工業技術研究院
Industrial Technology
Research Institute

Cost-effective FleXAs Mold into the R2R process feasibility development

Speaker : Dr. Hsin Chu Chen (陳信助)

Flexible Electronics Division (軟性電子組)
Electronic and Optoelectronic System Research Laboratories (電光與電子系統研究所)

E-mail : chenhc@itri.org.tw

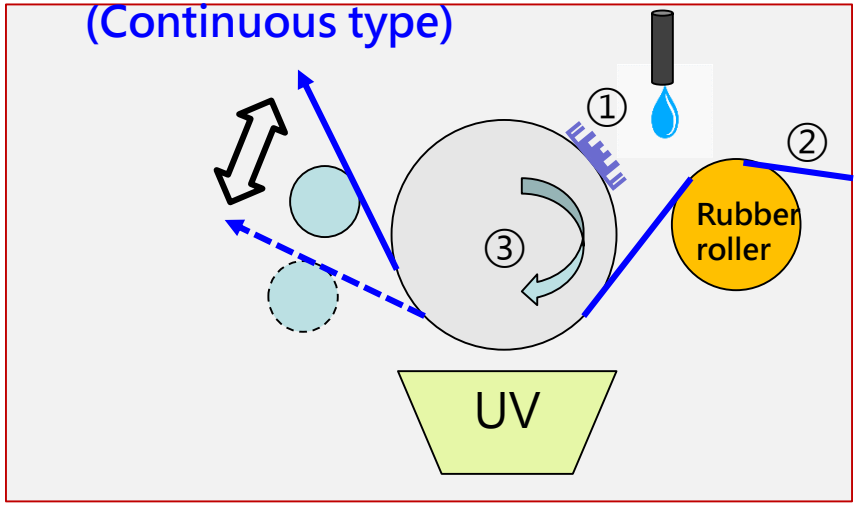
Sep. 9th, 2019

Outline

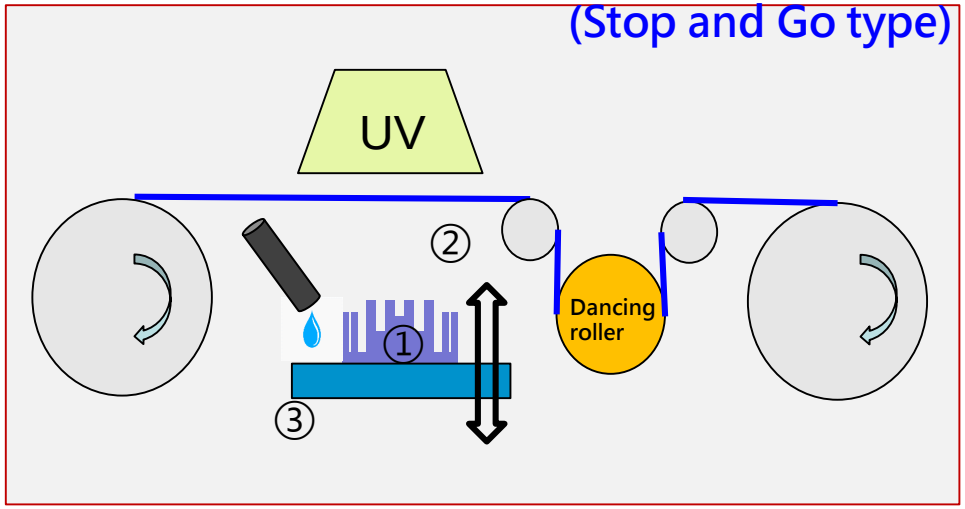
- Identify key factor : S2S to R2R process entrancement
- Collaboration Structure
- Process flow discussion
- Summary

Identify key factor : S2S to R2R process entrancement

R2R lamination equipment (Continuous type)



R2R lamination equipment (Stop and Go type)



Key factor:

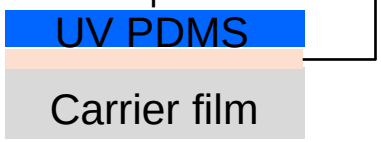
① FleXARs Nickel Mold

Silcon Mold (NECTEC)

FleXARs Nickel Mold (ITRI)

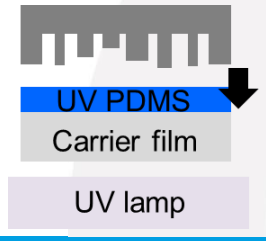
② Adhesion between of PDMS and Carrier film

Robust of Diploe-Diploe interaction development

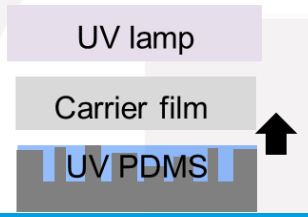


③ UV PDMS integration lamination process

Normal type S2S lamination



Reverse type S2S lamination



Collaboration Structure :

Target : FleXARs Nickel Mold into R2R Process Development

ITRI
NECTEC

*Base on S2S process develop progress

ITRI/NECTEC

FleXARs Nickel Mold development

- Si-mold with FleXARs microstructure: Micro pillar, C-RESS ,and Hexagonal guard ring (NECTEC)
- DoE of FleXARs Nickle mold including AR=1.5, AR=2.0 (target), and AR=3.0, 4.0 (Challenged target)

NECTEC

S2S process development

- UV PDMS on FleXARs Nickle mold fabrication
- UV PDMS with FleXARs Nickle mold laminate to Carrier film by S2S process
- FleXARs film with AR ≧ 2.0 Baseline process creation
- Process PQC
- Prototype fabrication

ITRI

S2S process transfer to R2R process feasibility verification

- UV PDMS on FleXARs Nickle mold with protection film (NECTEC)
- R2R process design base on S2S process
- R2R process tuning (film tension; film alignment; dynamic patterning)
- Prototype fabrication (Width=8cm;Length≦1M)

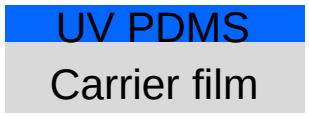
Process flow 1-1 : FleXARs Nickel Mold & S2S lamination (Normal type) Development

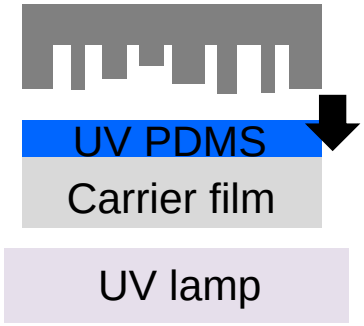
ITRI
NECTEC

FleXARs Silcon Mold (NECTEC) → FleXARs Nickel Mold (ITRI) → UV PDMS on Carrier Film (NECTEC) → S2S lamination (NECTEC)

FleXARs pattern (Negative)

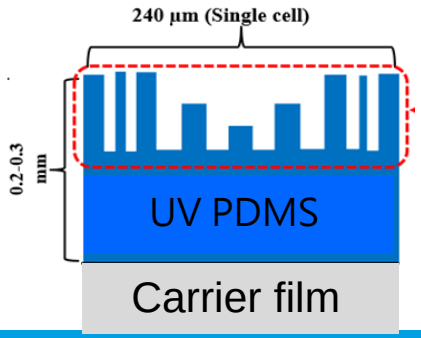
FleXARs pattern (Positive)





De-boding process (NECTEC) → FleXARs on Carrier Fim (NECTEC)

FleXARs pattern (Negative)



Technology Challenges

1.Nickel Mold and Transfer Film Pattern:
→AR=5.0
→Height ratio=1:20
2.Adhesion between PDMS and Carrier film
3.FlexARs pattern may be fillet due to a small amount of air in the FleXARs transfer mold.

Process flow 1-2 : FleXARs Nickel Mold & S2S lamination (Reverse type) Development

ITRI
NECTEC

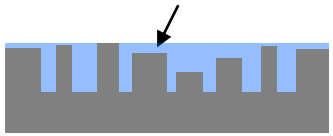
FleXARs Silcon Mold (NECTEC) → FleXARs Nickel Mold (ITRI) → UV PDMS on Nickel Mold (NECTEC) → S2S lamination (NECTEC)

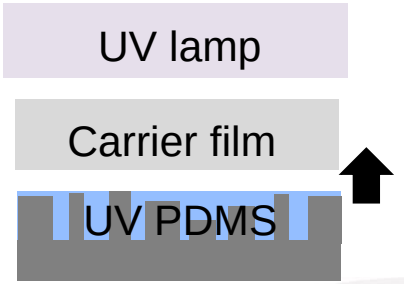
(Reverse type)

FleXARs pattern (Negative)

FleXARs pattern (Positive)

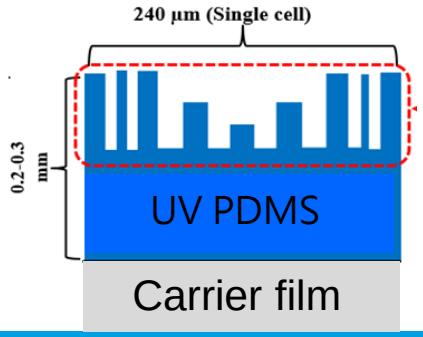
UV PDMS





De-boding process (NECTEC) → FleXARs on Carrier Fim (NECTEC)

FleXARs pattern (Negative)



Technology Challenges
1.Nickel Mold and Transfer Film Pattern: →AR=5.0 →Height ratio=1:20 2. Adhesion between PDMS and Carrier film

S2S process transfer to R2R process flow

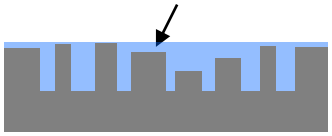
ITRI
NECTEC

FleXARs Silcon Mold (NECTEC) → FleXARs Nickel Mold (ITRI) → UV PDMS on Nickel Mold (NECTEC) → Protection Film add (NECTEC)

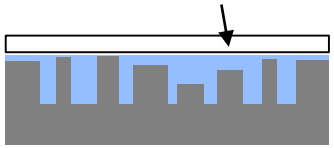
FleXARs pattern (Negative)

FleXARs pattern (Positive)

UV PDMS

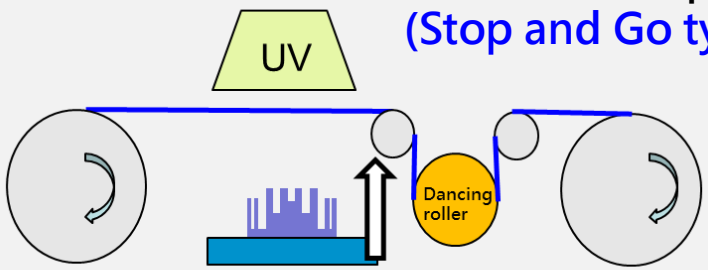


PF add



R2R process verification (ITRI)

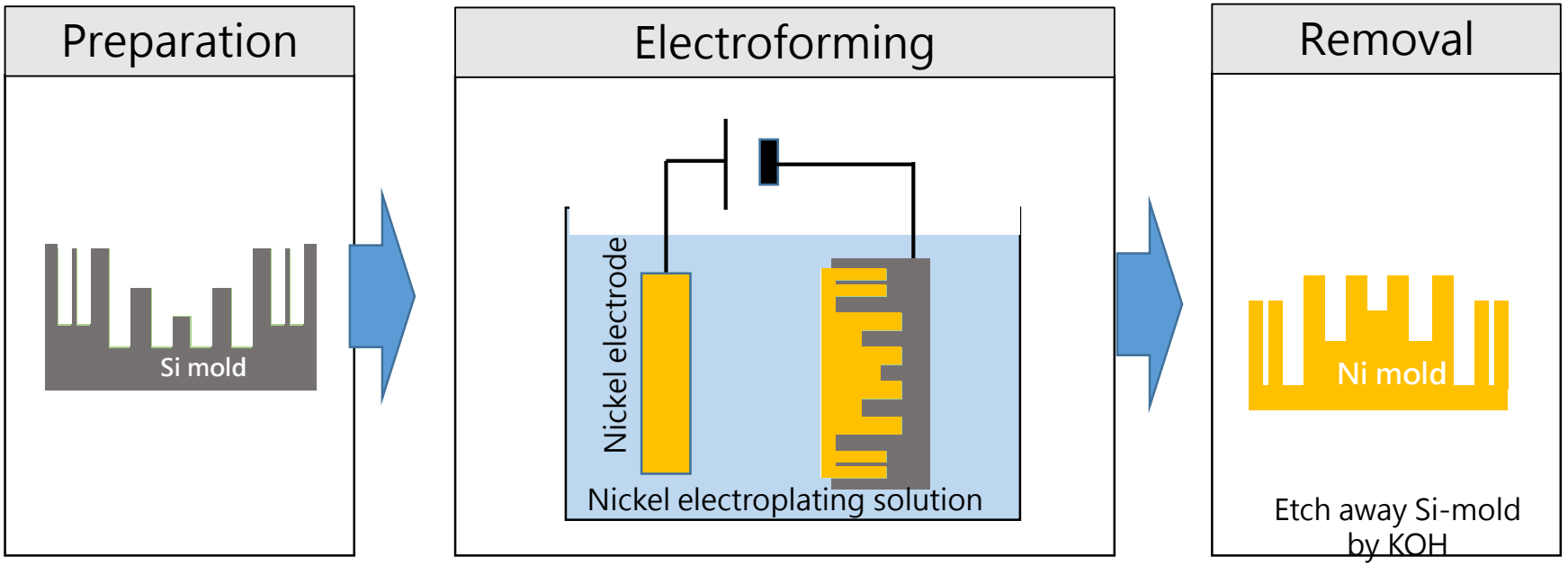
R2R lamination equipment (Stop and Go type)



Technology Challenges

1.UV PDMS on Nickel Mold with PF adding
2.R2R process tuning
→Lamination pressure
→Dynamic lamination
→Alignment
→FleXARs pattern quality after winder process

Nickle mold fabrication process flow



[Master mold]

- Master Si-mold lithography preparation
- Mold defect QC
- Particle control

[Key process parameter]

- Cleanliness of chemical bath
- Electrolyte composition adjustment
- Chemical PH balance in the bath
- Current density control in chemical bath

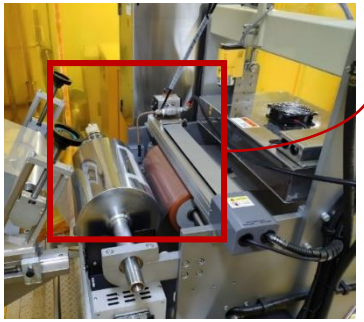
[Nickel mold]

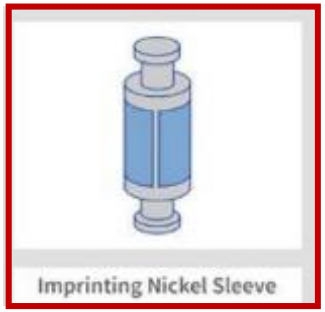
- Mold quality QC
- feature size、robust check

Advantage of Nickle mold in R2R process

lamination working mold / Compare item		Silicon mold	Nickel mold	PDMS mold
1	Cost	× High (by Litho.)	△ Middle (replica)	◎ Low (replica)
2	Durability	◎ High	◎ High	× Low
	-Hardness	*~1000 Hv*	*~600 Hv*	*~150 Hv*
	-Young's module	*165 GPa*	*~200 Gpa*	*~2 Mpa*
	-process damage (ex: UV or thermal)	*Low*	*Low*	*High*
3	Flexible feasibility for R2R process	×	◎	◎
	Final Rank	3	1 (best)	2

R2R compatible

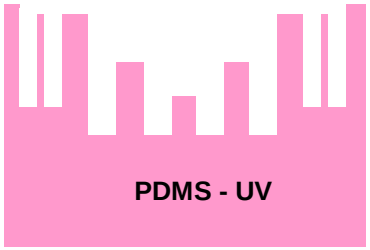
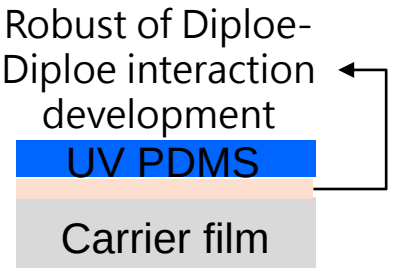
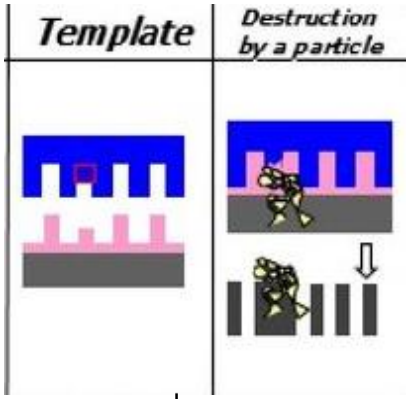
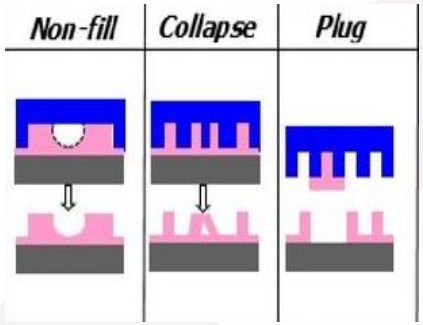
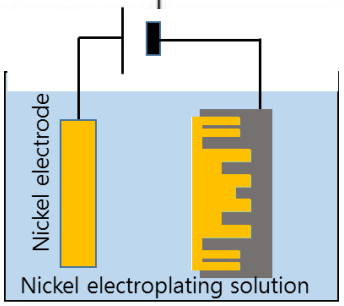




Nickel mold :

Mass production on flexibility and durability !!

Summary of Technology Challenges

FleXARs Nickel Mold process		S2S lamination process	
Item	Pic.	Item	Pic.
1. AR~5.0		1. AR~5.0	
2. High ratio = 1:20		2. High ratio = 1:20	
3. Particle control		3. Adhesion with carrier film (interface)	
4. Mold defect (error rate %)		4. Particle control	
5. Chemical bath PH balance & Current density control in chemical bath		5. Process window - UV dose - pressure - de-Nickel mold	

Collaboration Working Items and Schedule

*Base on S2S process develop progress

ITRI/NECTEC
FleXARs Nickel Mold development

NECTEC
S2S process development

ITRI
S2S process transfer to R2R process feasibility verification

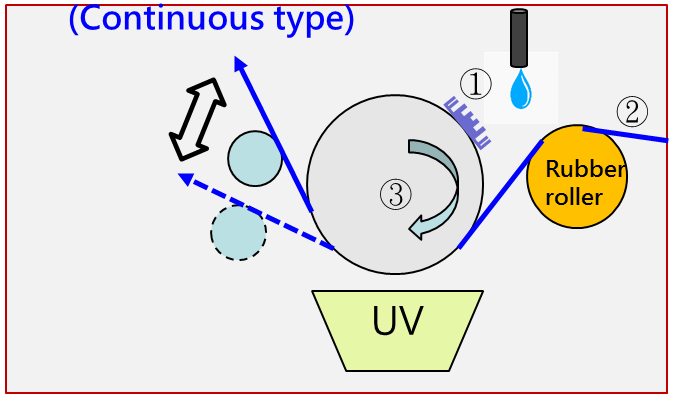
ITRI
NECTEC

Phase 1 | Phase 2 | Phase 3

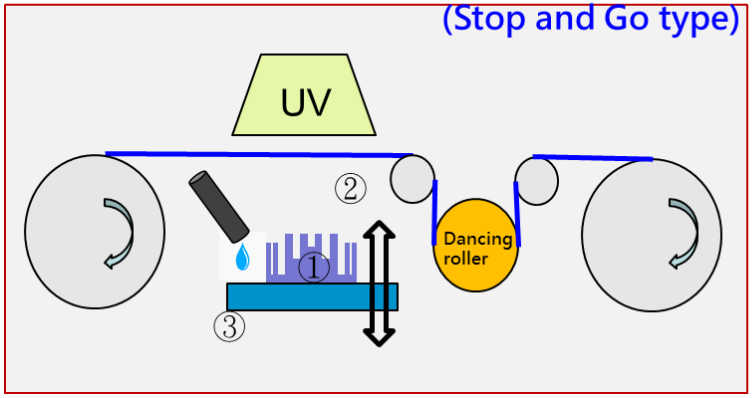
	2019				2020					
	9	10	11	12	1	2	3	4	5	6
FleXARs Nickel Mold development (ITRI) & Material and S2S process testing (NECTEC)	1st FleXARs Si-Mold	DoE of FleXARs Nickel Mold								
S2S process development (NECTEC) -Process baseline creation -Scratch and durability test		UV-PDMS, Carrier Film, and S2S process testing				2nd FleXARs Si-Mold	FleXARs Nickel Mold Fixing	S2S process fixing		
S2S process transfer to R2R process feasibility verification (ITRI)				S2S process transfer to R2R NECTEC provide the UV PDMS on FleXARs Nickel Mold			R2R process test & delivery -width=8cm, length≦1M			

R2R related patents from ITRI

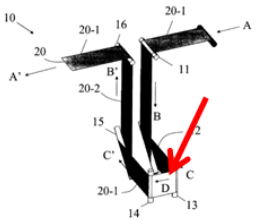
R2R lamination equipment
(Continuous type)



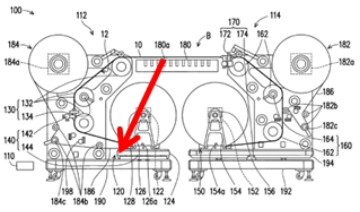
R2R lamination equipment
(Stop and Go type)



Web handling IP

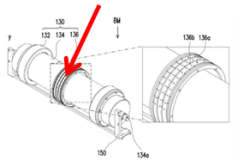


I344934/US7,926,758

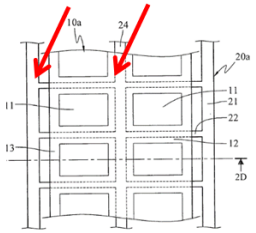


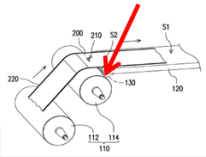
I541185/ZL201310140588.6

Film scratch preventing IP



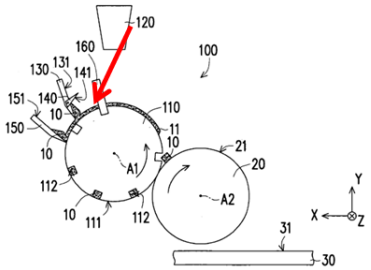
TW106101134/US 9,902,564



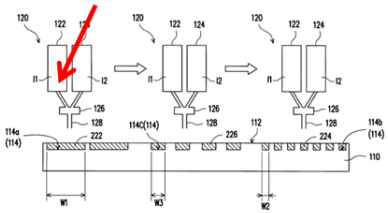


US 8,857,600

Printing material in structure IP

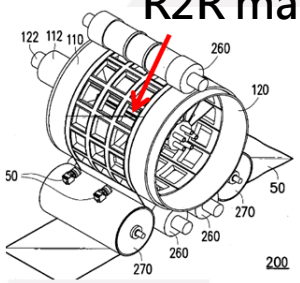


I574846/JP6207668



I574846/JP6207668

R2R mask IP



I555865

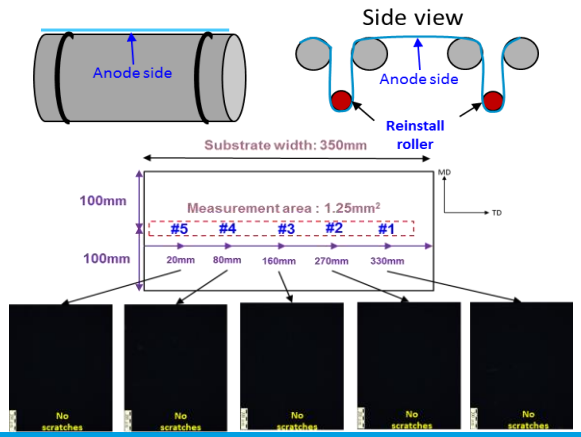
Summary of R2R equipment for mass production

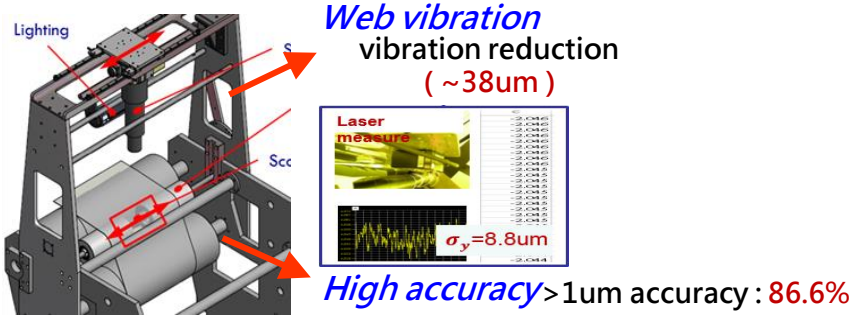
We have high ability and more experience in R2R equipment design.

1. Vibration reducing (tension control & motor selection)
   → Stability of coating, AOI inspection and lamination process

2. Precise alignment in each roller (parallel<100μm)
   → to avoid pattern shifting

3. Design of step roll → to avoid effective area scratch





Thank You for Your Attention!

E-mail : chenhc@itri.org.tw

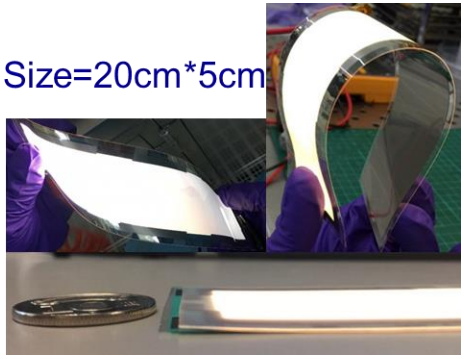
Target Vision of Lab23 at ITRI

Flexible and Printed Electronics Business

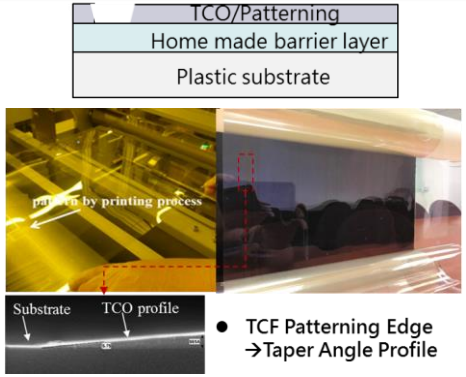
12 sets of R2R equipment with 350 mm web width

Lab23 Open Platforms / Industry Collaboration

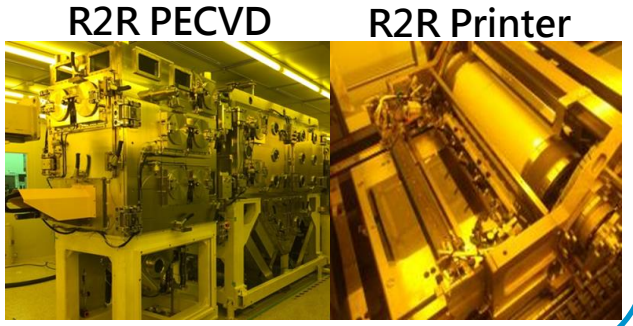
Flexible Substrate Technologies



Multi-Function of Electrode & Pattern



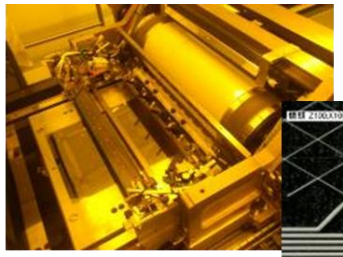
R2R Technologies (Vacuum / Printing)



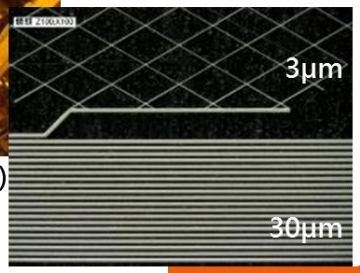
R2R Technologies (Vacuum / Printing)

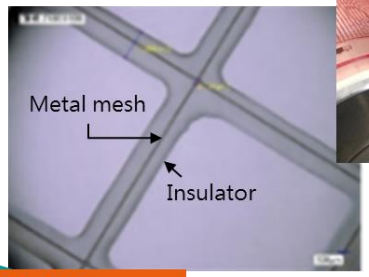
Technology provides:

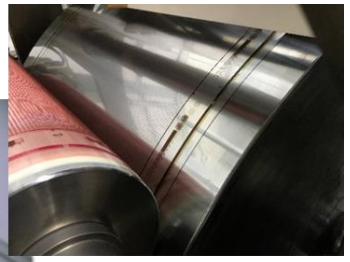
- Multi-layer substrate with interface design (thin glass/plastic substrate handling)
- Customized printing (line width from 3μm to >100μm)
- Hydrophobic and Moisture barrier solutions



(R2R Gravure printer)







(R2R Flexographic Printing)

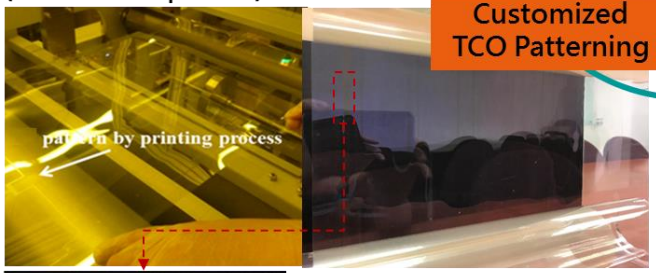
Fine Line Metal Meshes

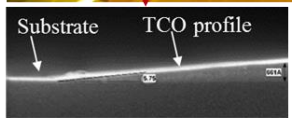
Multi-Layer printing

Customized TCO Patterning

Plasma treatment

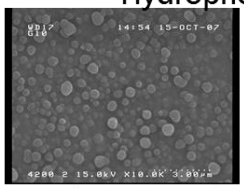
(R2R Screen printer)

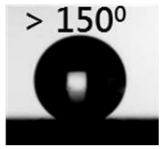




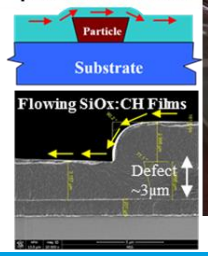
- TCF Patterning Edge
  →Taper Angle Profile

Super-Hydrophobicity





Surface planarization

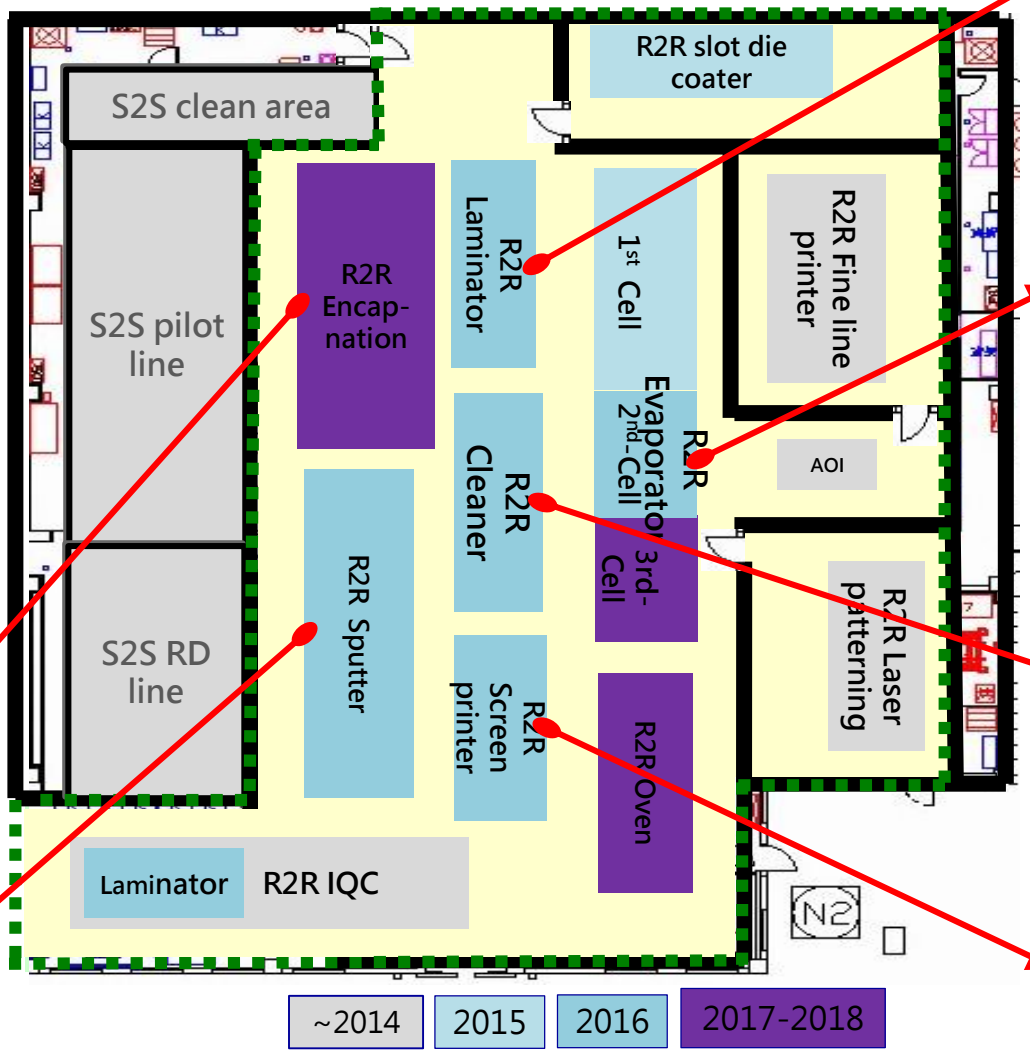


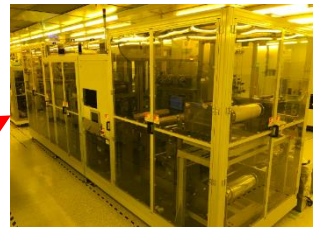
(R2R PEVCD)

Process Equipment @ R2R Platform

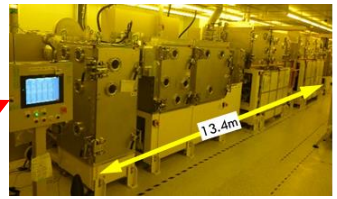
12 sets of R2R equipment with 350 mm web width

- Slot die coater
- Gravure offset printer
- Laser patterning
- Evaporator
- Cleaner
- Oven
- Laminator
- Screen printer
- PECVD
- Sputter
- IQC tester
- Puncher





R2R Laminator
(2016-2017)

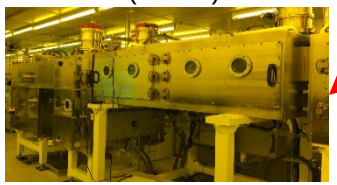


R2R Evaporator
(3 Tandem Cell)
(2015~2017)

R2R Cleaner
(2016-2017)

R2R Screen Printer
(2016-2017)

R2R PECVD
(2017)

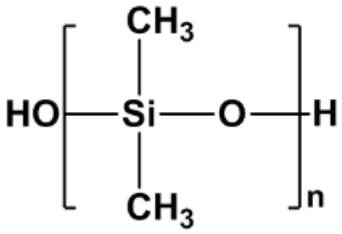


R2R Sputter
(2017)

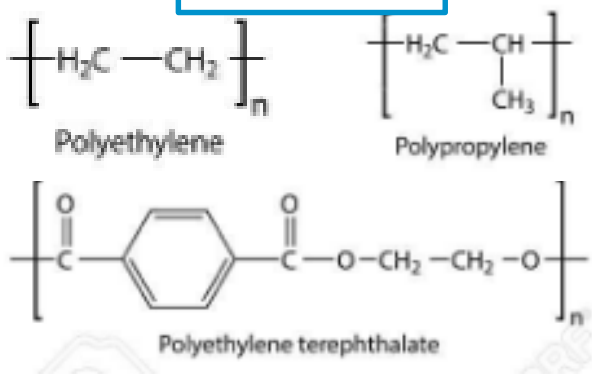
Process flow 2 : Adhesion of PDMS and Carrier film Development

Step 1
Carrier Film testing

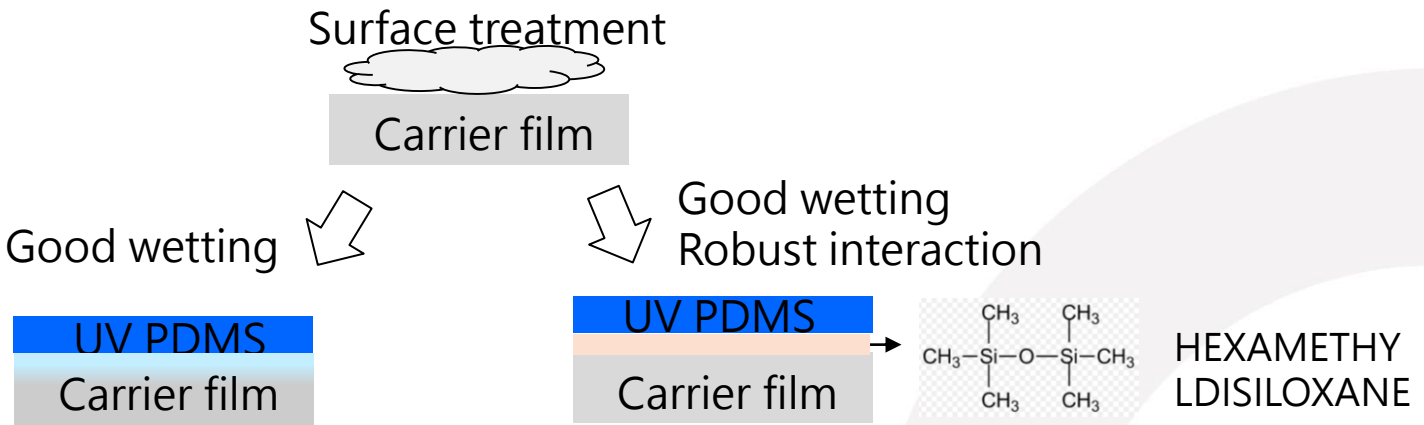
Material
UV-PDMS



Carrier
Film



Step 2
Robust of Diploe-Diploe interaction development



Budget	Technology difficulty
PECVD cost	PECVD coating tuning

DoE of Nickle Mold fabrication (ITRI)

Purpose :

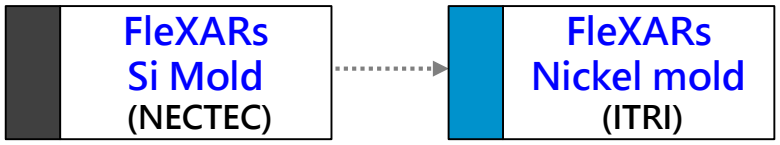
(1) Transfer the original Si-mold to more durable Ni-mold

(2) Confirm the suitable AR ratio for 3 kinds of imprint structure by checking the mold defect

Discuss :

(1) DoE test require 2~6 Si – molds

Imprint Pattern DoE				
Structure	***Factor***	***Parameter (AR)***		
• Micro pillar • C-RESS	CD=1.0um ; Space=1.0um	AR= 1.5	AR= 2.0	AR= 3.0
Hexagonal guard ring	CD=20um ; Space=20um	AR= 2.0	AR= 3.0	AR= 4.0



FleXARs pattern (Negative)

FleXARs pattern (Positive)

Si - mold

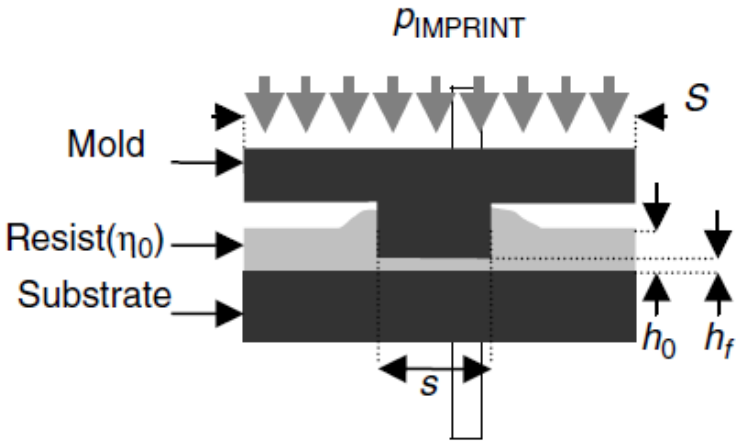
Ni - mold

Quality check					
L/S ; AR	***Mold defect***				
	Non-fill	***Collapse***	***plug***	***template***	***particle***
(1/1 ; 1.5)					
(1/1 ; 2.0)					
(1/1 ; 3.0)					
(20/20 ; 2.0)					
(20/20 ; 3.0)					
(20/20 ; 4.0)					

Modeling of the thermal nanoimprint process

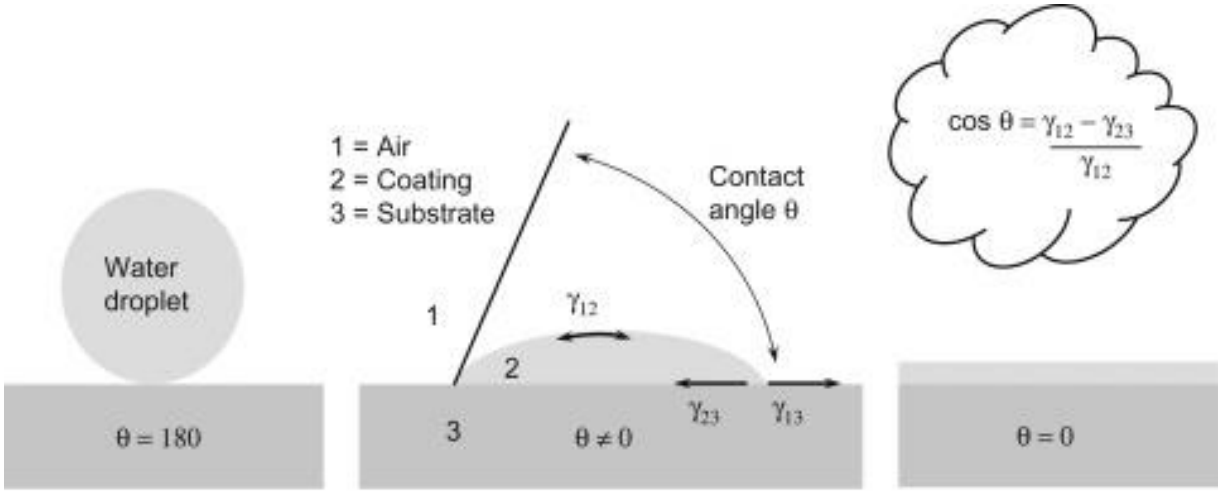
Stefan's equation

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



$p = p_{IMPRINT}\, S/s$

η_0 : the zero shear viscosity of the resist
s : the width of the line
h_0 : the initial resist layer thickness
h_f : the final resist layer thickness (residual layer)
p : the effective imprinting pressure on the line



Non-wetting
e.g. Hydrophobic

γ_{12} = Energy at interface between air and coating
γ_{13} = Energy between air and substrate
γ_{14} = Energy between coating and substrate

Wetting
e.g. Hydrophillic

$\gamma_{13} + \gamma_{12} < \gamma_{23}$

$-1 < \frac{\gamma_{13} - \gamma_{12}}{\gamma_{12}} < 1$

$\gamma_{13} - \gamma_{23} > \gamma_{12}$

Ideally, γ_{13} wants to be as high as possible with γ_{23} as low as possible.
The system will want to form with the minimum total energy