22ND INTERNATIONAL CONFERENCE & EXHIBITION ON
DEVICE PACKAGING
SHERATON GRAND AT WILD HORSE PASS PHOENIX, AZ
MARCH 2-5, 2026 • WWW.DEVICEPACKAGING.ORG

Ultra-Thick PR Patterning for High Aspect Ratio Fine Pitch Cu Pillars Enabling Advanced LPDDR Packaging

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Outline

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2. Experimental

A. PR Materials

B. Litho Simulation

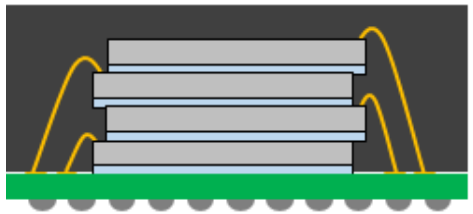
C. i-line PR Patterning

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1. Introduction

- **On-device AI demands higher I/O density and wider memory bandwidth within limited package area.**
- **Conventional i-line PR struggles to achieve stable high-AR patterning beyond 200 µm thickness**
  : fundamental challenges in simultaneously achieving high resolution and straight vertical profiles in thick PR
- **We optimize PR transmittance and exposure NA to enable ultra-thick, high-AR Cu pillar integration.**

	Advanced Package	Conventional Package
		
Interconnection	Cu Pillar	Gold Wire
Memory Stack	≥ 4H	≥ 4H
I/O Count	x 512	≤ x 64
I/O Pad Pitch	≤ 50㎛	≥ 60㎛
Total Package Height (*Normalized)	x 0.4	1

2. Materials : i-line Negative PR for Packaging

■ Radical cross-linking negative PR was used due to depth-tolerant cross-linking and mechanical stability.

Table. PR materials for Ultra-thick PR

Tone	Negative		Positive	
Type	**Radical Type**	**Cationic Type**	**CAR**	**DNQ**
Primary chemistry	Radical cross-linking	Acid-driven cross-linking	Acid-catalyzed Deprotection	DNQ/Novolac dissolution
Reaction Initiation	Photo radical generation	Photo Acid generation +PEB	Photo Acid generation + PEB	Direct photo-decomposition
Depth-wise Response (UV attenuation)	🟡 Moderate (Threshold base)	🔴 Top dominant (Acid diffusion length limit)	🟡 CD Blur (Strong acid diffusion)	🔴 Top dominant (UV intensity dependency)
Bake dependence	🟢 Low	🔴 High	🔴 High	🟢 Low
Mechanical stability	🟢 High	🟢 High	🔴 Low	🔴 Low
Applicability to Thick PR(>100㎛)	🟢 Advantage	🟡 Limited	🟡 Limited	🟡 Limited
Typical Use	Cu Pillar, Bump, RDL	Specialty coatings (Thick permanent coating, MEMS, etc)	Bump, RDL	Pad, RDL

2. i-line Litho Simulation & Patterning

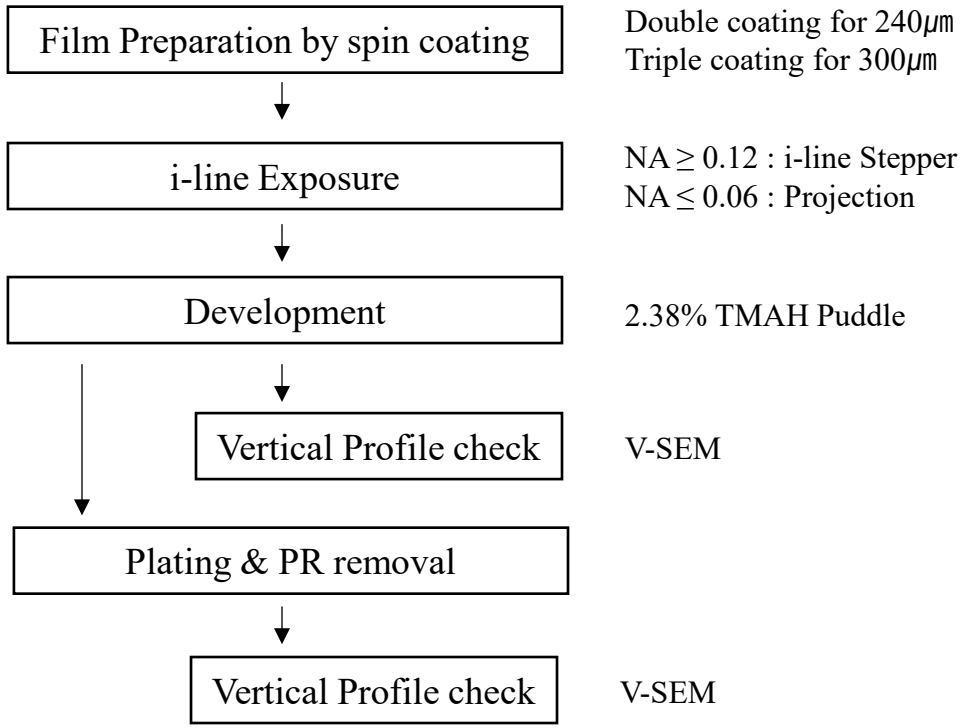
■ **To minimize depth-wise CD variation in thick PR,**

①Material(i-line transmittance) and ②Process condition(Lower NA exposure) were investigated.

Table. Simulation Parameters

PR Type		**Radical type negative PR**
Simulation Tool		LAB (GenlSys)
Simulation Parameters	Underlying layer	Ti/Cu Seed Metal
	Wavelength	365nm(i-line)
	Develop type	2.38% TMAH
	PR Thickness	240㎛, 300㎛
	i-line Transmittance (Normalized)	4 grades (0.3, 0.5, 0.7, 1.0)
	NA	0.15, 0.12, 0.10, 0.06, 0.04
	Mask Pitch	50㎛
	Mask CD	30㎛

Figure. Patterning Process Flow



3. Simulation on i-line Transmittance

- **Top CD remained nearly constant, but bottom CD exhibited non-monotonic dependence on transmittance.**
- **This indicates that radical-type negative PR bottom operates in a threshold-limited regime.**

Table. Simulation parameters on PR transmittance

Simulation Tool		LAB (GenlSys)
Simulation Parameters	PR Thickness	240㎛
	i-line Transmittance (Normalized)	4 grades (0.3, 0.5, 0.7, 1.0)
	Wavelength	i-line(365nm)
	Exposure NA	0.15
	Dose	1100, 1500 mJ/cm2 (Focus -30㎛)
	Development	720sec(2.38% TMAH)
	Mask Pitch	50㎛
	Mask CD	30㎛

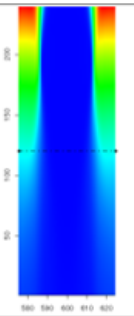
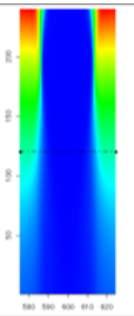
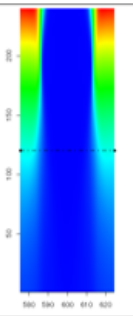
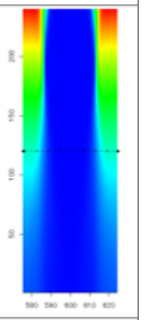
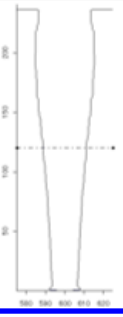
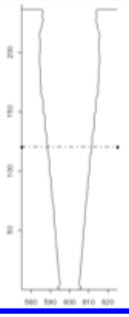
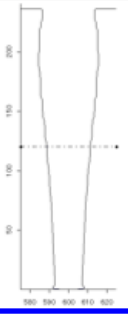
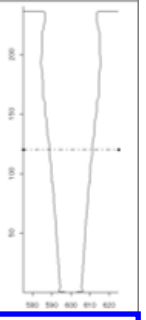
PR	PR-1	PR-2	PR-3	PR-4
Normalized i-line Transmittance	1.0	0.7	0.5	0.3
Normalized Dose	1	1.4	1.4	1.4
Optical image				
After development				
Top CD	30.5	30.5	29.9	30.5
Bottom CD	14.4	9.1	14.3	10.6
Top/Bottom CD Ratio	**2.0**	**3.2**	**2.1**	**2.8**

Figure. Depth-wise simulation profile according i-line transmittance

3. i-line Patterning according to Transmittance

- **The Most vertical PR profiles were obtained at a transmittance of 0.5 at 240㎛ PR ADI thickness.**
- **This demonstrates the existence of an optimal transmittance window for ultra-thick negative PR.**

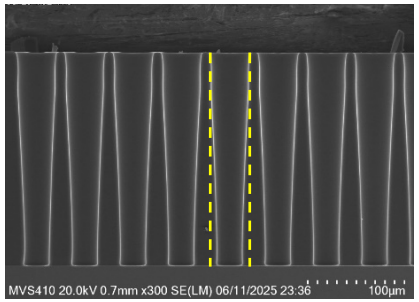
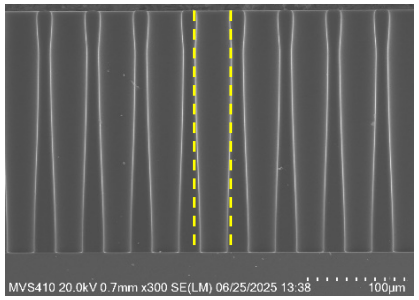
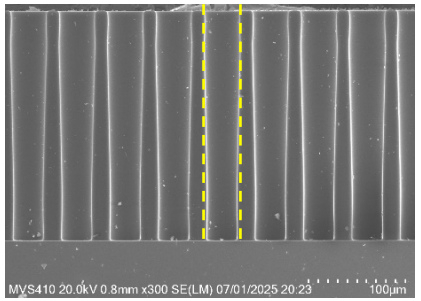
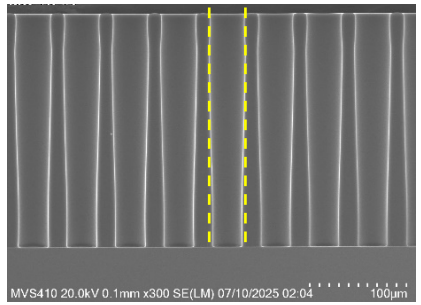
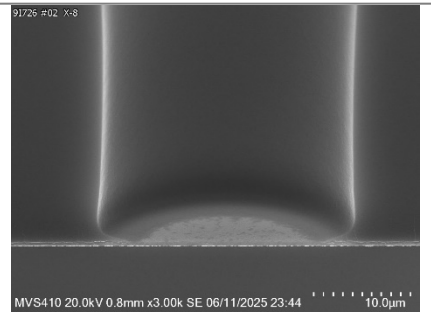
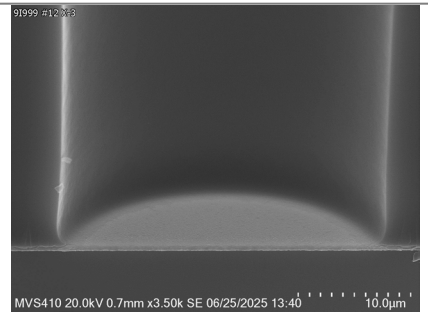
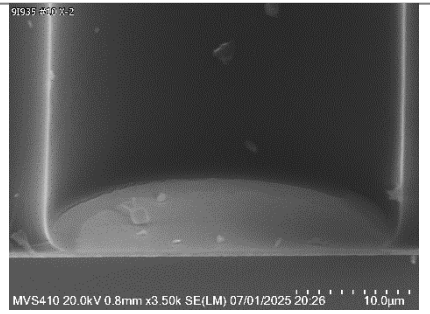
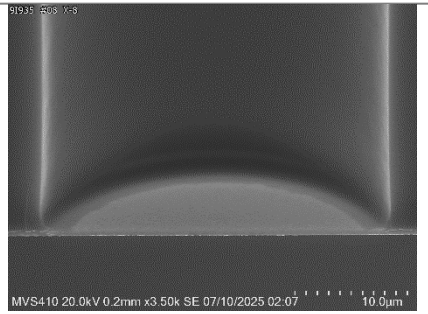
	PR-1	PR-2	PR-3	PR-4
i-line Transmittance* *Normalized	1.0	0.7	0.5	0.3
Top CD [㎛]	37.4	37.0	37.4	37.5
Bottom CD [㎛]	21.4	27.3	30.8	29.7
V-SEM Image				
				

Figure. PR vertical Profile according to i-line Transmittance

3. Simulation on Exposure NA

- **Radical cross-linking begins at approximately 10 mJ/cm2 and PR becomes less soluble in developer.**
- **When NA 0.02, the surface of unexposed area is exposed to >10 mJ/cm2, so it is not dissolved.**
- **When NA ≥ 0.10, the deep part of the unexposed area is exposed, and the rectangularity is reduced.**

Table. Simulation parameters on exposure NA

Simulation Tool		LAB (GenlSys)
Simulation Parameters	PR Thickness	240㎛
	i-line Transmittance*	1.0 *Normalized
	Wavelength	i-line(365nm)
	Exposure NA	0.02 - 0.18
	Dose	1200 mJ/cm2 (Focus -30㎛)
	Development	600sec(2.38% TMAH)
	Mask Pitch	60㎛
	Mask CD	30㎛

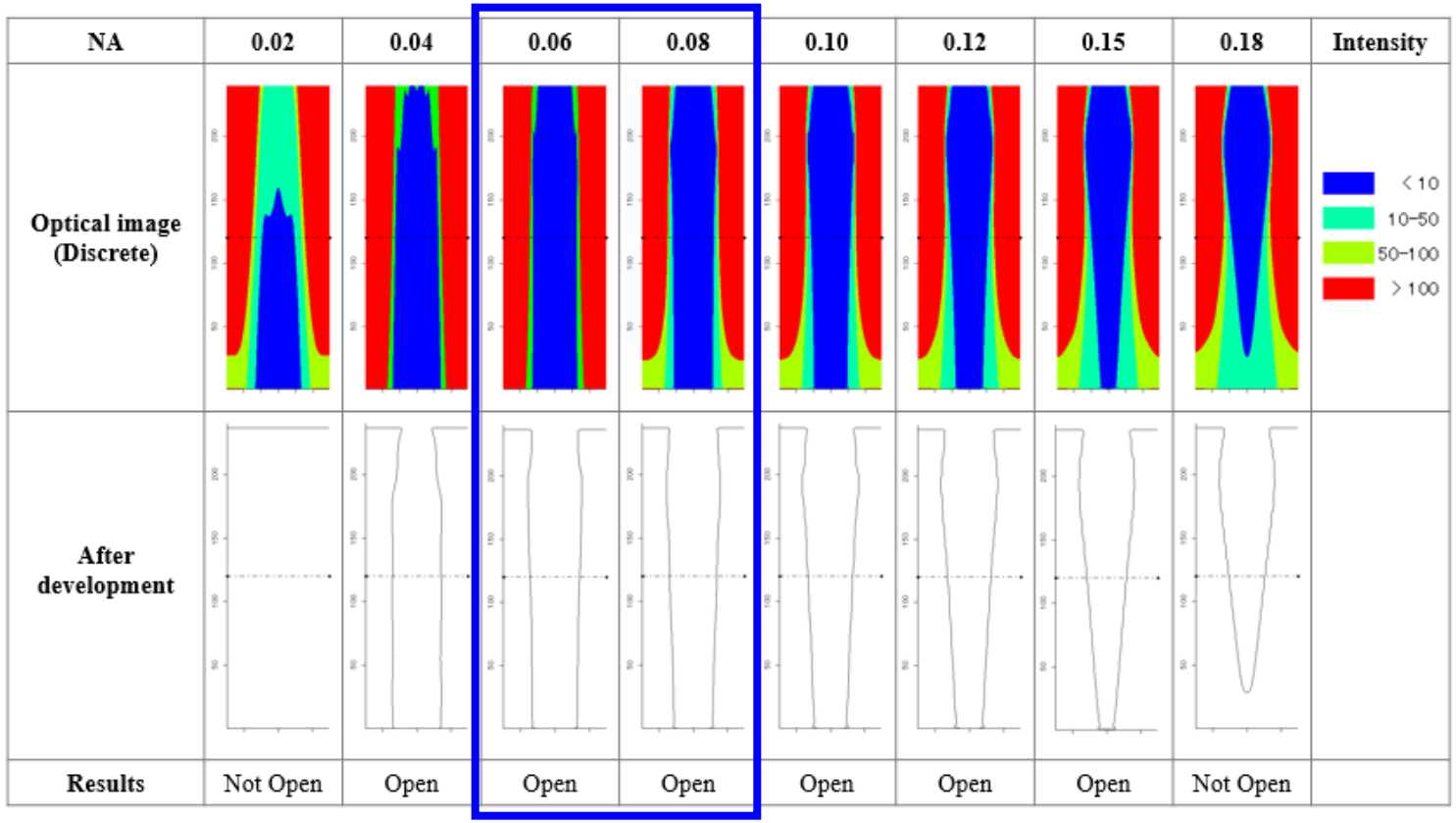


Figure. Depth-wise simulation profile according i-line transmittance

3. Merit and Demerit of Low NA

- **Merit of low NA: Focus margin increases. → High rectangularity of optical images at deep locations.**
- **Demerit of low NA: Resolution decreases. → Low optical contrast between exposed and unexposed areas.**

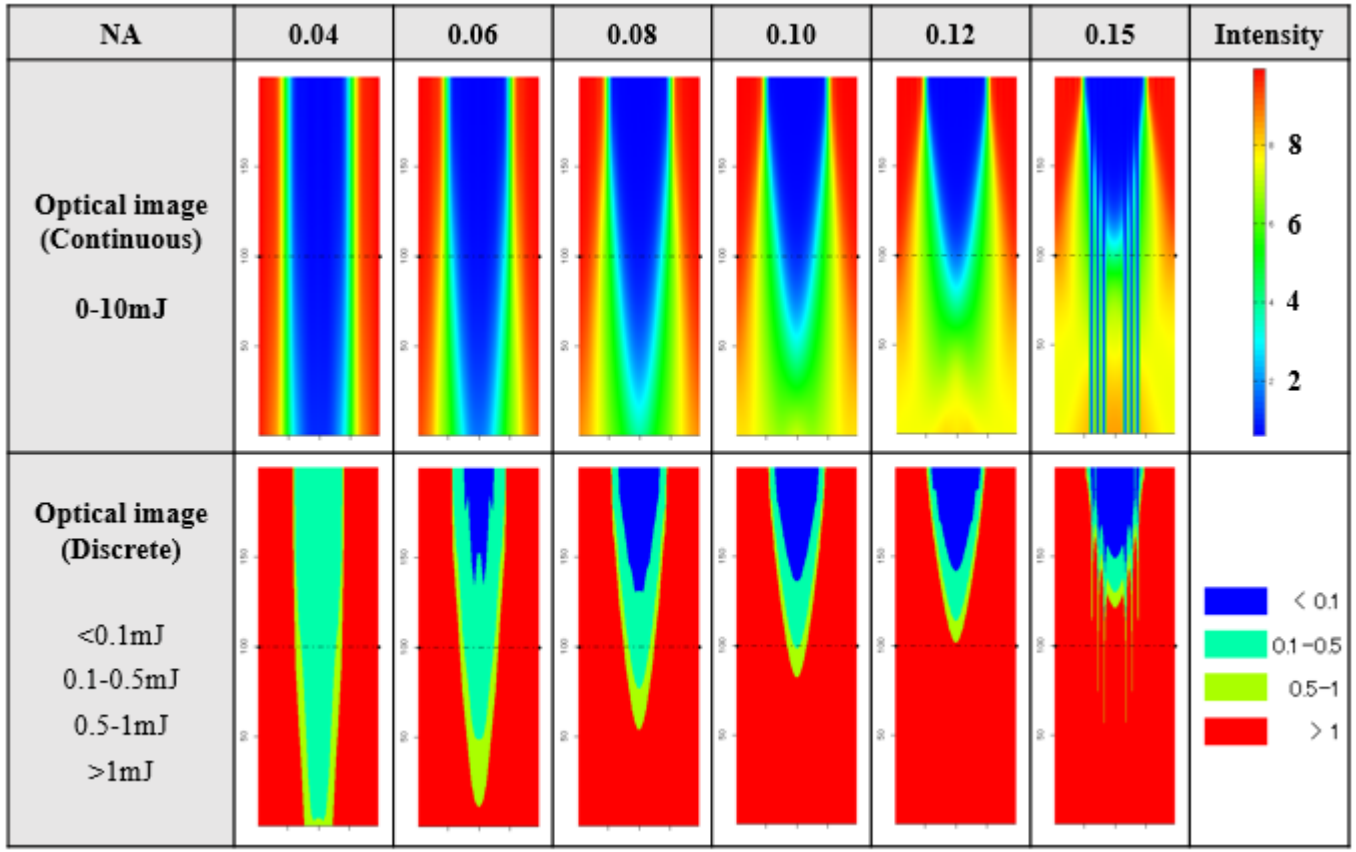


Figure. Litho simulation result on NA Impact on PR optical contrast Gradient

3. i-line Patterning according to NA

- **The most vertical Profiles obtained at NA 0.12, while Further NA reduction resulted in profile degradation.**
- **This indicates that an optimal window exists where DoF benefits are balanced with tool-dependent irradiance and illumination characteristics.**

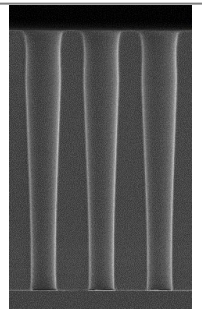
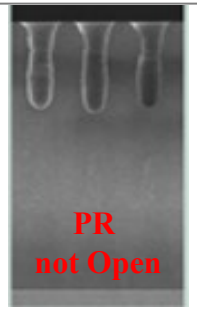
NA		0.15	0.12	0.06	0.04
Exposure Tool		Stepper	Stepper	Projection	Projection
FT 220㎛	Normalized Dose	1	1	0.6	0.5
	PR Profile				
FT 300㎛	Normalized Dose	-	1.4	0.8	0.6
	PR Profile	-			

Figure. PR vertical Profile according to Exposure NA

3. Cu Pillar Formation with Thick PR at NA 0.12

- For the 220 µm-thick PR, fine-pitch patterns with an aspect ratio of 8.1 were successfully formed.
- For the 300 µm-thick PR, high AR patterning with an aspect ratio of >13 were enabled.
- Subsequent Cu electroplating using the optimized PR template resulted in successful Cu pillar formation

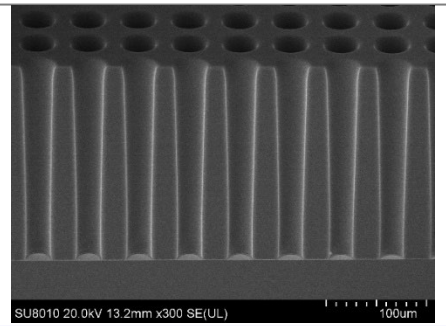
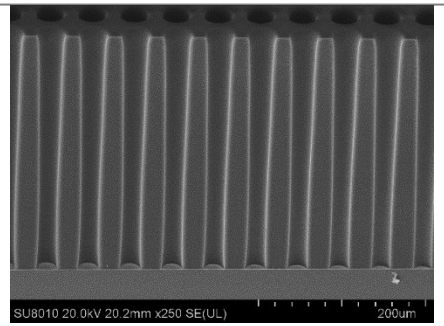
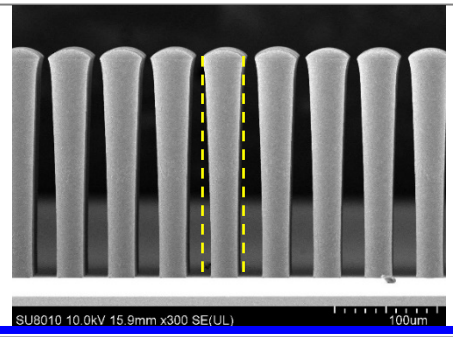
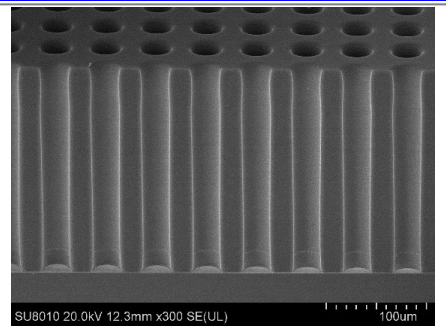
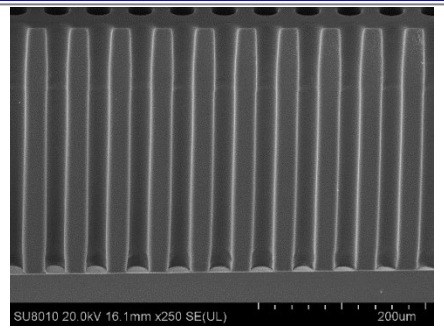
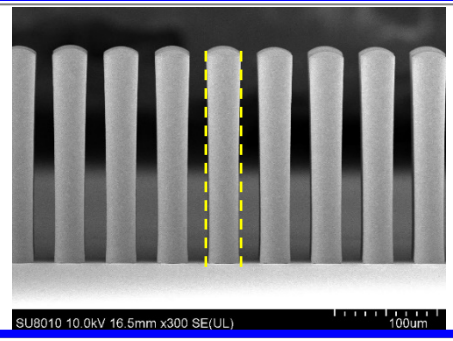
Step	After Development		After Cu pillar formation
Thickness	PR 220µm	PR 300µm	Cu >200µm
Aspect Ratio	8.1	~13	-
PR-1			
PR-3			

Figure. Cu Pillar(>200µmT) Formation with Thick PR

4. Conclusion

◆ Summary

- High AR Ultra-Thick(~300㎛) PR i-line Patterning for Fine Pitch Cu Pillar formation for Advanced LPDDR Packages.

◆ Key Results

1) Lithography simulation enabled predictive evaluation of new PR materials, significantly improving development efficiency.

2) Optimal process window was identified through joint optimization of PR transmittance and exposure NA in thick PR patterning.

3) Within optimized conditions, AR of 8.1 at 220 μm and approximately 13 at 300 μm PR thickness were achieved.

◆ Future Plan

- Assess the feasibility of implementing vertical Cu pillar stack structures in next-generation LPDDR packages.

- Extend ultra-thick PR capability beyond 300 μm to support higher-density memory stacking and bandwidth scaling.