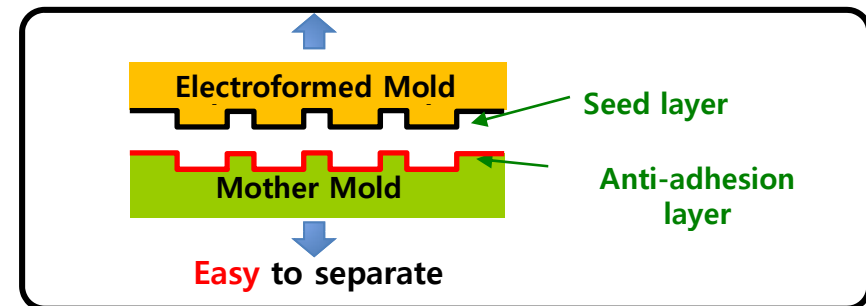


Anti-adhesion Layer for Electroforming

Without Anti-adhesion layer

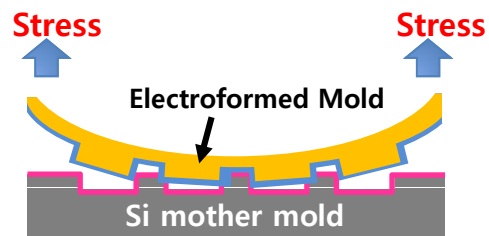


With Anti-adhesion layer



- Anti-adhesion layer can be formed as a precursor reacts on the surface by themselves.
- Anti-adhesion layer is effective for stiction free, high precision of patterns and possible to reuse a mother mold.

Disadvantages of anti-adhesion layer for electroforming ?



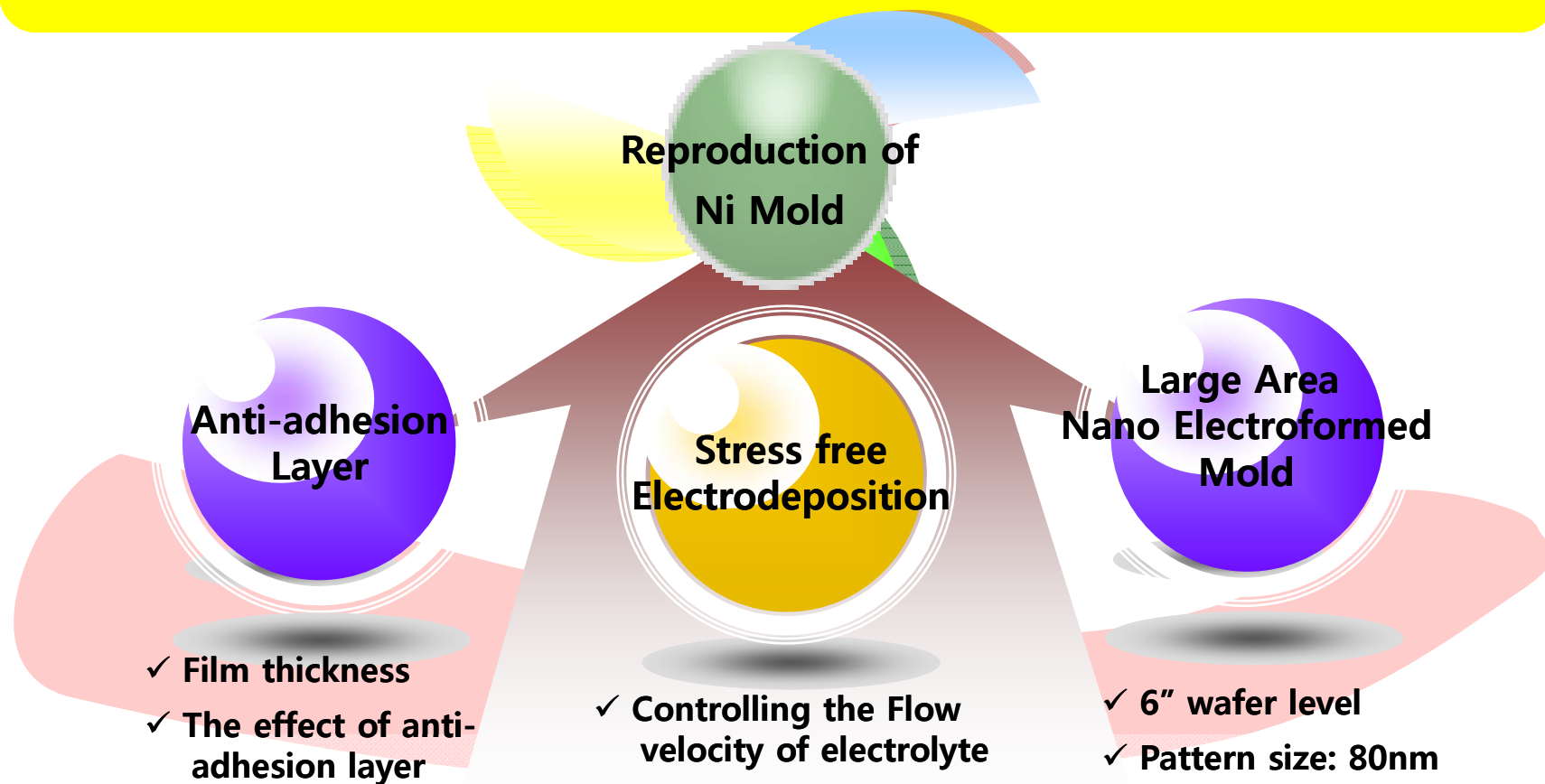
- ✓ Low adhesion
- ✓ Presence of film stress

- Due to hydrophobicity of film, the delamination of electrodeposited film happens during electrodeposition.
- The electrodeposited film stress is very critical, especially on large area electroforming process

➔ **Film stress should be controlled**

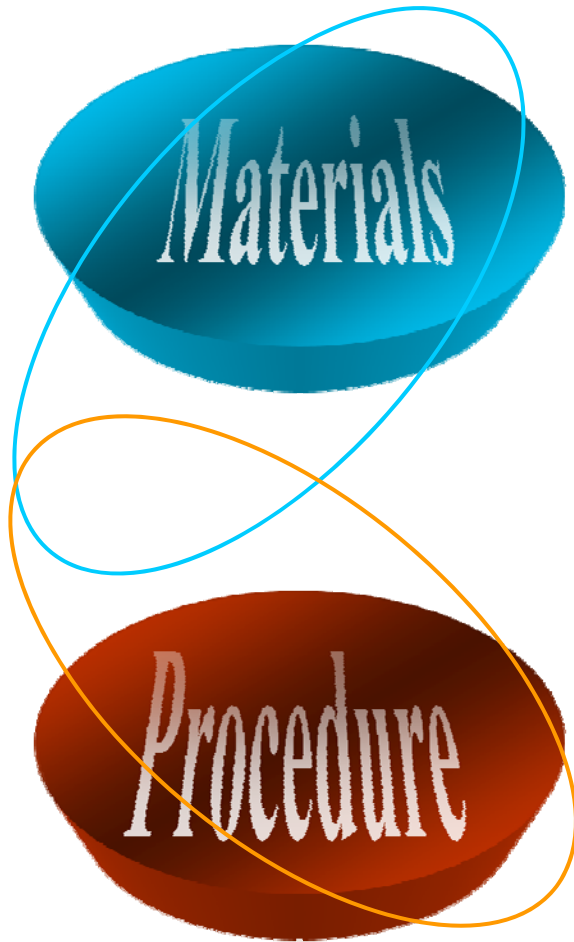


To Develop **Large Area** CoNi Alloy Electrodeposition Process for **Stress Free** Electroforming Mold





Materials & Procedure

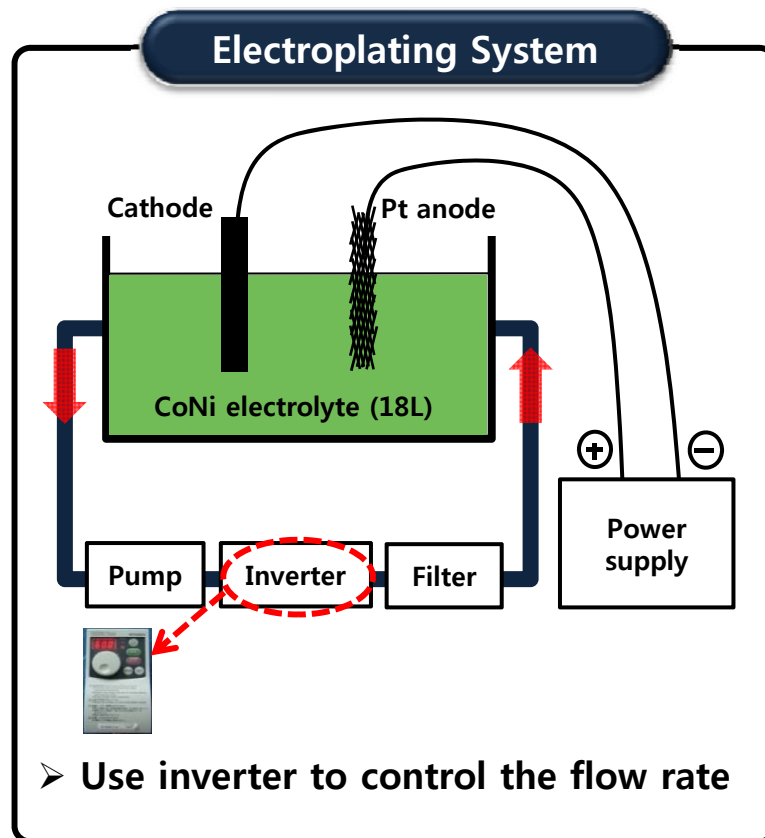


- ✿ Substrate – 6" Si wafer (Nano Patterned Si Mold)
- ✿ Vapor SAM precursor - FOTS (Fluor octyl trichloro silane)
- ✿ Electrolyte - CoNi chloride electrolyte (18L)

- ✿ Sputter - Seed layer deposition
- ✿ Vapor-SAM equipment - Anti-adhesion layer deposition
- ✿ Electroplating equip. - Electrodeposition
- ✿ Ellipsometer – Anti-adhesion layer thickness
- ✿ Optical microscope / FE-SEM / AFM - shape and size of patterns



Conditions of Electrodeposition



Bath compositions

Chemicals	Concentration (M)
Ni ²⁺ (as NiCl ₂ · 6H ₂ O)	0.2
Co ²⁺ (as CoCl ₂ · 6H ₂ O)	0.008, 0.05
NaCl	0.7
H ₃ BO ₃	0.4
Additive	0.01

Operating conditions

Parameters	Condition
Plating temperature (°C)	23
Current density (mA/cm ²)	10
pH	4
Anode material	Pt
Flow velocity of plating solution (m/s)	0, 1, 2, 3, 4

Analysis

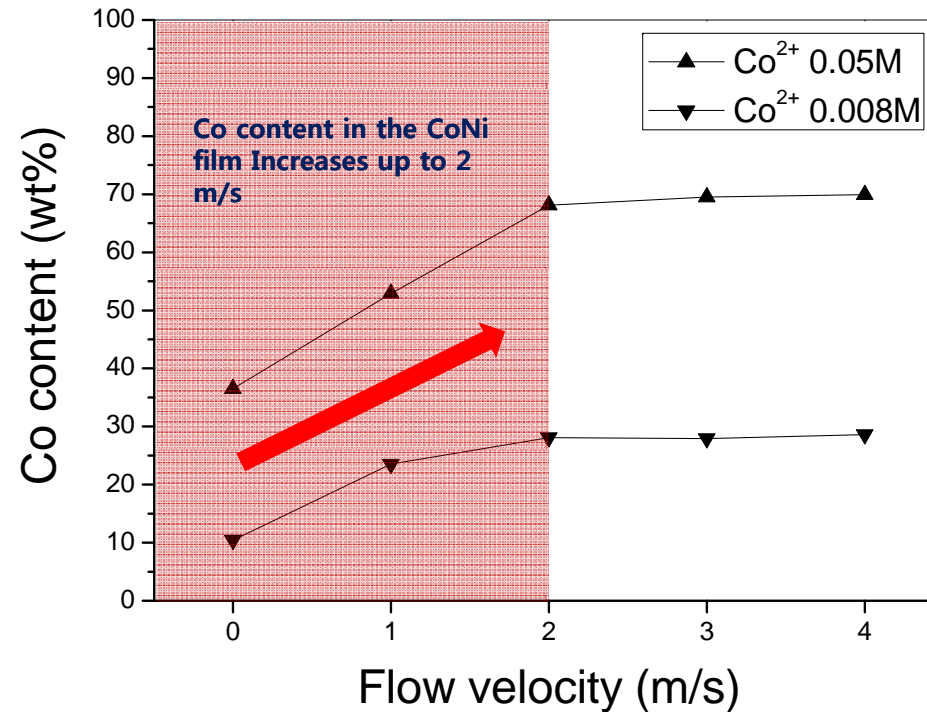
- Stress analyzer
- Energy Dispersive X-ray Spectroscopy(EDX)

- The effect of electrolyte flow rate on CoNi film stress was investigated by varying the flow velocity of plating solution using inverter pump.
- Frequency inverter was used for controlling flow rate of pump.

❖ Reference : D. Y. Park, et al., *Electrochemical and Solid-State Letters*, 8 (2) C23-C25 (2005)



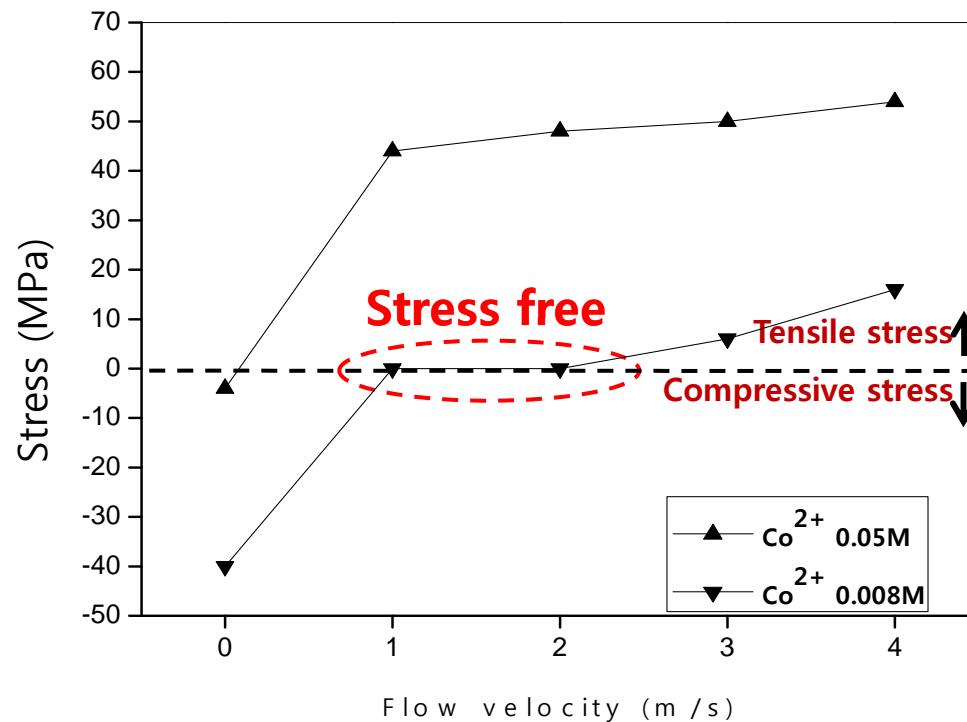
Dependence of **Film Compositions** on Flow Velocity in the Plating



- ❖ The Co content increases **with increasing the flow velocity** of plating solution and reached to a max at 2 m/s..
- ❖ The anomalous codeposition can be maintained **with agitation**.
- ❖ As increasing the agitation speed, **Co content can be preferentially deposited**.



Dependence of **Film Stress** on Flow Velocity in the Plating Bath



Co^{2+}	0.008M
Flow velocity	1~2m/s

- ❖ The stress changed **from compressive to tensile stress mode** with increasing Co^{2+} concentration.
- ❖ The stress free CoNi film was deposited at **the flow velocity of 1~2 m/s** in the electrolyte containing **0.008M Co^{2+}** .
- ❖ **The agitation also affects the stress of CoNi films.**
- ❖ **6inch size nano patterned electroforming mold** was fabricated from this condition.



Electroforming Process for Stamp Duplication

Process for Si mother mold



(a) Photolithography process



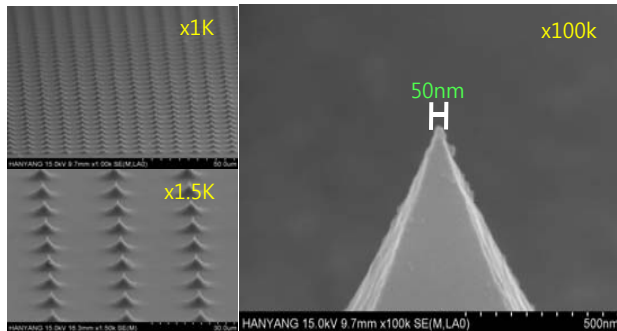
(b) SiO₂ etching (ICP Etcher)



(c) Isotropic Si etching (ICP Etcher)



(d) Si mother mold



Electroforming process



Anti-adhesion layer deposition



Anti-adhesion layer deposition



Seed layer deposition



Electrodeposition



CoNi Electrodeposition



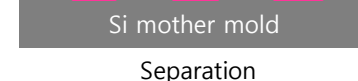
2nd duplicated CoNi stamp



1st duplicated CoNi stamp



1st duplicated CoNi stamp



Si mother mold



2nd duplicated CoNi stamp

Separation

Separation



Analysis

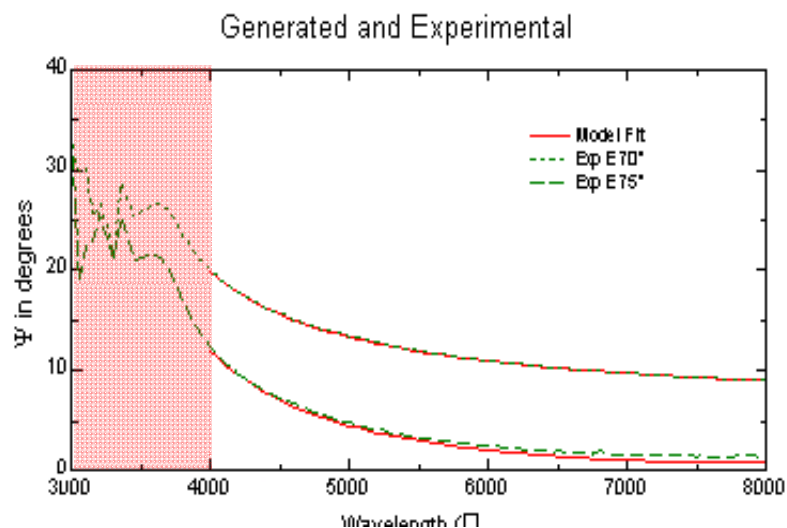
Ni Seed layer 20nm

Anti-adhesion layer

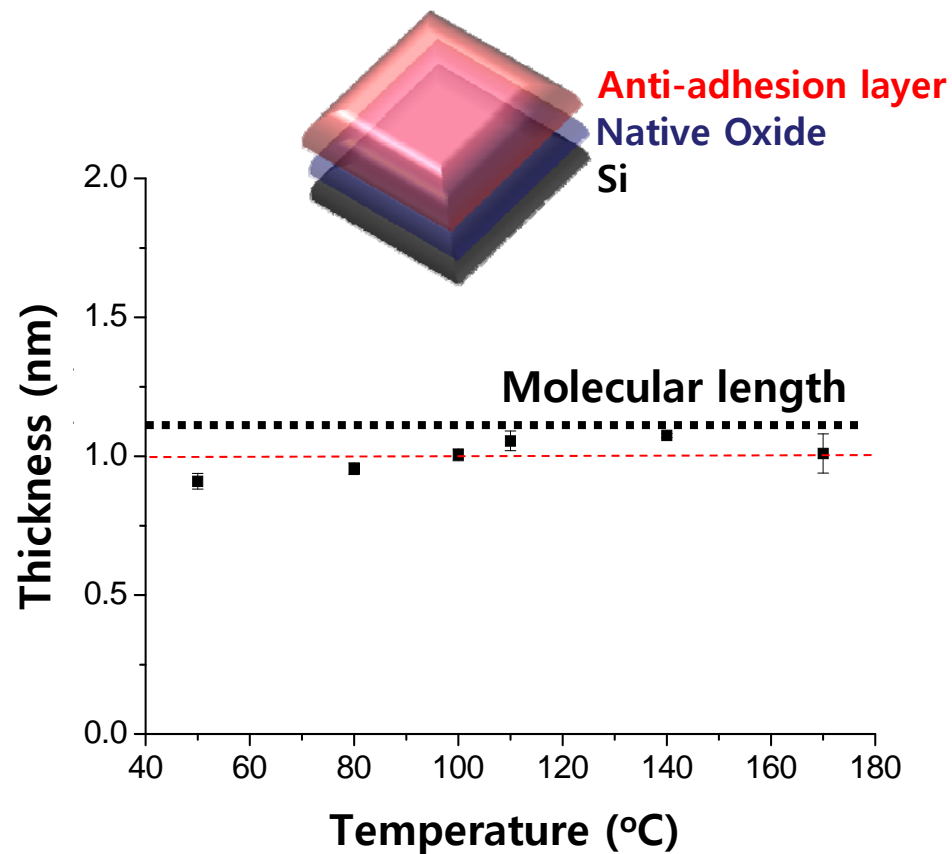
- The Si Mother mold was fabricated by an isotropic etch method using ICP etcher.
- The isotropic dry etching processing was applied by the ICP etcher to form nano sized structures on the Si substrate.



Thickness of Anti-adhesion Layer




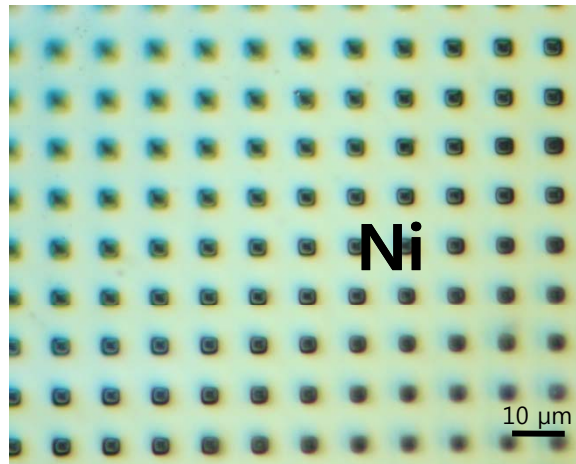
- Precursor Length : 1.1 nm
- Native Oxide : 1.7 nm
- Cauchy Model
- Wavelength : 400 ~ 800 nm (per 2 nm)





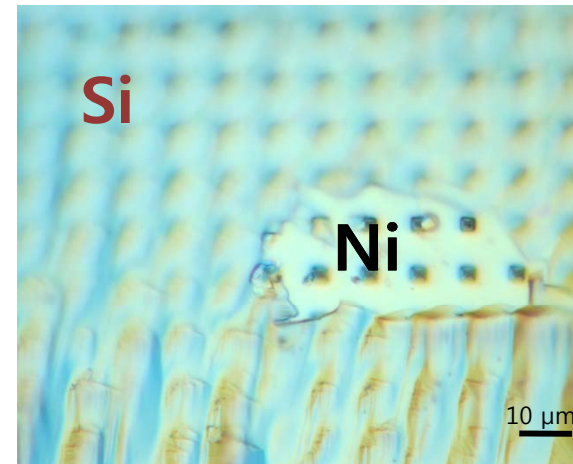
The Effect of Anti-adhesion Layer

 With anti-adhesion layer



The surface of reproduced CoNi stamp after separation **with Anti-adhesion layer**

 Without anti-adhesion layer



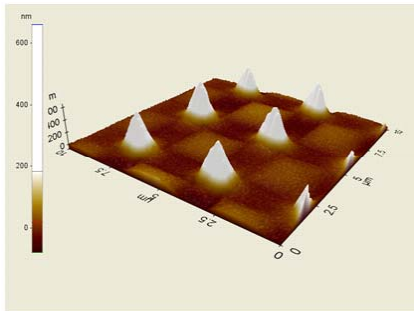
The surface of reproduced CoNi stamp after separation **without Anti-adhesion layer**

- ❖ The **stiction problem** arises after separation **without anti-adhesion layer**.
- ❖ Anti-adhesion layer makes Si mother mold **easy to separate** and reproduce CoNi stamp.

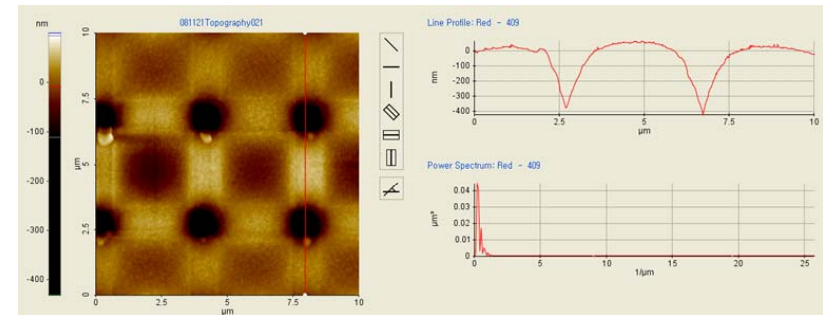
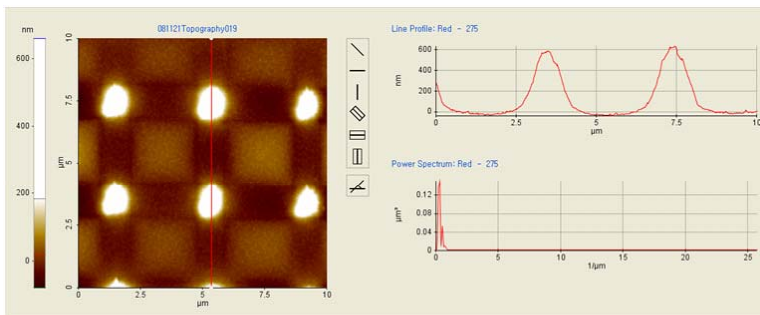
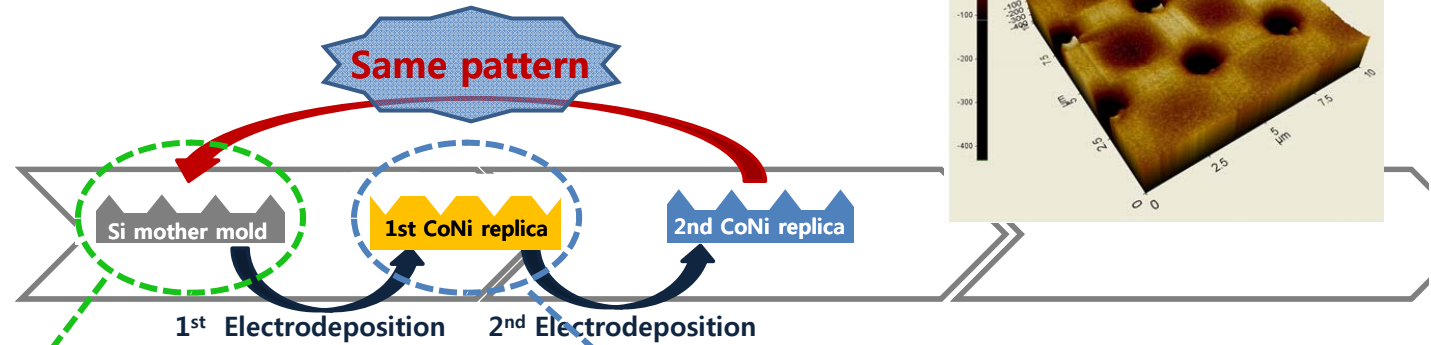
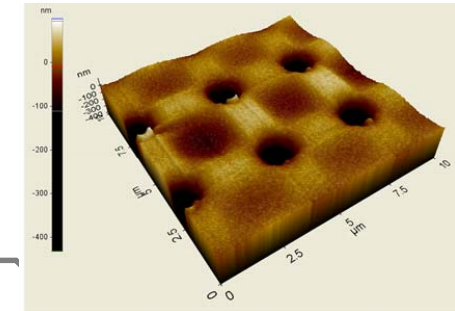


AFM Images of Reproduced Nano Tips

❖ Si mother mold



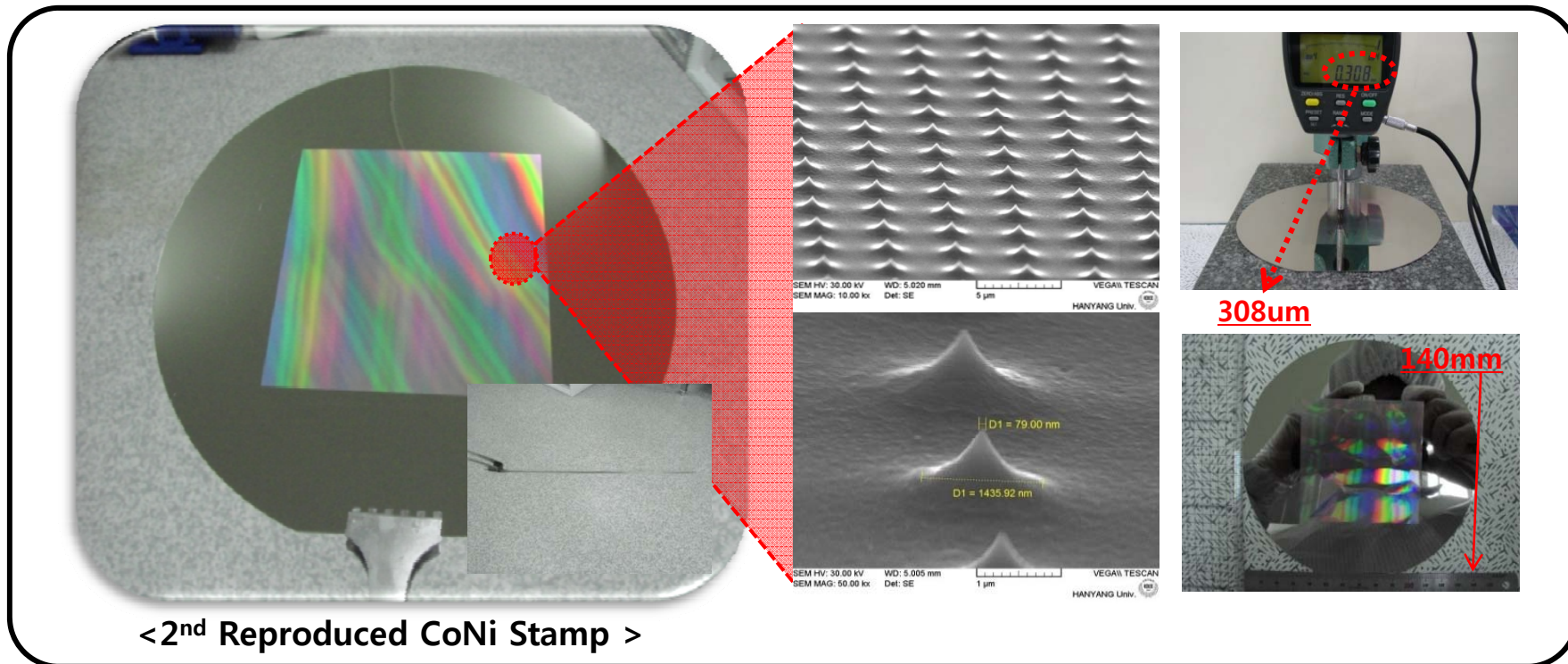
❖ 1st reproduced CoNi mold



✓ CoNi mold was reproduced and it has patterns which are opposite images of Si mother mold.



Nano CoNi Stamp



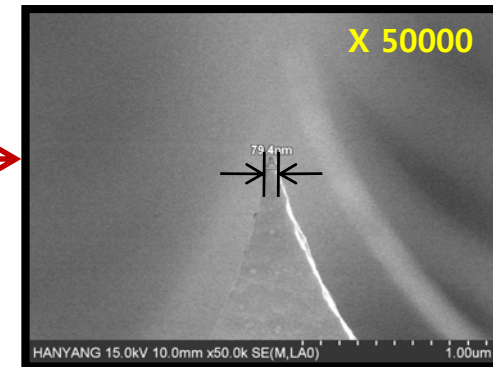
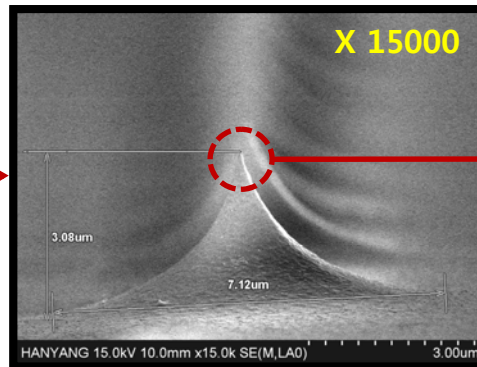
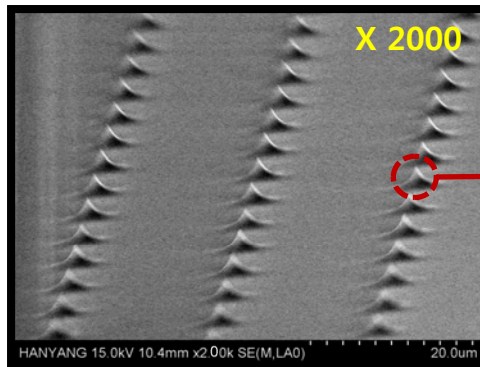
Width of tip	80 nm
Pitch / Average height	4 μm / 1 μm
Stamp size	140mm (Diameter)
Patterned area	70 mm x 70 mm
Stamp thickness	308 μm

- ❖ Nano CoNi stamp can be easily fabricated by using anti-adhesion layer depotision and stress free electrodeposition.
- ❖ This process enables us to cost effectively produce metal nano stamp.



Si Mother Mold vs. Reproduced Stamp

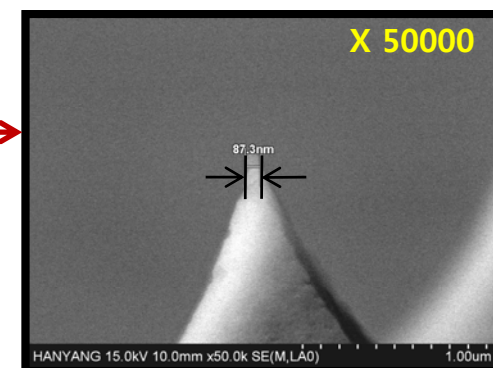
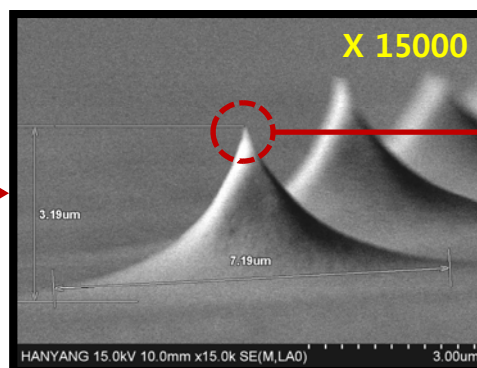
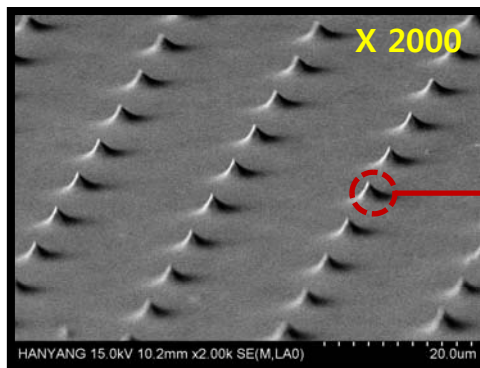
Si mother mold



- Height : 3.08 um
- Width of bottom : 7.12 um

- Width of top : 79.4 nm

2nd reproduced CoNi stamp



- Height : 3.19 um
- Width of bottom : 7.19 um

- Width of top : 87.3 nm

➤ The tip size of Si nano mold was about **80nm** and the 2nd reproduced CoNi nano tip was about **87 nm**



Summary

- ❖ The stress free CoNi film were deposited at **the flow velocity of 1~2 m/s** in the electrolyte containing **0.008M Co²⁺**.
- ❖ Anti-adhesion layer **makes it easy to separate** Si mother mold and reproduces CoNi stamp without sacrificing Si mother mold.
- ❖ We fabricated 140 x 140 mm² electroforming mold which has 80 nm size nano patterns by using **anti-adhesion layer deposition and stress free electrodeposition**.



Thank You for Your Attention

