Impacts of Back Grind Damage on Si Wafer Thinning for 3D Integration

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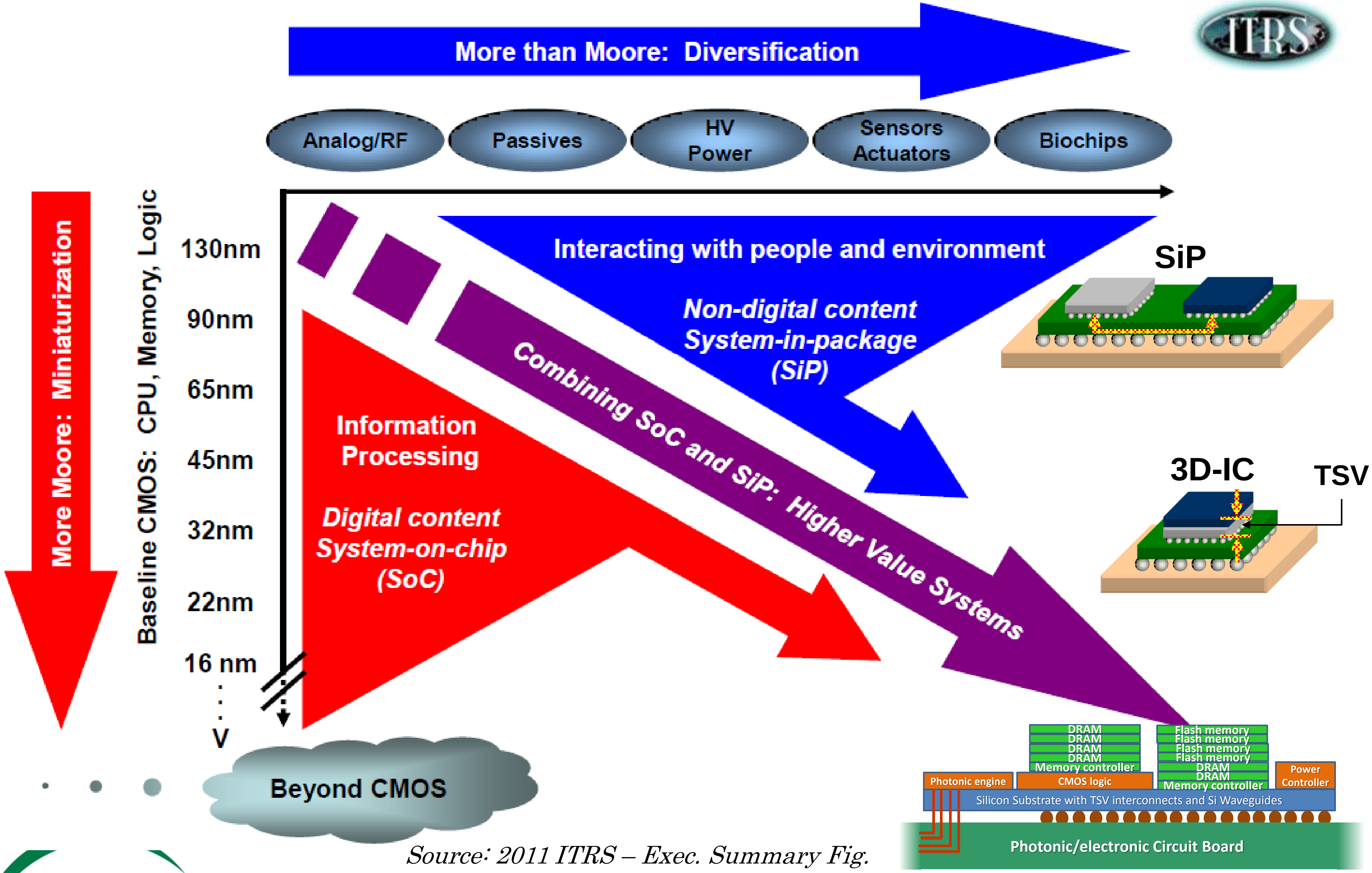
Tokyo Institute of Technology

Outline

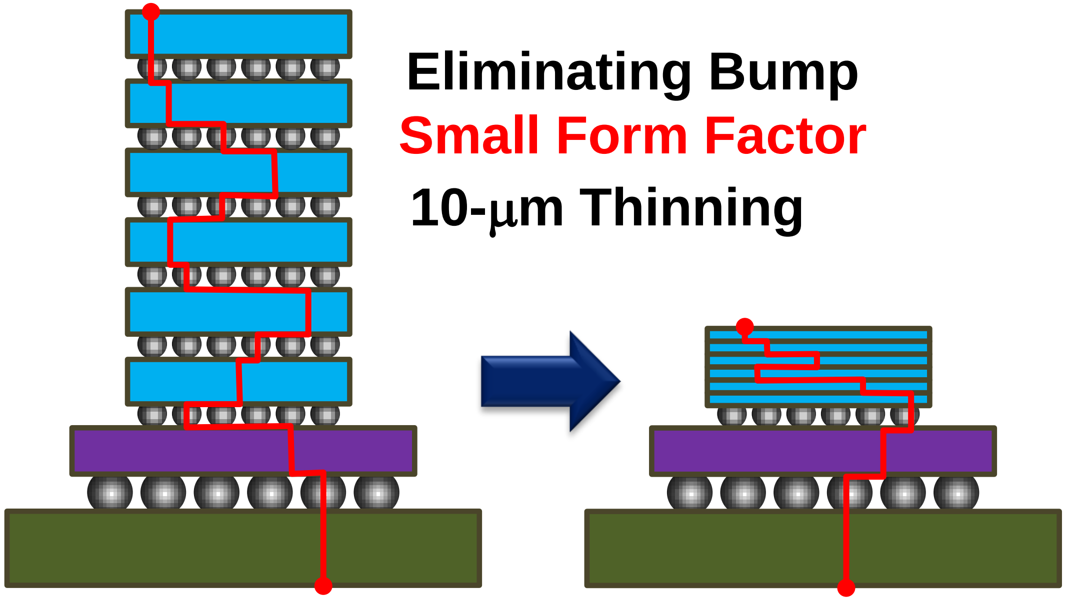
1. Background and motivation
2. Experimental
    - Thinning conditions and characterization
3. Subsurface damaged layers in thinned wafers
    - Impacts of coarse grinding thickness
    - Remaining damages after fine grinding
    - Subsurface structure after CMP
4. Impact of ultra-thinning on device characteristics

3D Integrations for “More than Moore”



Source: 2011 ITRS – Exec. Summary Fig.

Bumpless 3D-IC Structure with Ultra-thinned wafers



Eliminating Bump

Small Form Factor

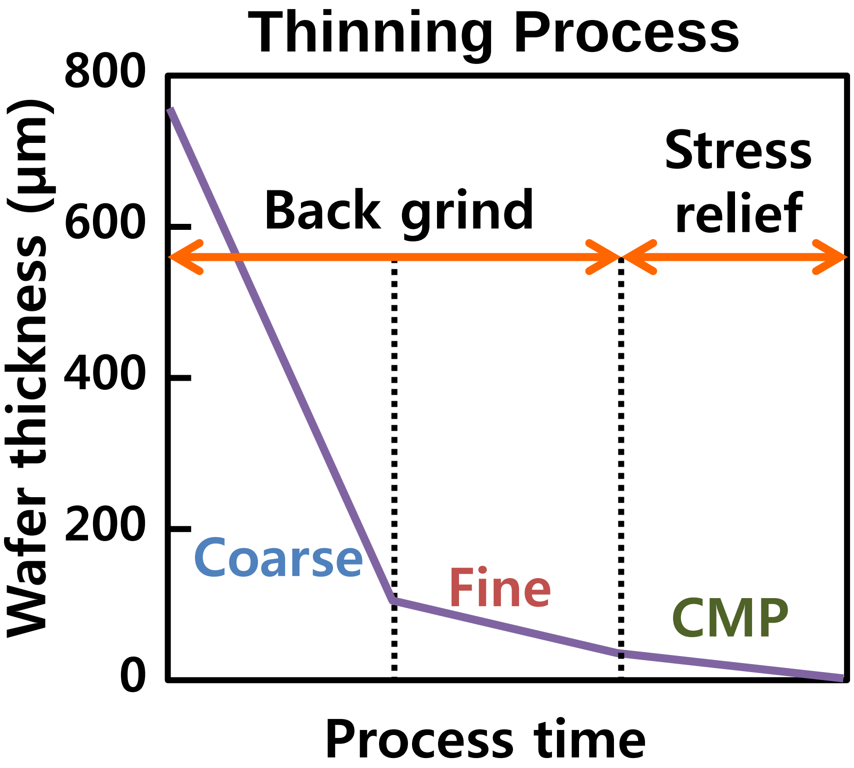
10-µm Thinning

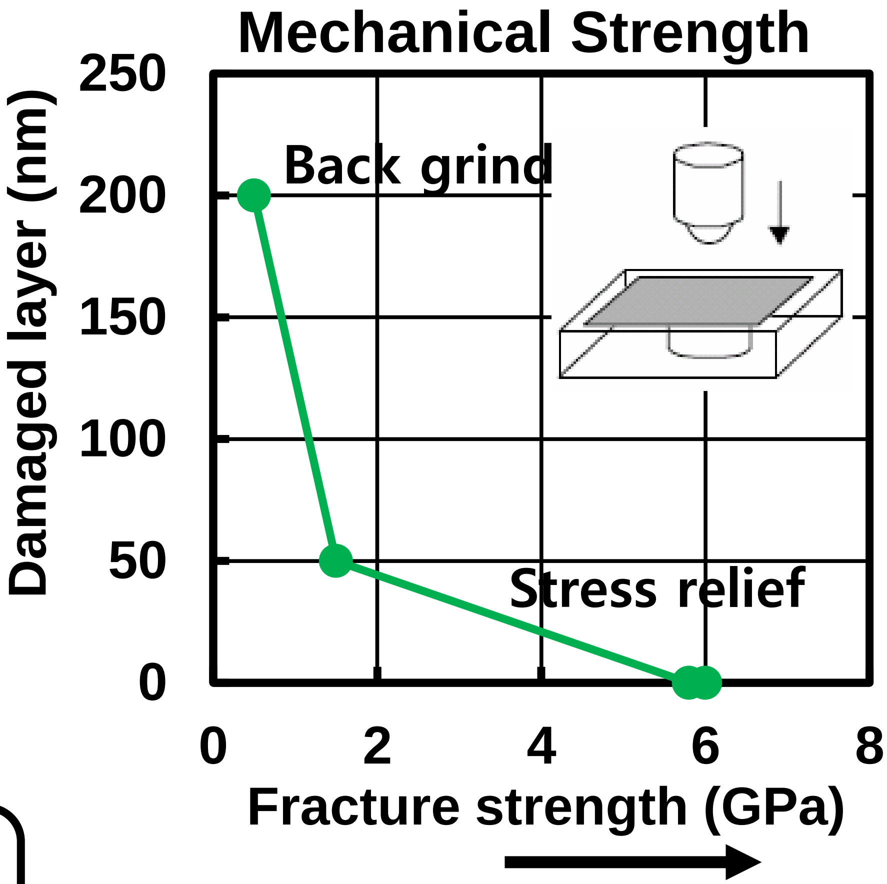
Benefits of 10-µm Thinning

- Low aspect ratio for TSV processing
- Wiring length shortening
- RC delay mitigation
- Low power consumption

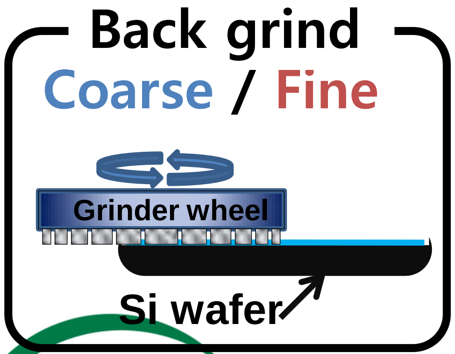
T. Ohba: Microelectron. Eng.2010

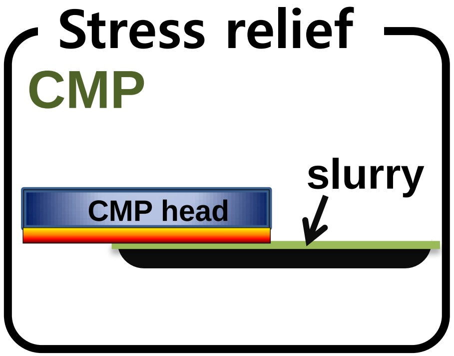
Wafer Thinning by Grinding & Polishing





Gettering ability: weaker





Optimizing coarse- and fine-grinding, and CMP conditions are crucial.

T. Nakamura, Fujitsu Labs.

Motivation

Analyzing subsurface damaged layers caused by thinning;

1. Damages and defects dependence on removed Si thicknesses
2. Impacts of grinding & polishing conditions on the damages
3. Impacts of ultra-thinning on device characteristics
4. Features of the damaged layer; thickness, microstructure, defects, stress etc

Experimental: Sample Preparations

Thinning conditions

Sample No.	Wafer thickness	Grinding thickness (µm)		
		Coarse grind	Fine grind	Stress relief
1	650	125	-	-
	300	475	-	-
	100	675	-	-
	690	75	10	-
2	650	75	50	-
	630	75	70	-
	600	75	100	-
	320	425	30	-
3	300	425	50	-
4	649	75	50	1
	647	75	50	3
5	645	75	50	5

Grinding & Polishing apparatus: DGP8761

	Particle size
Coarse grind	#320
Fine grind	#2000

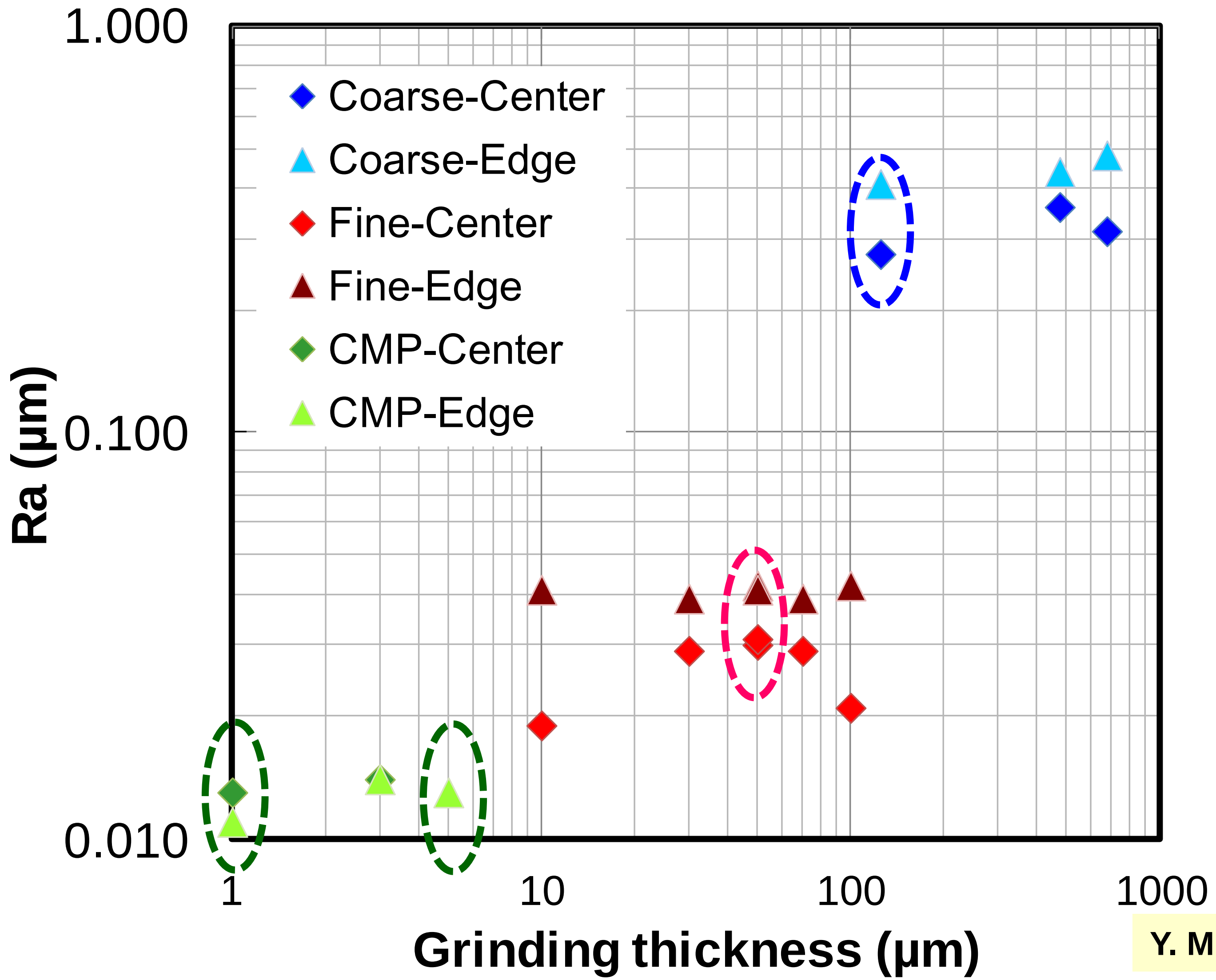
Impacts of coarse-grind thickness on remaining damages

Remaining damages after fine-grinding

Experimental: Damage Analyses

- **Laser microscopy**
  - **Surface roughness: Ra (due to grinding marks)**
- **μ-Raman scattering analysis: 458 nm Ar$^+$ laser, 0.7 μmϕ**
  - **Subsurface structural change: crystalline & amorphous peaks**
  - **Elastic strains & stresses: TO phonon peak shifts**
- **Cross-sectional TEM**
  - **Micro structures & defects in the subsurface: bright field images under the (110) zone axis**
- **Positron annihilation analysis**
  - **Vacancy-type defects: S parameters in Doppler broadening spectra**

Grinding Thickness Dependence of Ra

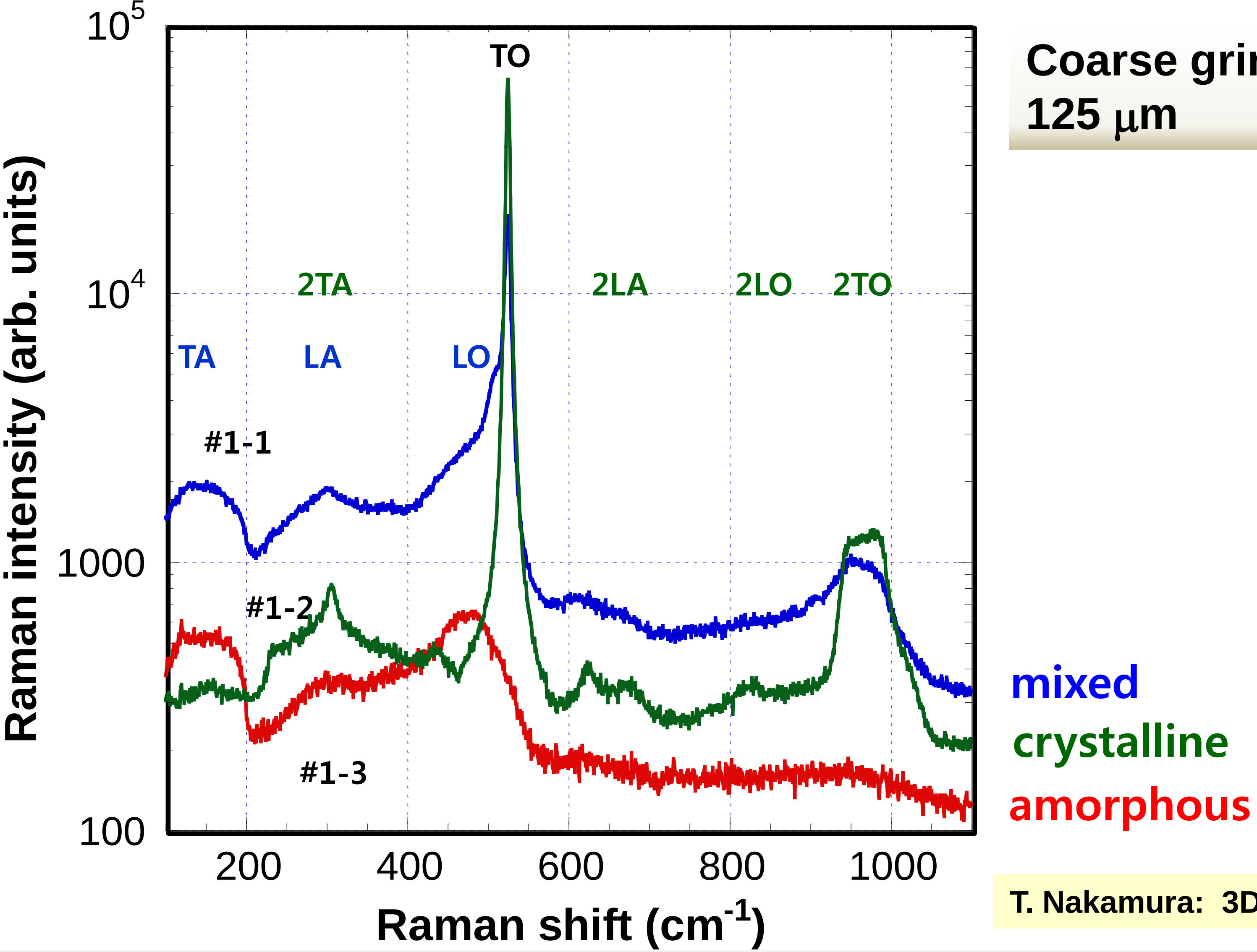


Y. Mizushima: JJAP2014

- ✓ **Ra; Surface roughness depends on the grinding abrasive condition**
- ✓ **Removed thickness dependence is smaller than in-plane variations**

Raman Spectra from Coarse-grind Subsurface

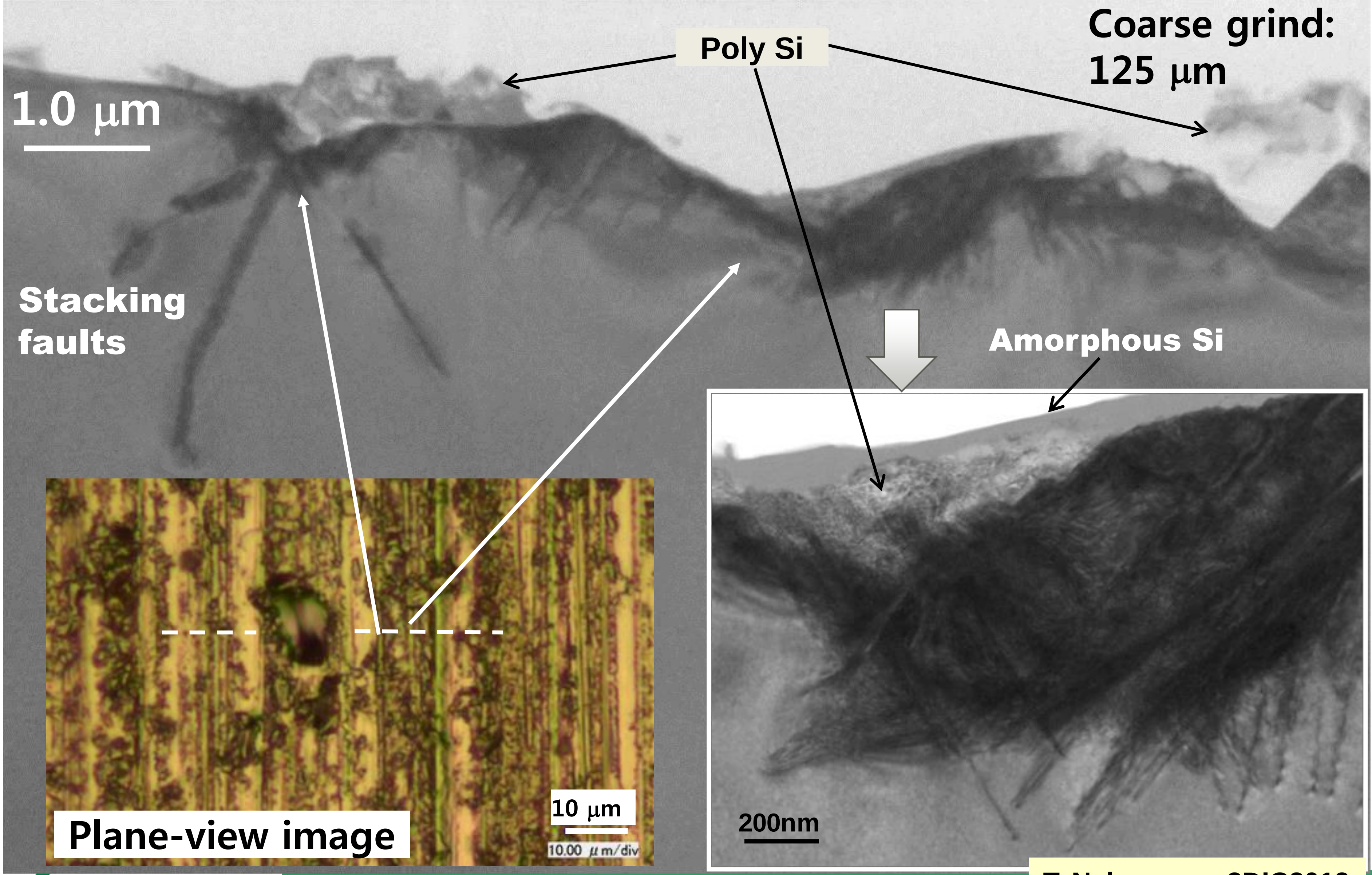
Coarse grind:
125 μm



T. Nakamura: 3DIC2013

- ✓ **Three types of spectra: amorphous, crystalline, and mixed structure**

X-TEM Observation of Coarse-grind Damage



T. Nakamura: 3DIC2013

Impacts of Coarse-grind Thickness

Thinning conditions

Sample No.	Wafer thickness	Grinding thickness (µm)		
		Coarse grind	Fine grind	Stress relief
1	650	125	-	-
	300	475	-	-
	100	675	-	-
	690	75	10	-
2	650	75	50	-
	630	75	70	-
	600	75	100	-
	320	425	30	-
3	300	425	50	-
4	649	75	50	1
	647	75	50	3
5	645	75	50	5

Grinding & Polishing apparatus: DGP8761

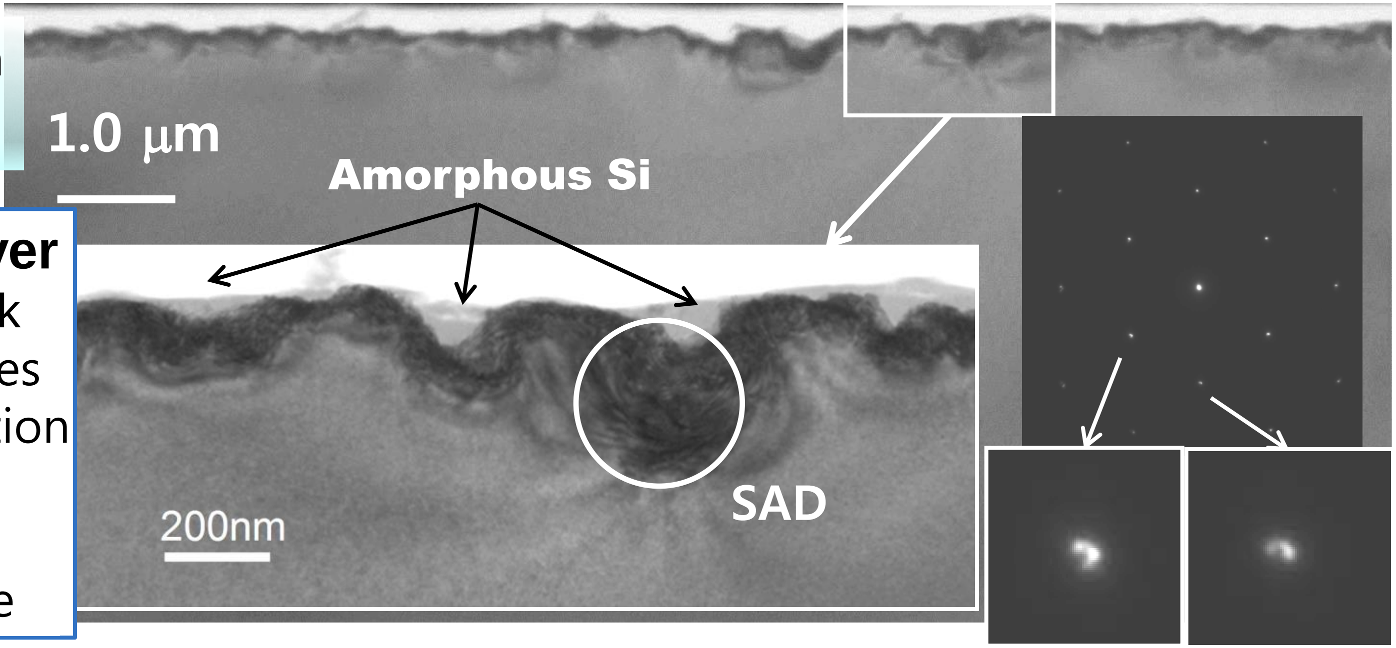
	Particle size
Coarse grind	**#320**
Fine grind	**#2000**

Subsurface Damage after Fine Grinding

T. Nakamura: 3DIC2013

Coarse grind: 75 μm

Fine grind: 50 μm

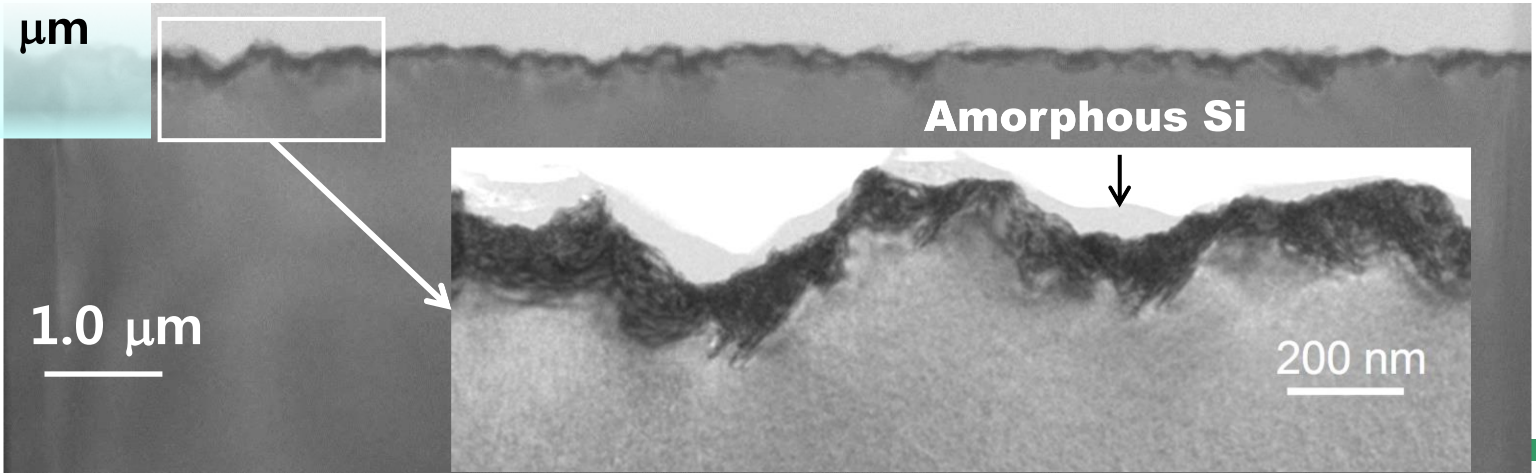


Dark contrast layer

- 100 ~ 200 nm thick
- Interference fringes
- Distorted dislocation contrasts
- Almost original crystalline structure

Coarse : 425 μm

Fine : 50 μm



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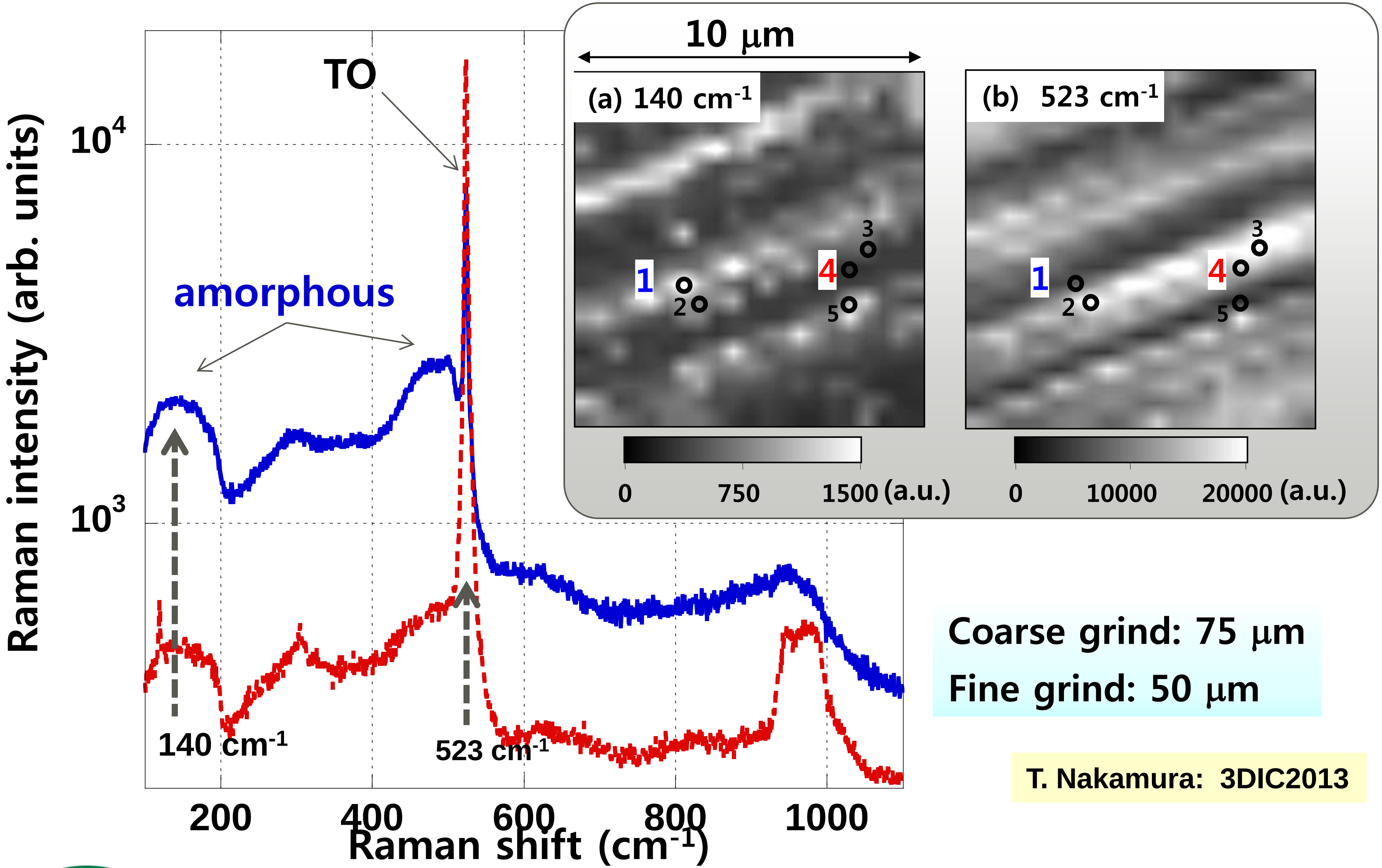
Raman Spectra and Imaging of Subsurface



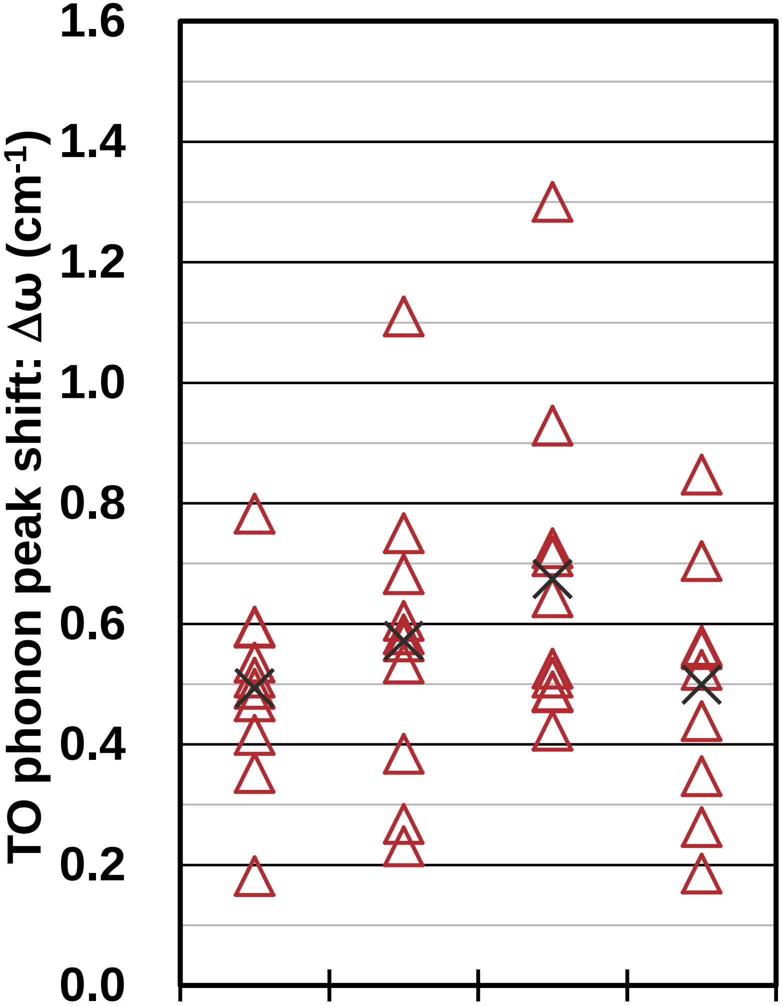
Coarse grind: 75 μm

Fine grind: 50 μm

T. Nakamura: 3DIC2013

Amorphous and crystalline Si areas remain along grinding marks.

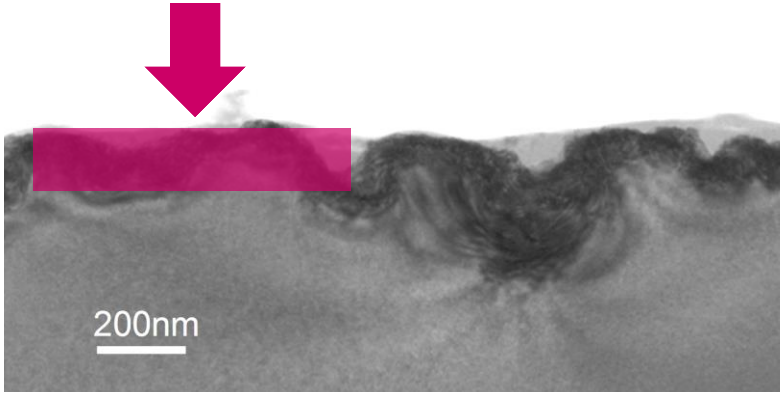
Ground Thickness Dependence of Peak Shift



	No.		2		3
Ground thickness	Coarse	75	75	425	425
	Fine	10	50	30	50

Ar$^+$ Laser: 458 nm

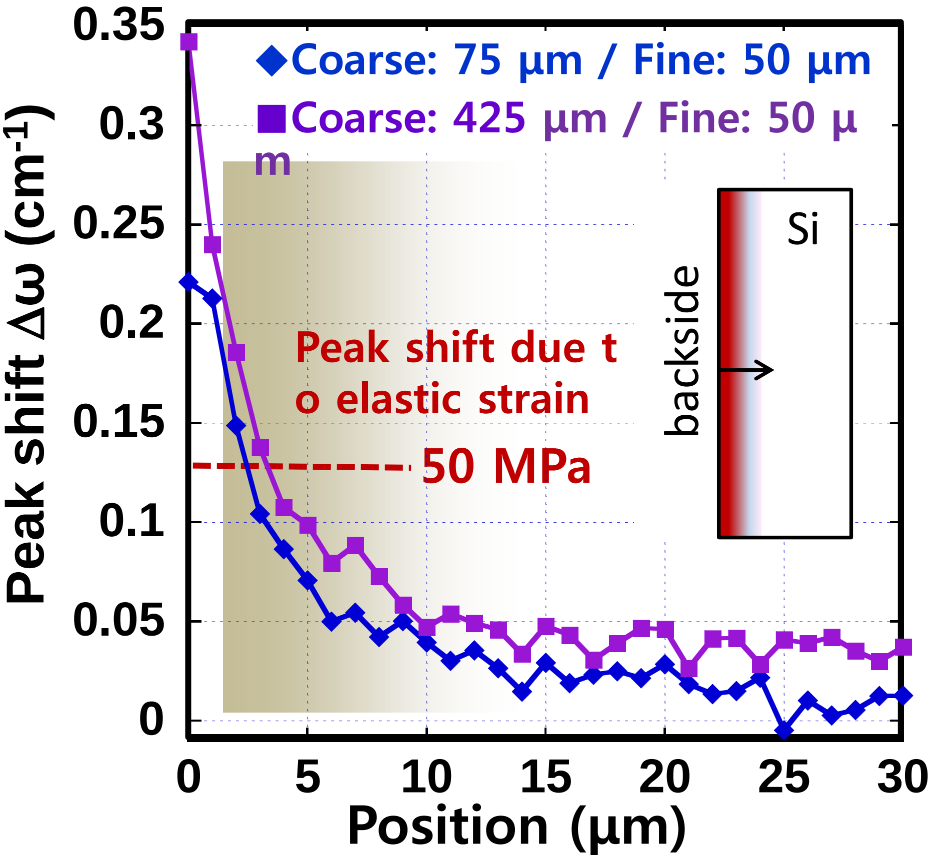
Beam size: 0.7 μm

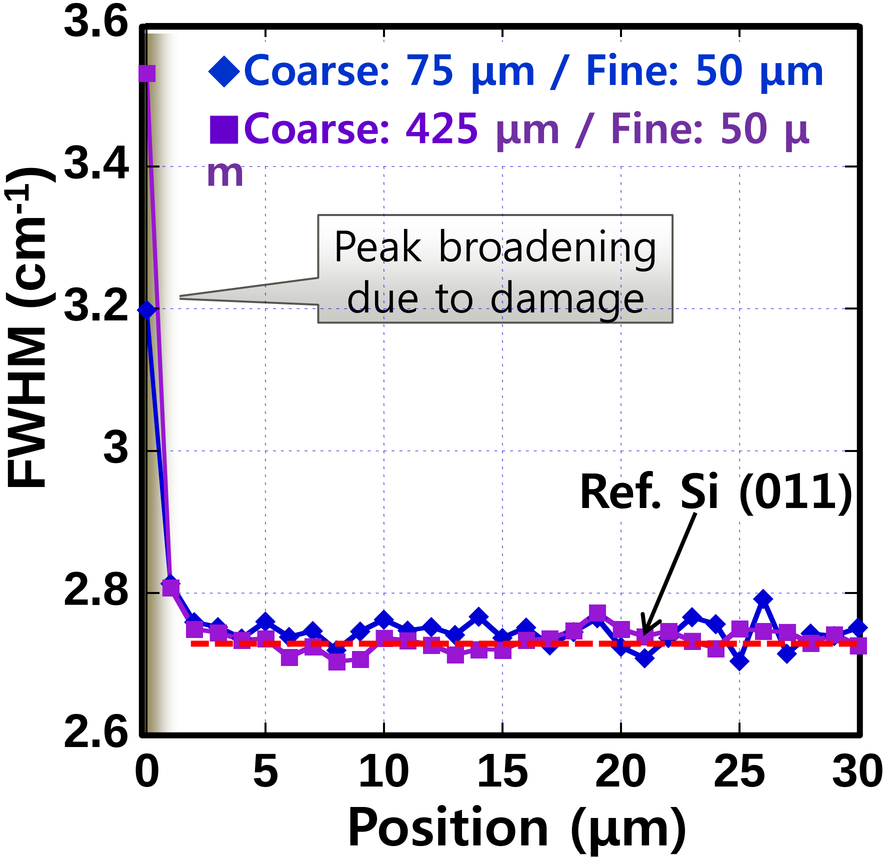


- ✓ **Δω was obtained from randomly chosen ten points**
- ✓ **Higher peak shifts are ascribed to compressive lattice strains**
- ✓ **Coarse-grind thickness dependences are smaller than the large variations**

Y. Mizushima: JJAP2014

Raman Peak Distribution: (110) Cross-section





- ✓ Plastic-deformed damaged layer is localized within less than1 µm depth
- ✓ Damaged layer influences inside compressive strains ranging up to 15µm depth

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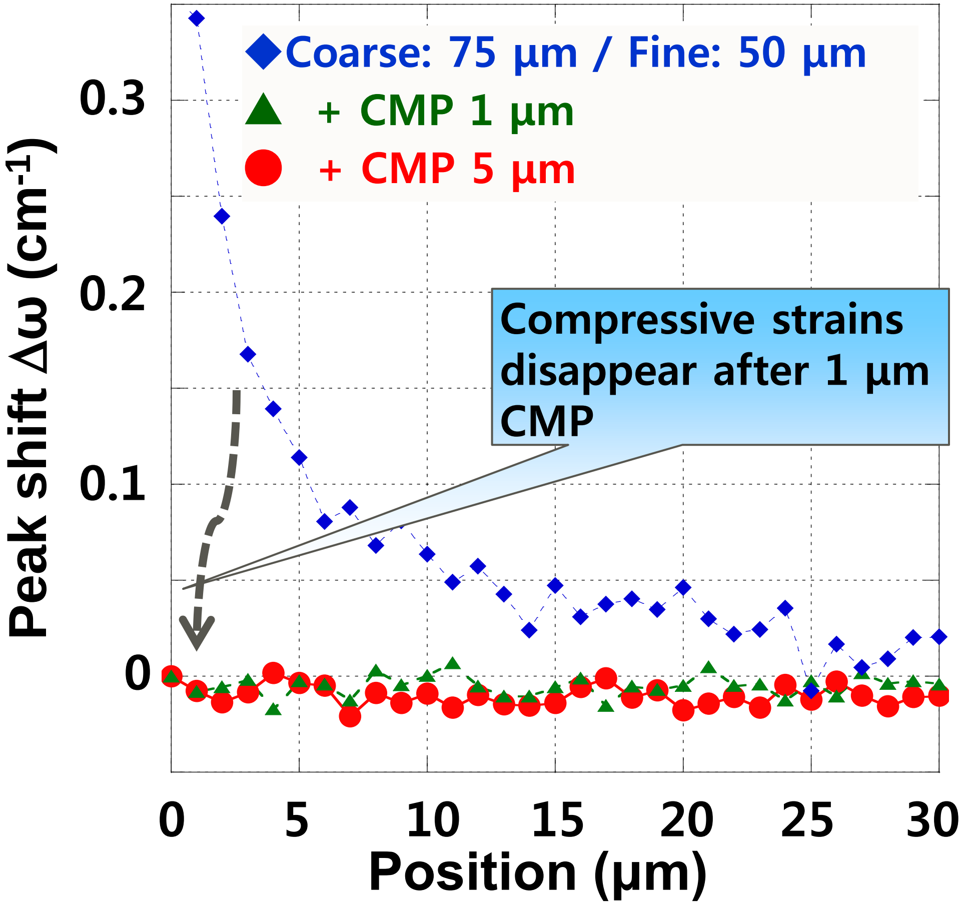
Raman Peak Distribution after CMP

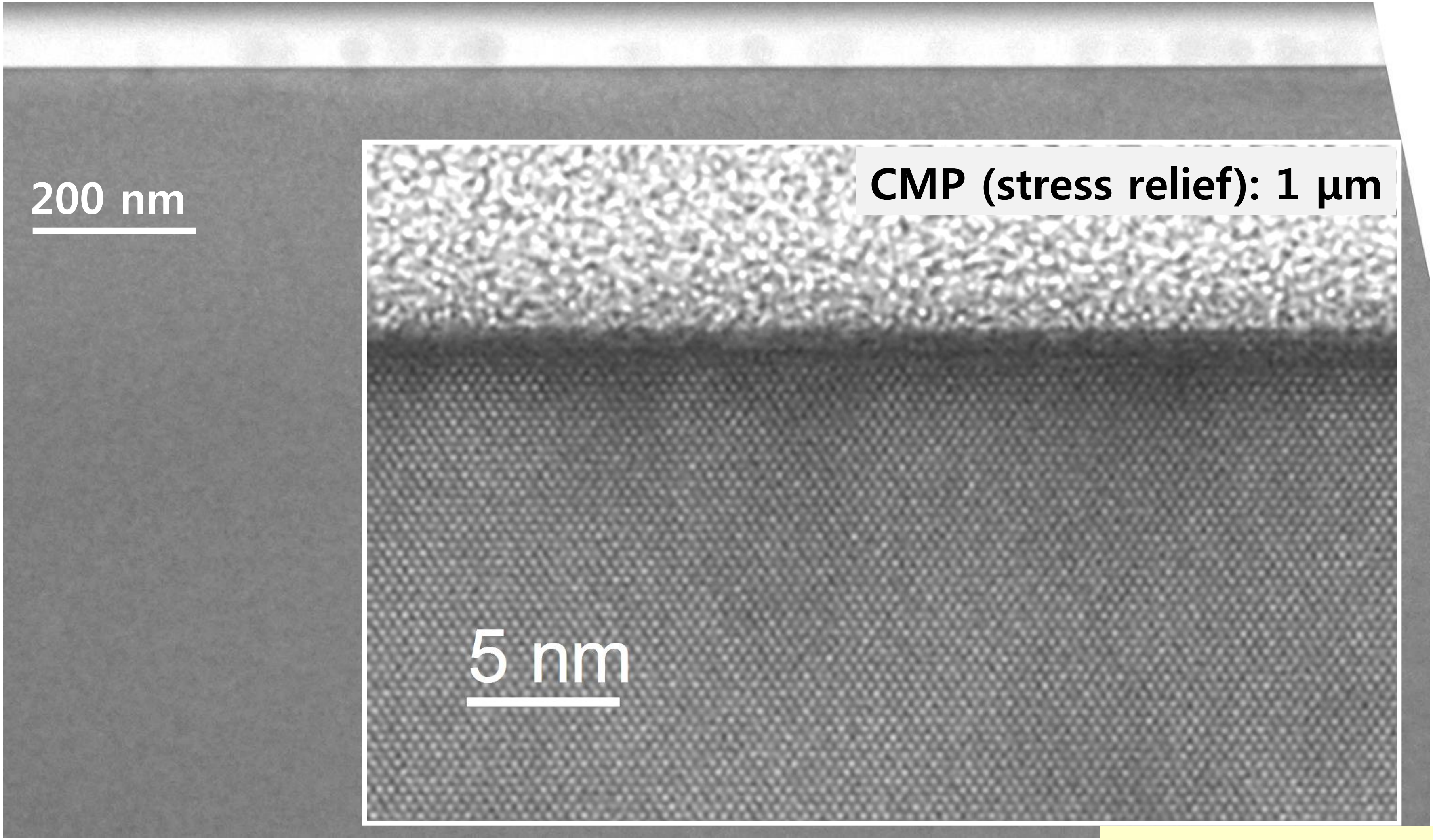


Compressive strains disappear after 1 μm CMP

- ✓ **The elastic strains ranging up to about 15 μm depth are caused by plastic-deformed damaged layer (< 1 μm thick)**

T. Nakamura: 3DIC2013

X-TEM Images of Backside Surface after CMP



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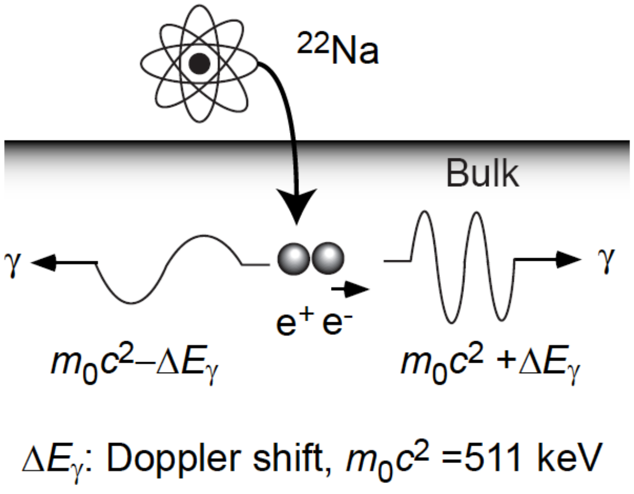
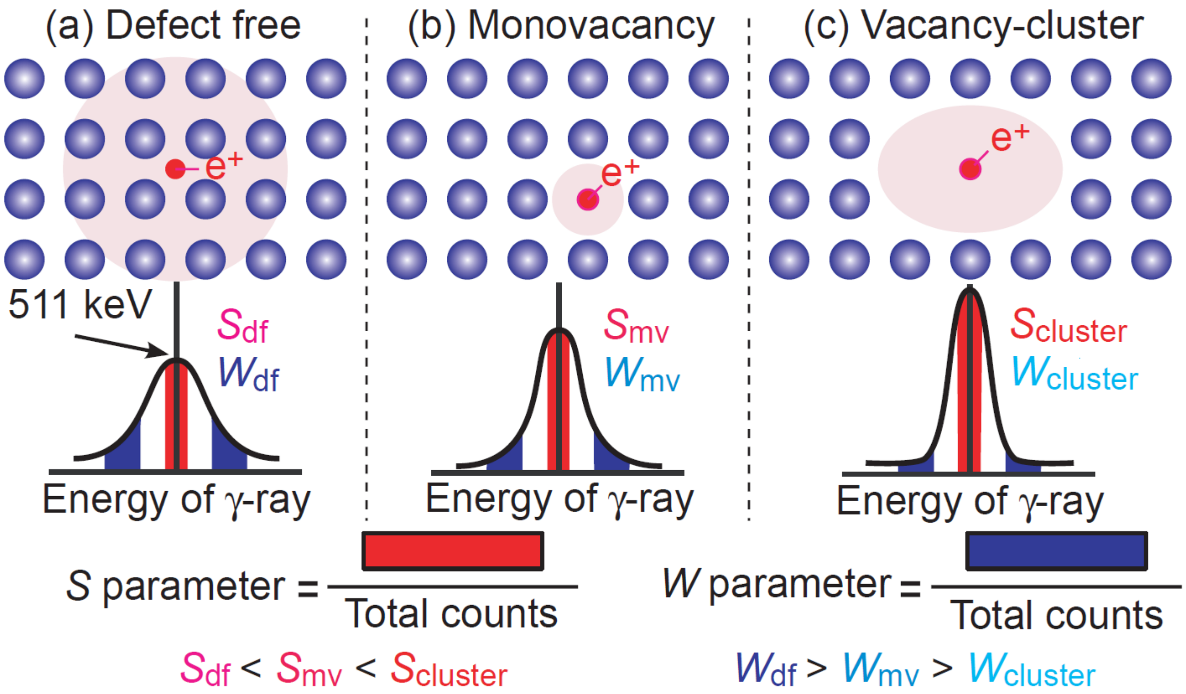
- ✓ Defective dark contrast layers disappear
- ✓ Atomically flat surface is observed after polishing only 1 µm thick

Trapping of positrons by vacancy-type defects

A freely diffusing e^+ may be localized in an open space because of the Coulomb repulsion from ion cores.





E: incident positron energy

🟥 **: low momentum part**

✓ **Larger S parameter means larger size of vacancy-type defects**

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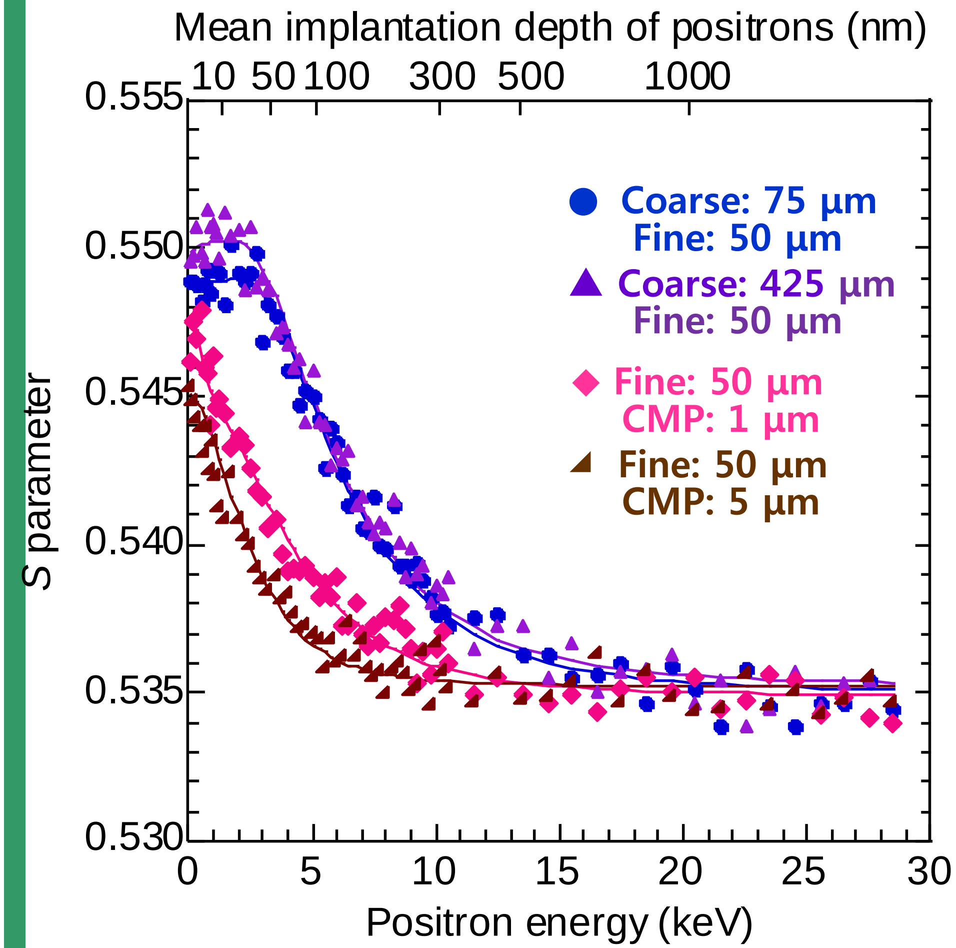
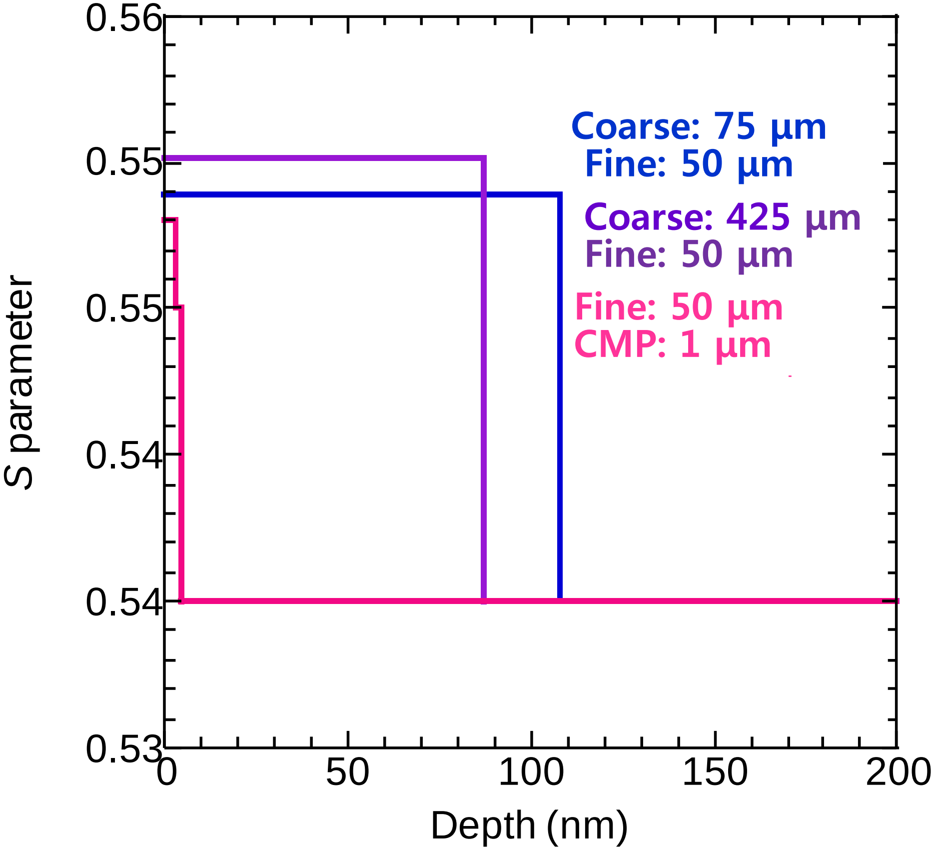
Depth Distributions of S Parameters





- ✓ **After fine grinding, vacancy-type defects range up to 0.1 µm depth**
- ✓ **S parameter distributions can distinguish defect density deference between 1- and 5- µm thick CMP samples.**

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Defects induced by grinding of Si wafers

The lifetime spectrum of a positron was measured at E = 2 keV and it was decomposed into two components.

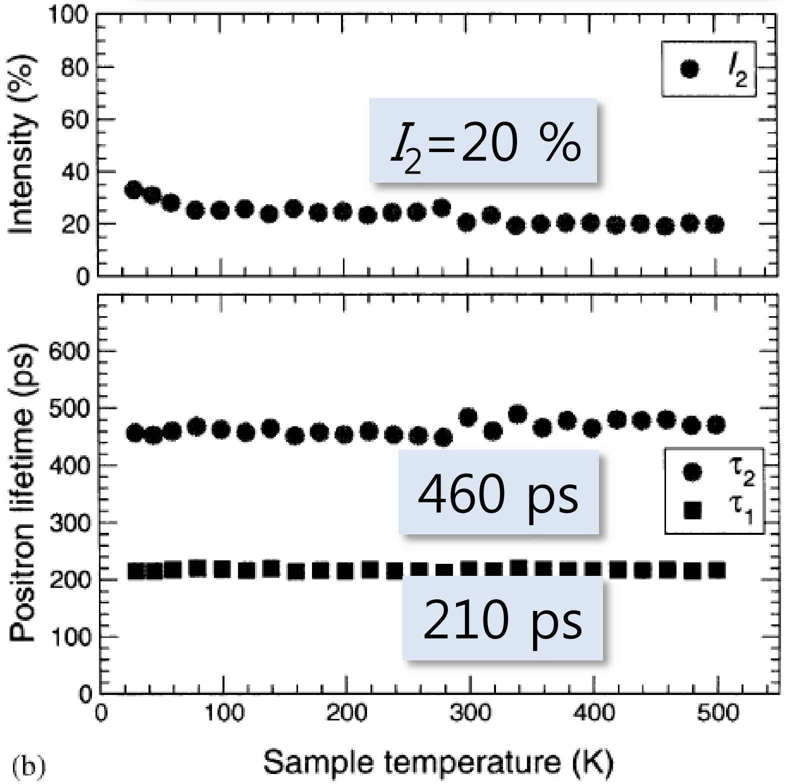
t_1 = 285 ± 9 ps → Vacancy (V or V_2)

t_2 = 490 ± 20 ps (I_2 = 11 ± 2 %) → Vacancy cluster (V_{18})

Leipner *et al*., Physica B 340-342, 617 (2003)

Fz-Si (P doped) was deformed at RT and 800°C up to 16% in an anisotropic multi-anvil apparatus under a confining pressure of 5 GPa.

Uedono *et al*., JAP 116, (2014)



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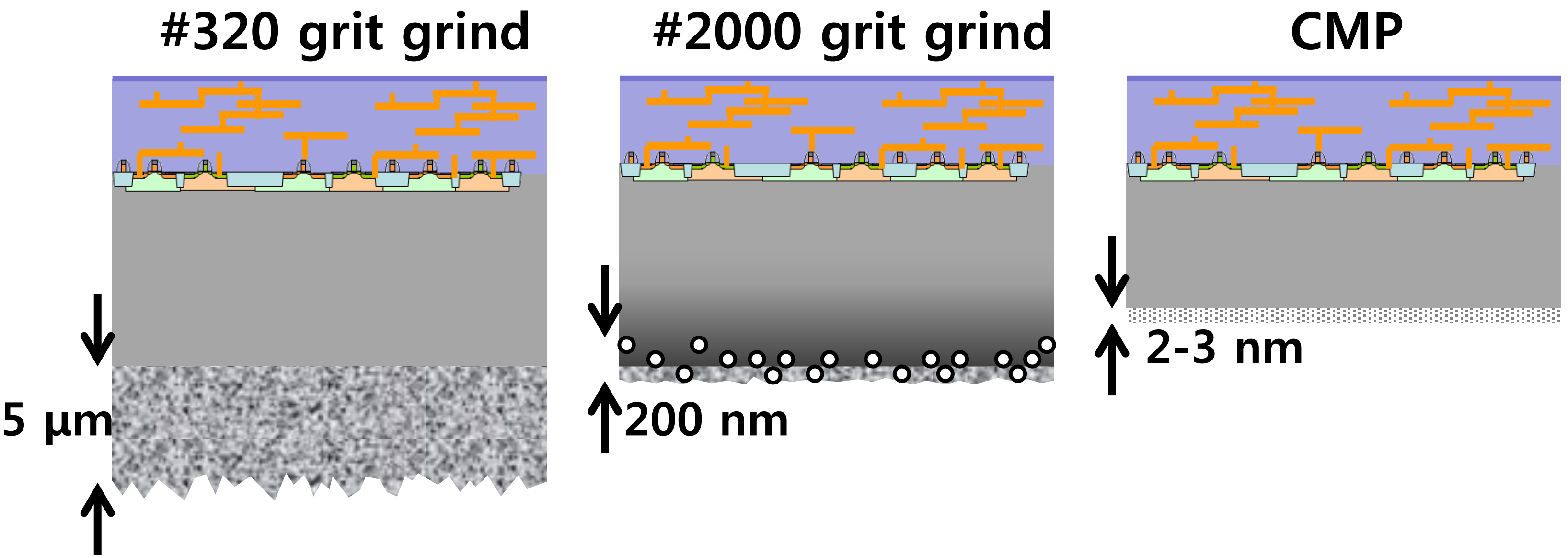
Summary: Subsurface Damages

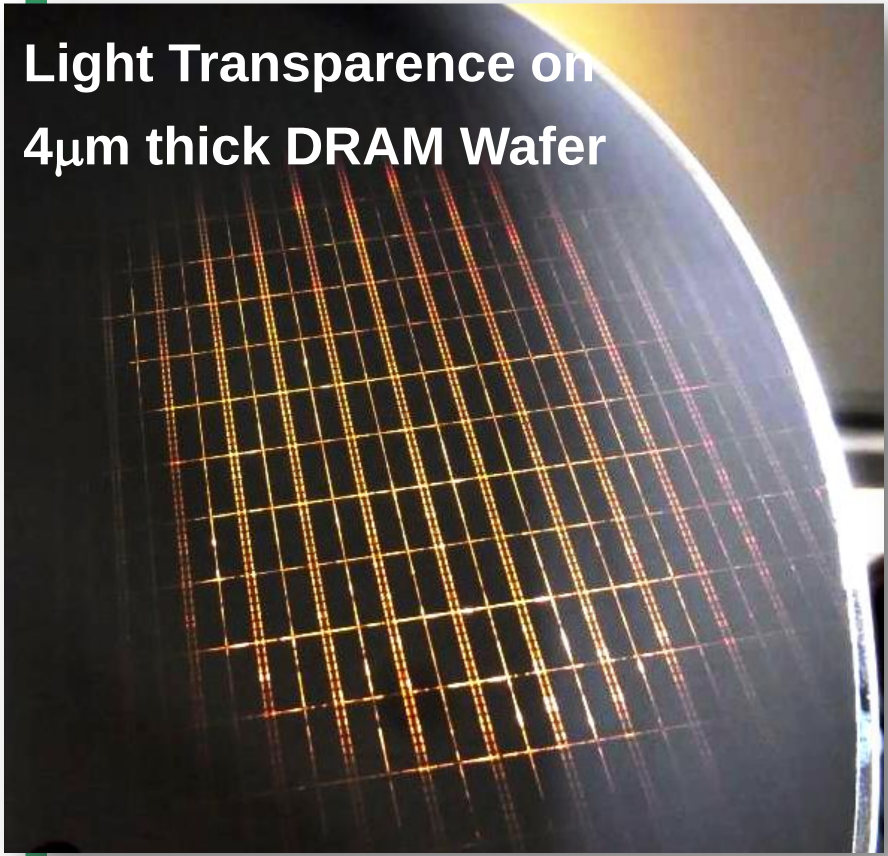


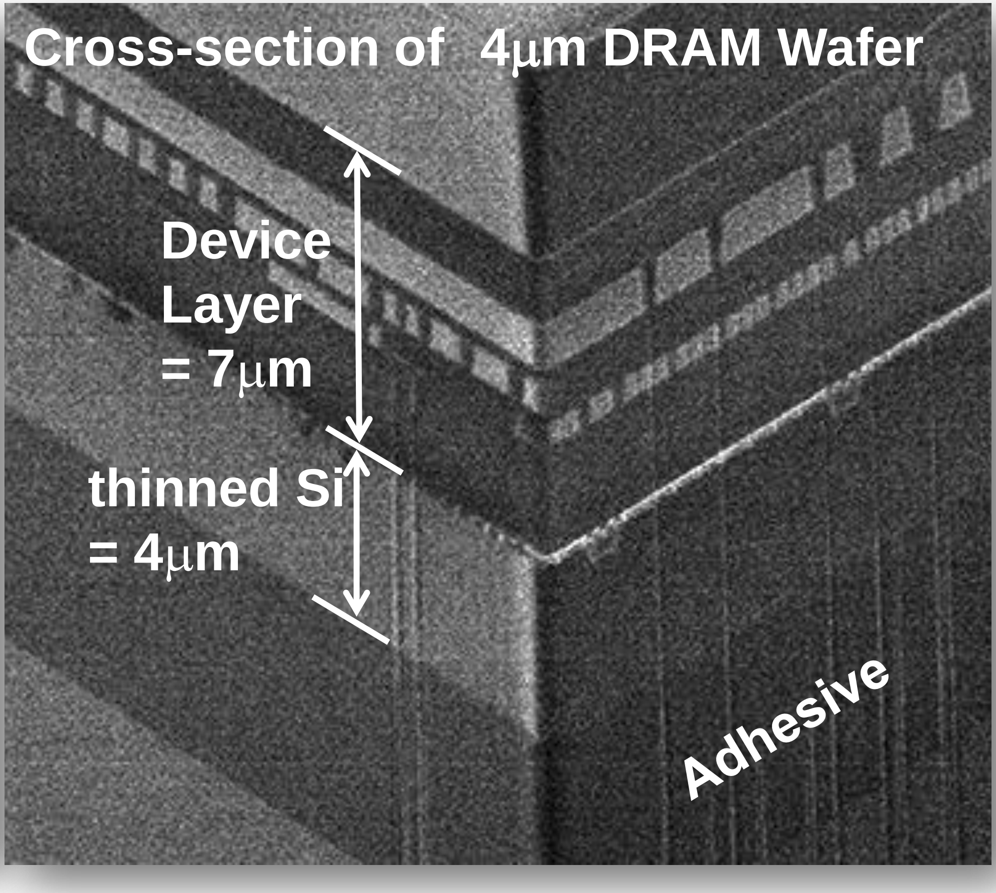
1. **Coarse grinding damages cause the roughness and defects of less than 5 µm depth.**

2. **After fine grinding plastic-deformed damaged layer with less than 200 nm thick still remains.**

3. **CMP process enables to remove residual damages such as structural defects and lattice strains except vacancy-type defects.**

Ultra-Thinning of 300mm Wafer with 2 Gb DRAM

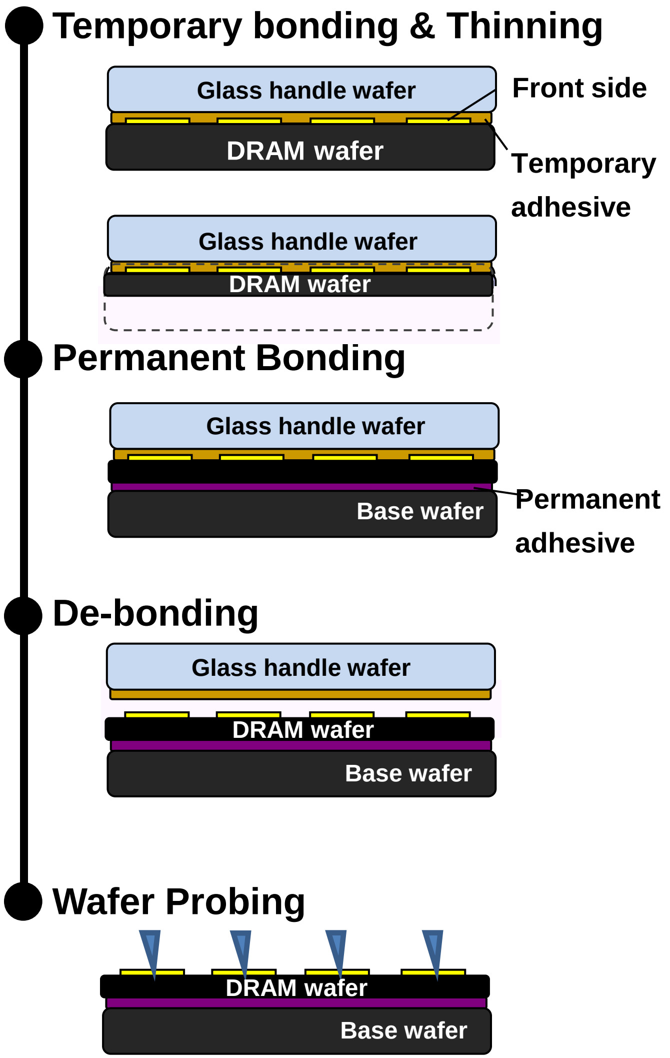




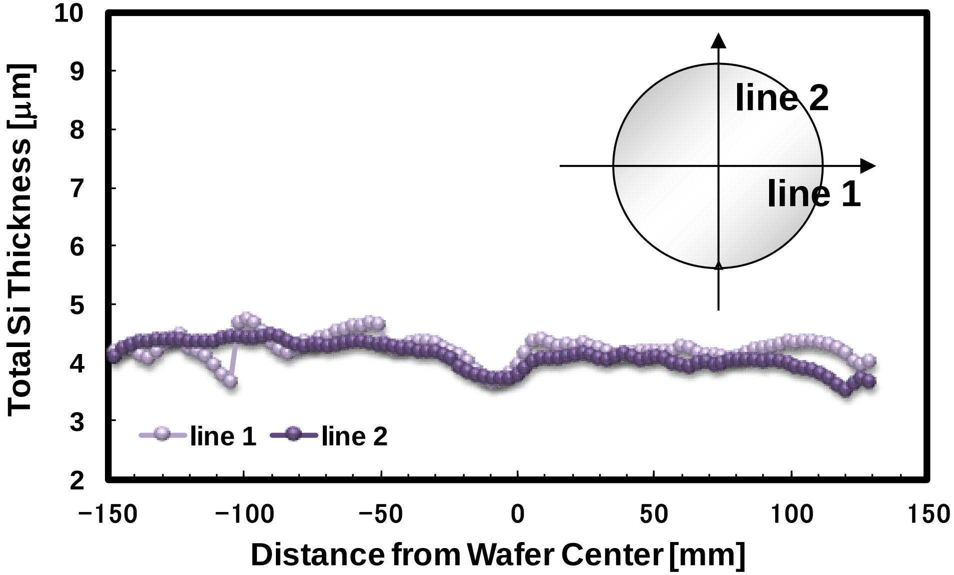
Extremely thinned down wafer from 775 to 4-μm, that is about 0.5 % of its original thickness.

Y. S. Kim: VLSI2014

Sequence of Wafer-on-a-Wafer (WOW) Process



- **Temporary bonding & Thinning**
- **Permanent Bonding**
- **De-bonding**
- **Wafer Probing**



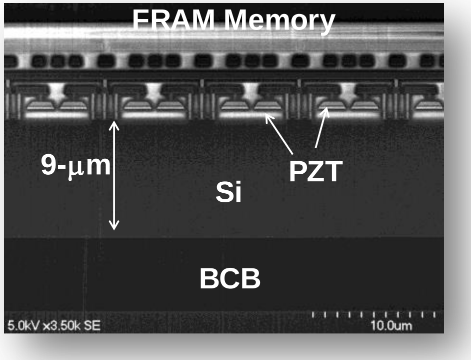
Si thickness [μm]	Mesh size of grind wheel		TTV [um]
	Coarse	Fine	
40	#320	#2000	1.94
20			1.39
8			1.92
4			1.02

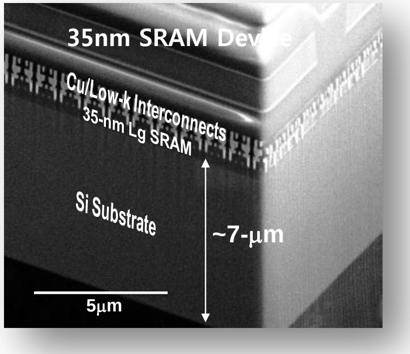
Y. S. Kim: VLSI2014

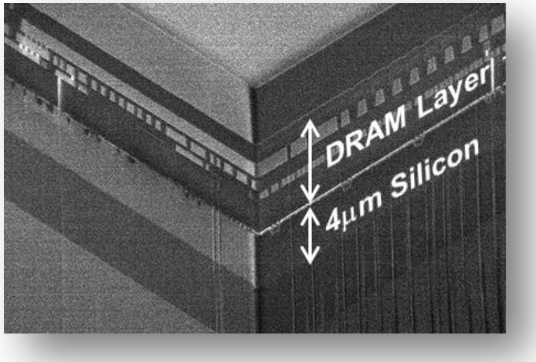
Effect of Ultra-thinning on Device Characteristics

Device Node	FRAM ~180nm	Logic 45nm (Lg 35nm)	DRAM 40nm (2Gb)
Thickness	9µm	7µm	4µm

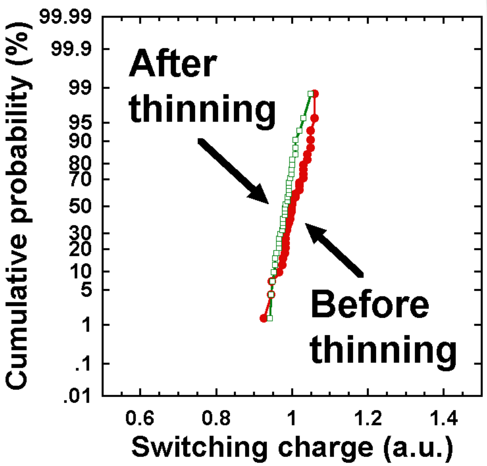
SEM Picture

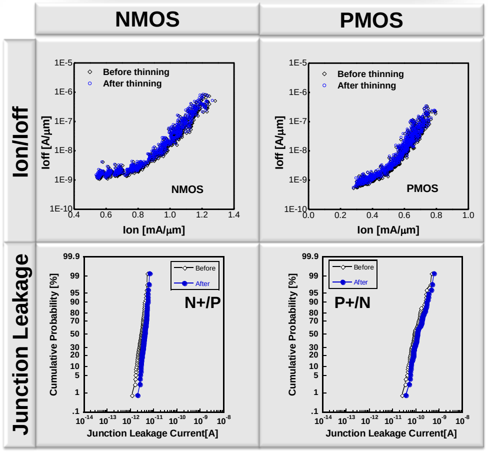


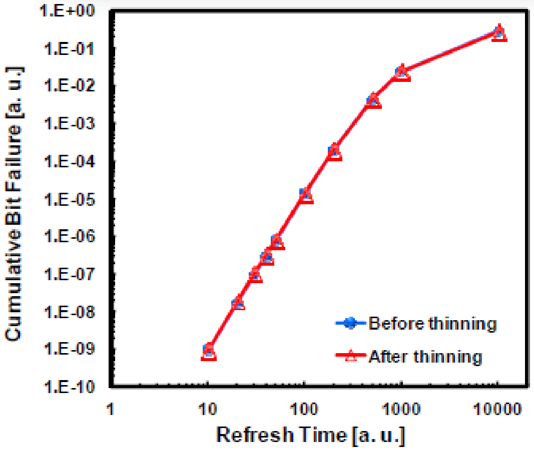




Electrical Property







	VLSI2010	IEDM2009	VLSI2014

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Acknowledgments

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