Laser grooving technique for dicing nanoscale low-k wafer

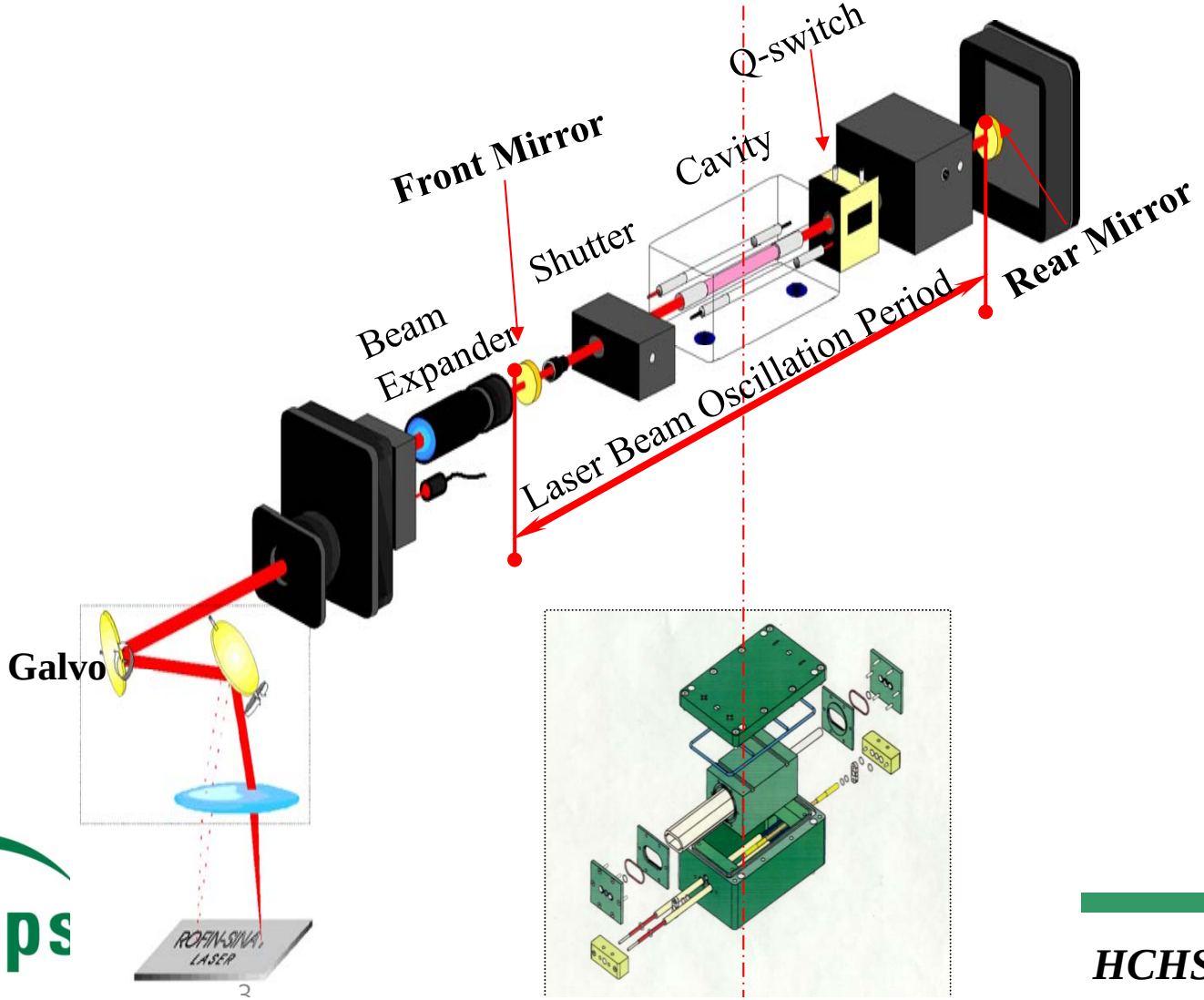
Hsiang-Chen Hsu and Shih-Jeh Wu
Professor
Department of Mechanical and Automation Engineering
I-Shou University

Outline

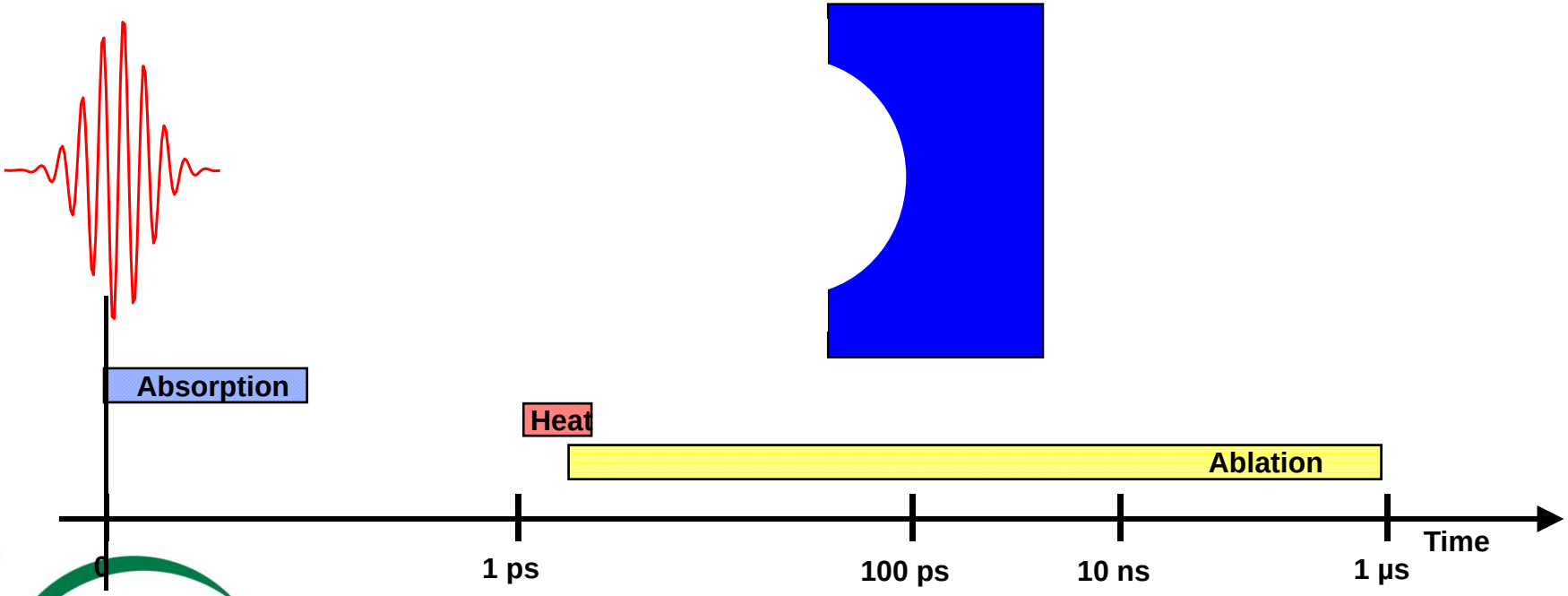
- **Background**
- **Experimental Works**
- **Results**
- **Summary**

Background

- Principle of Laser Marking



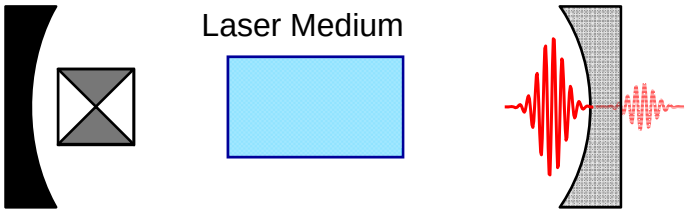
- Ultra-short Pulse Laser - Material Interaction
  - Energy transfer from (pulsed) laser light to electrons (Absorption)
    - After Electron-Phonon-Interaction-Time (EPIT)
    - Energy transfer from Electrons to Phonons: Heat
      - Ablation of material

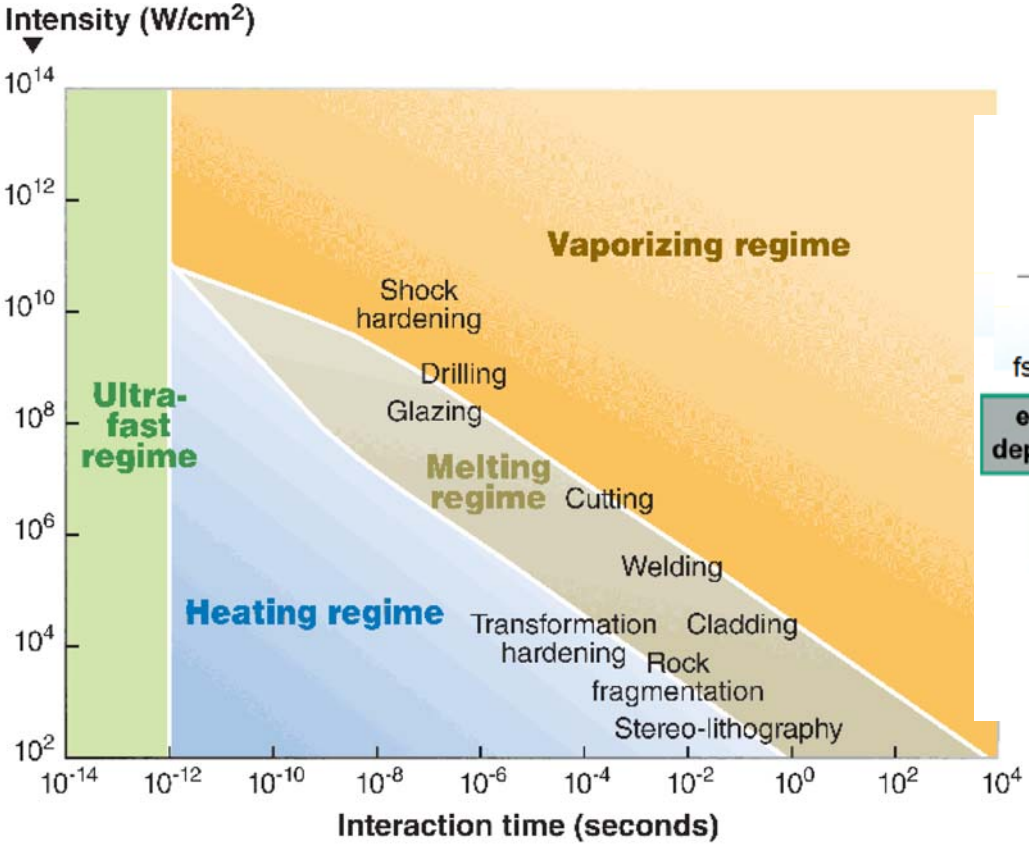


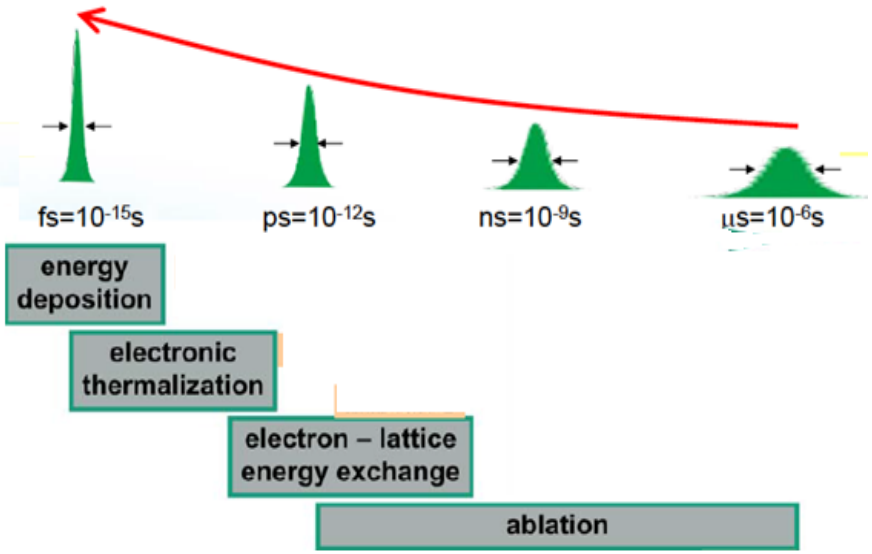
kmeps

- Obtaining ps-Pulses

- ps (and fs) Oscillators:
  - Tens of MHz Repetition Rate (given by reson ator length)







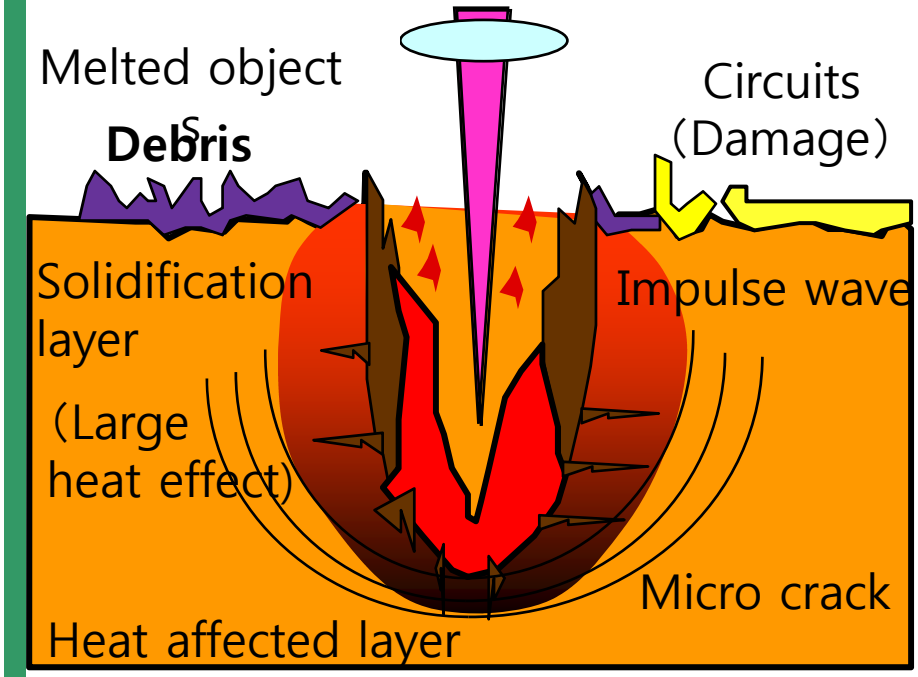
"Defining ultrafast fiber lasers is a tricky business", Tom Hausken www.laserfocusworld.com/articles/341575)

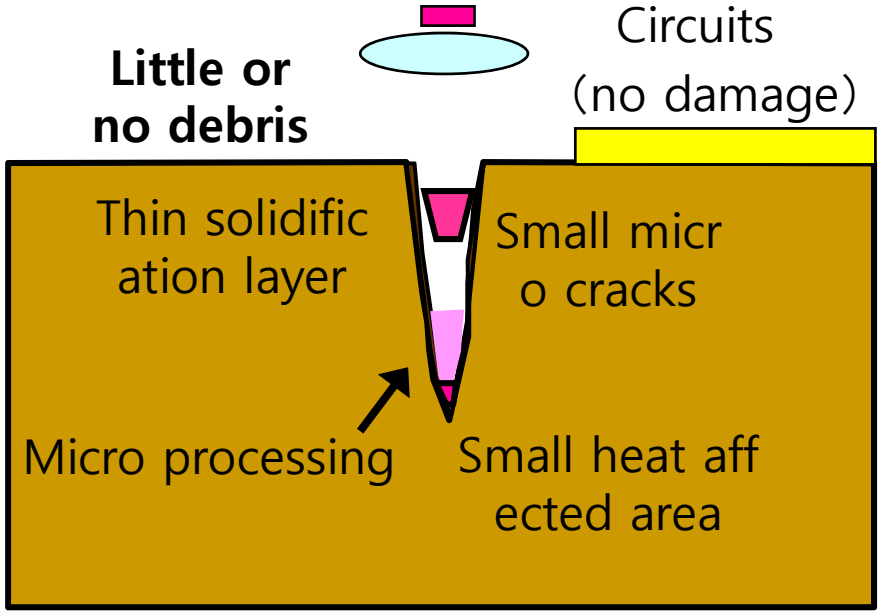
Long pulse las er(>1ns)

Pulse laser beam (Conventional)

Ultra-short lase r(<10 ps)

Ultra-hort pulse la ser beam





- Small amount of energy volume, High peak-power
- Processing with little or no heat affect, small micro crack

kmeps

- Key Parameters for Laser Machining

✓ power(W)
✓ repetition-rate(Hz)
✓ defocus(mm)
✓ speed(mm/s)
✓ index(mm)

- Reciprocal Effects

- ✓ power - depth
- ✓ frequency - depth/surface debris
- ✓ defocus – beam size
- ✓ speed – surface ripple/debris
- ✓ index - overlap

- Low-k Wafer Structure

2 um Cu

1 um Cu-Seed

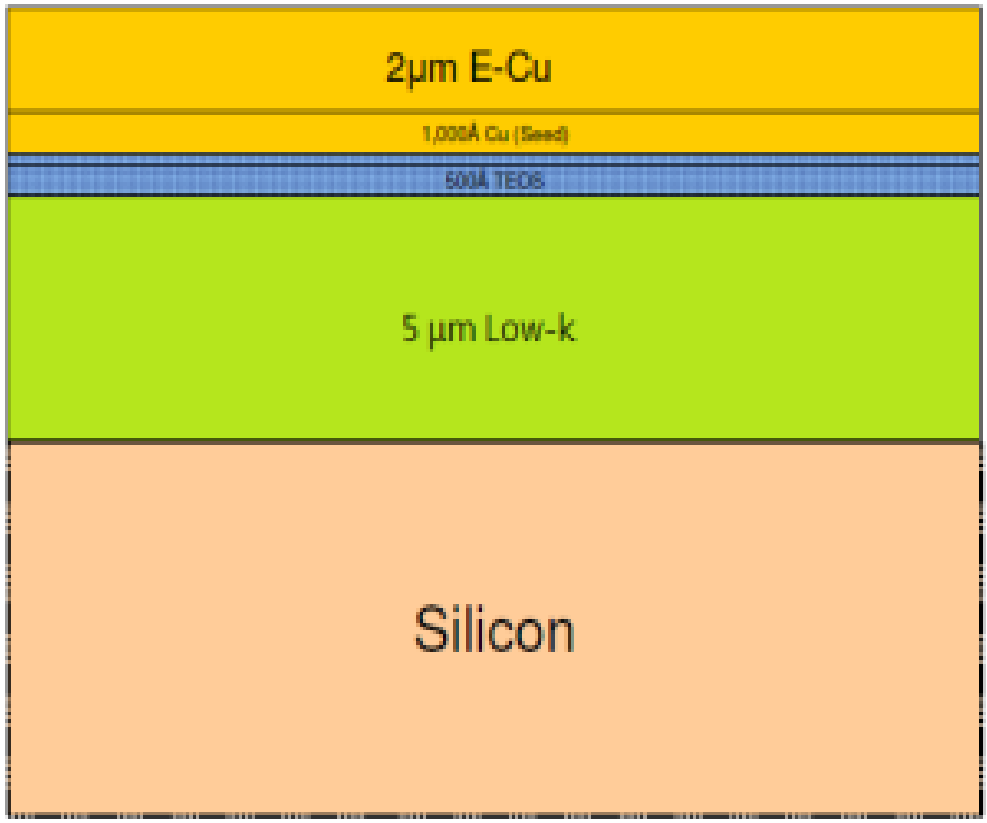
250A Ta(Tantalum)

500A TEOS

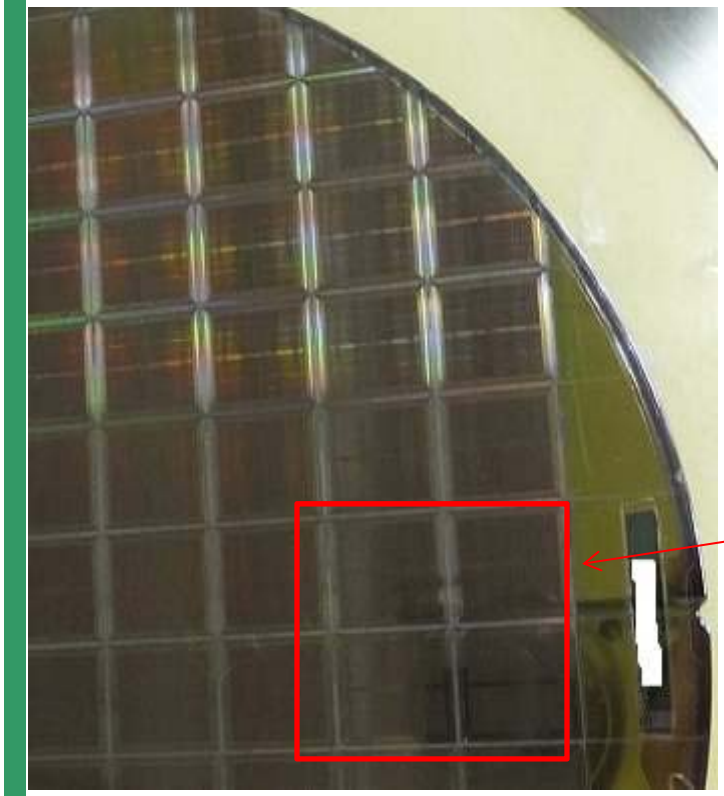
(tetraethyl orthosilicate, $Si(OC_2H_5)_4$)

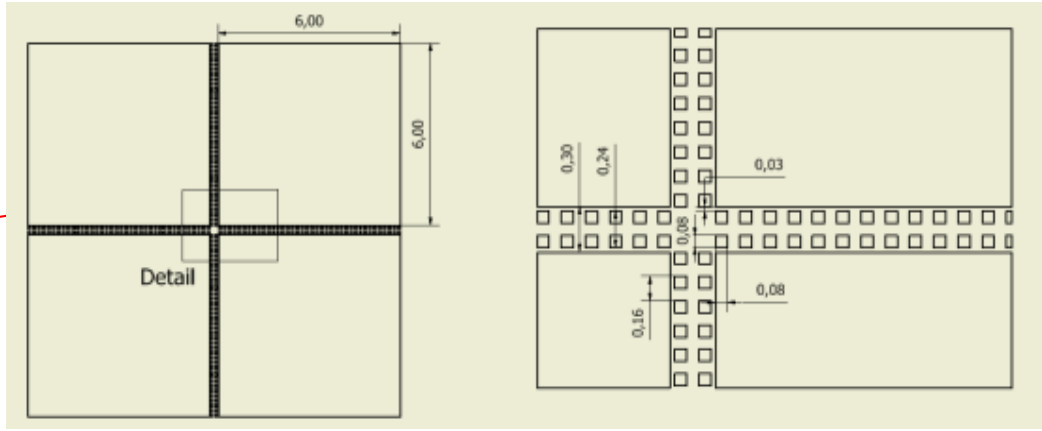
4-5um Low-k

Silicon



- Pattern



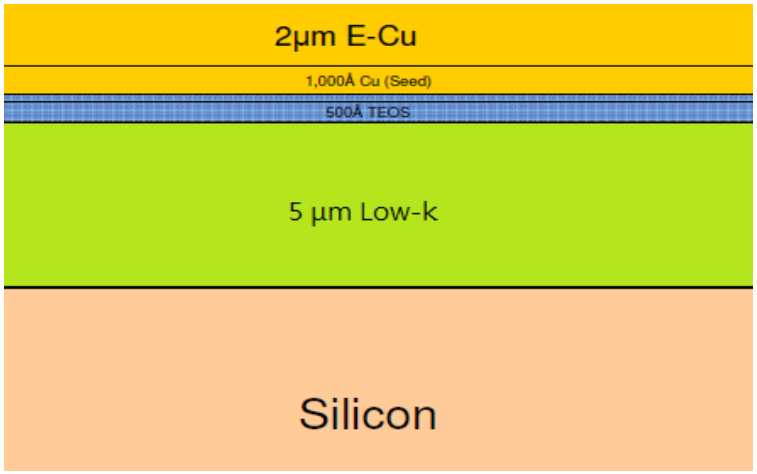


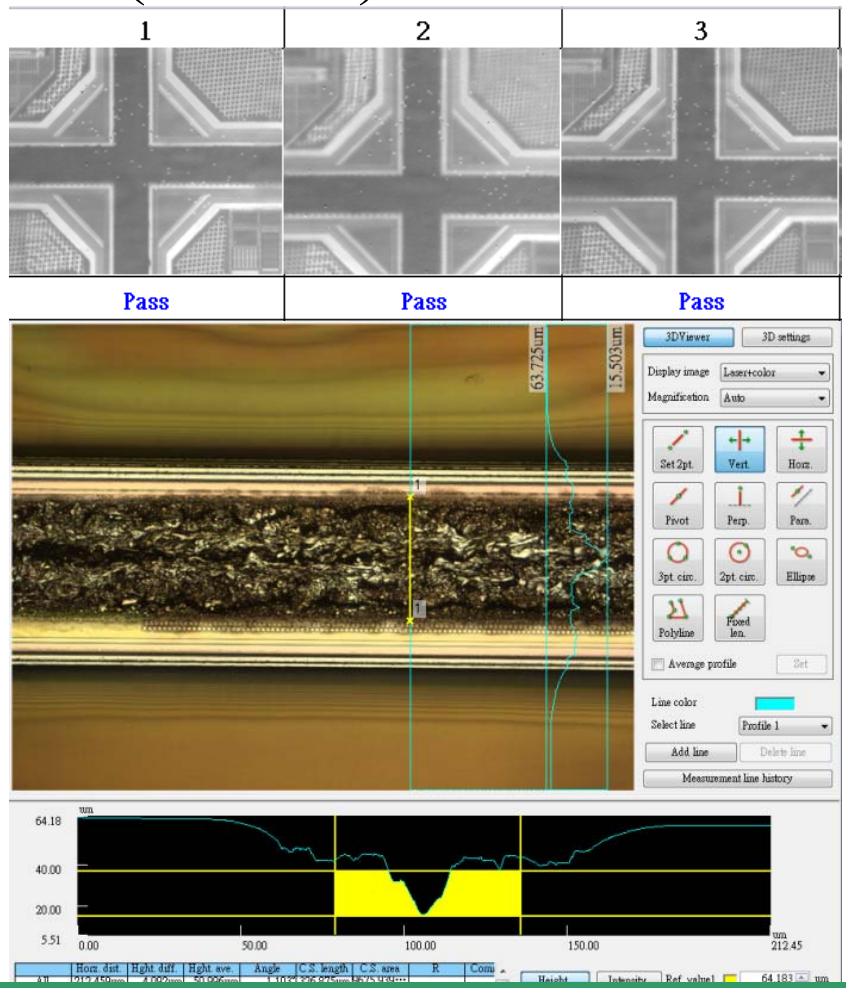
Experimental Works

- Laser Machine

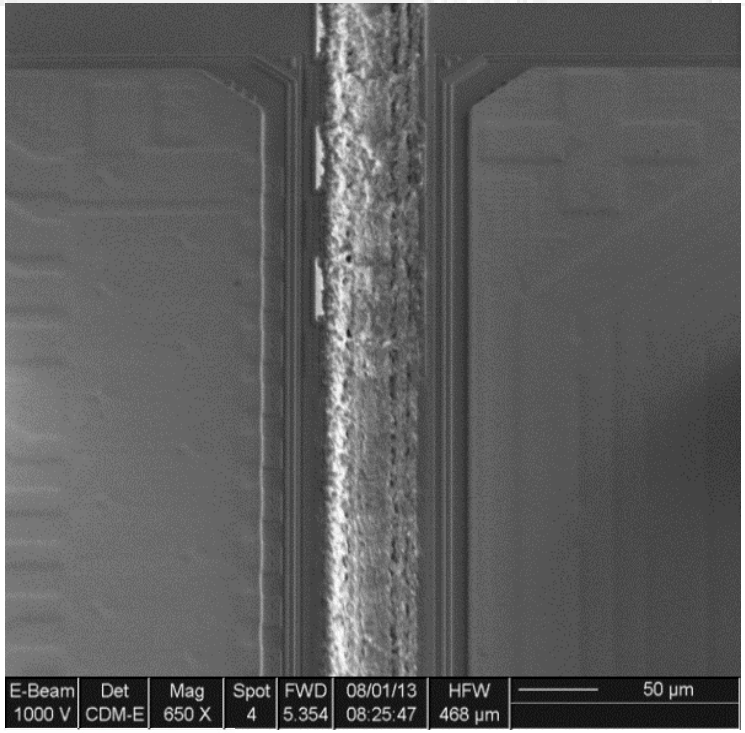
Wavelength of the laser light	**515 nm**
Maximum average power	30 W
Diffraction factor M^2	<1,3
Pulse duration	<10 ps
Base frequency (set ex works)	200, 400, 600 oder 800 kHz
Maximum pulse energy[1]	150 µJ
Beam diameter at the exit window	5 mm

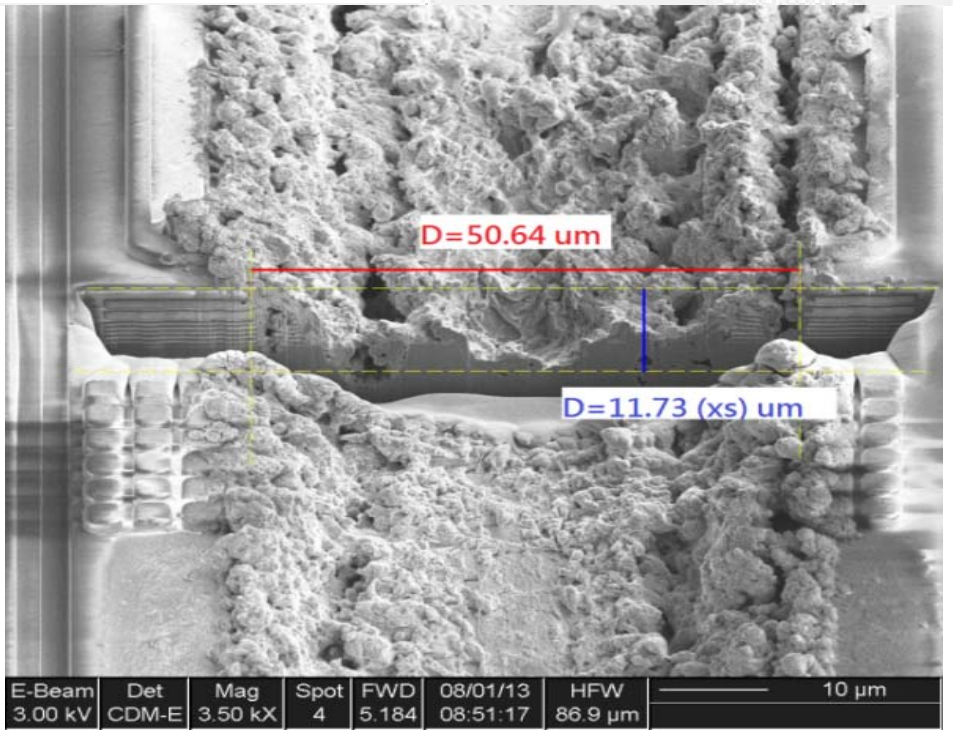
- Grooving on Cu-low K wafer (45nm<) street






Cutting street width
Laser Debris height
Laser width
Seal ring
Debris bottom opening
Laser depth
Seal ring
Debris top opening
100.00
200.00


E-Beam 1000 V
Det CDM-E
Mag 650 X
Spot 4
FWD 5.354
08/01/13 08:25:47
HFW 468 µm
50 µm


D=50.64 um
D=11.73 (xs) um
E-Beam 3.00 kV
Det CDM-E
Mag 3.50 kX
Spot 4
FWD 5.184
08/01/13 08:51:17
HFW 86.9 µm
10 µm

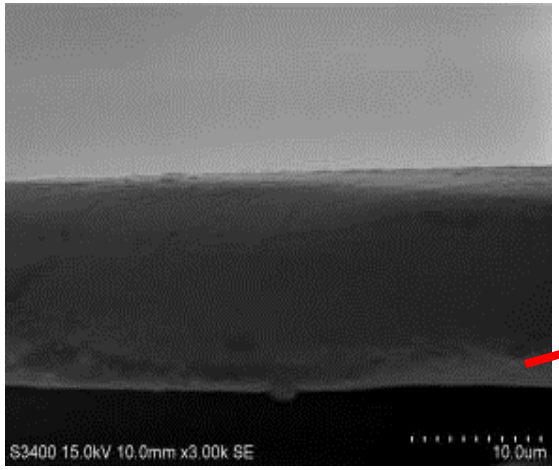
Repeatability

- Laser: 6M, spot size 17 μm with 5W.
- Speed: 550mm/s
- Top viewed and depth measured by SEM
- Result:

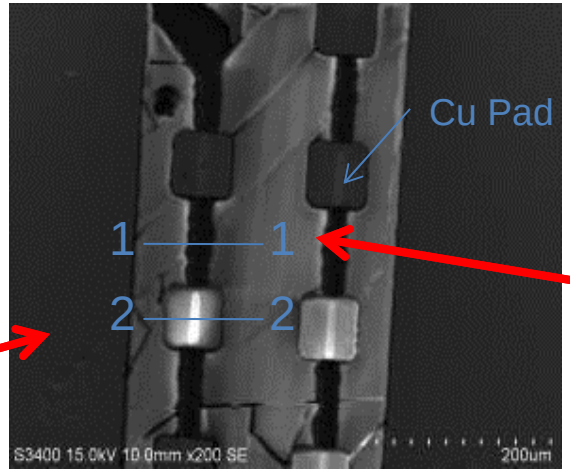
  No HAZ, Particles or Recast

  Channel Depth 6.02μm and Width 16.8 μm

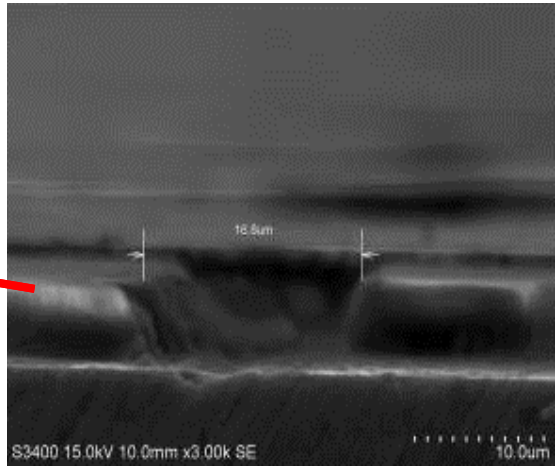
  Test pads is not removed



2-2 cross section



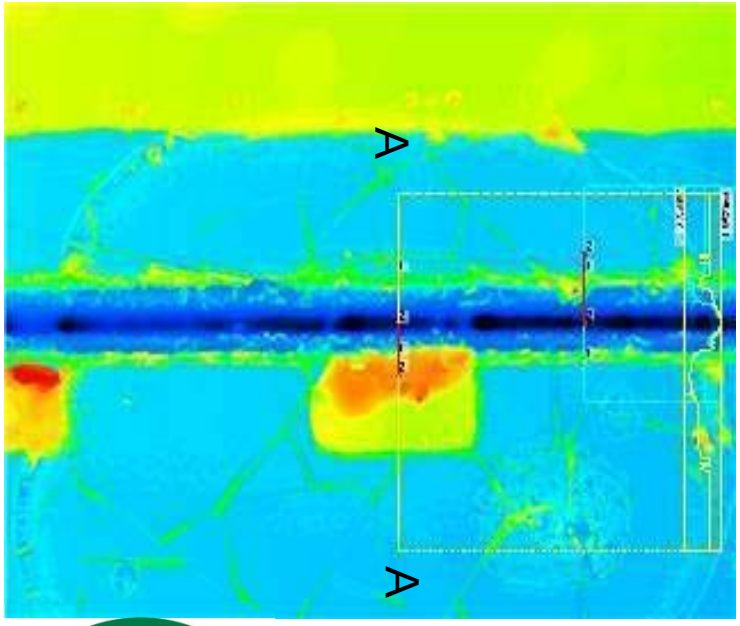
Top view

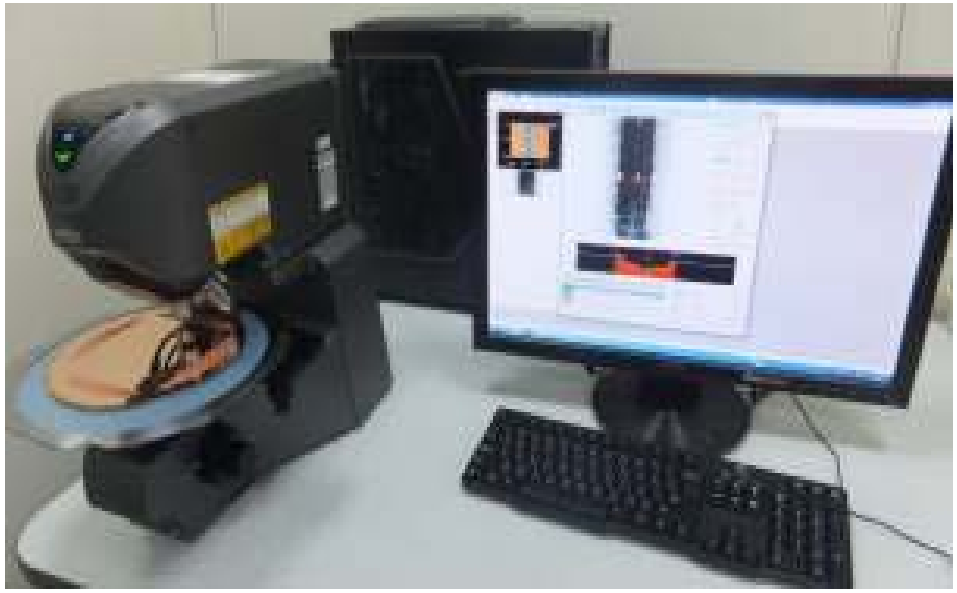


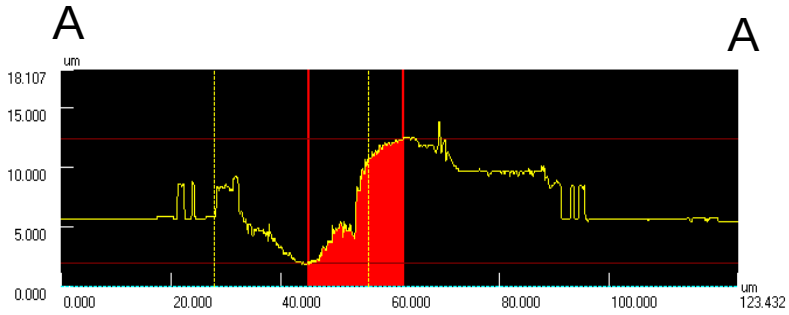
1-1 cross section

First Try of Overlap Scribing & 3D Confocal Microscopy(In May 2013)

Power = 10W
Speed = 300mm/s
2 passes overlap 100%(17um)
Depth = 10.344um
Width = 17um







A-A Cross Section

• DOE---Taguchi Methods

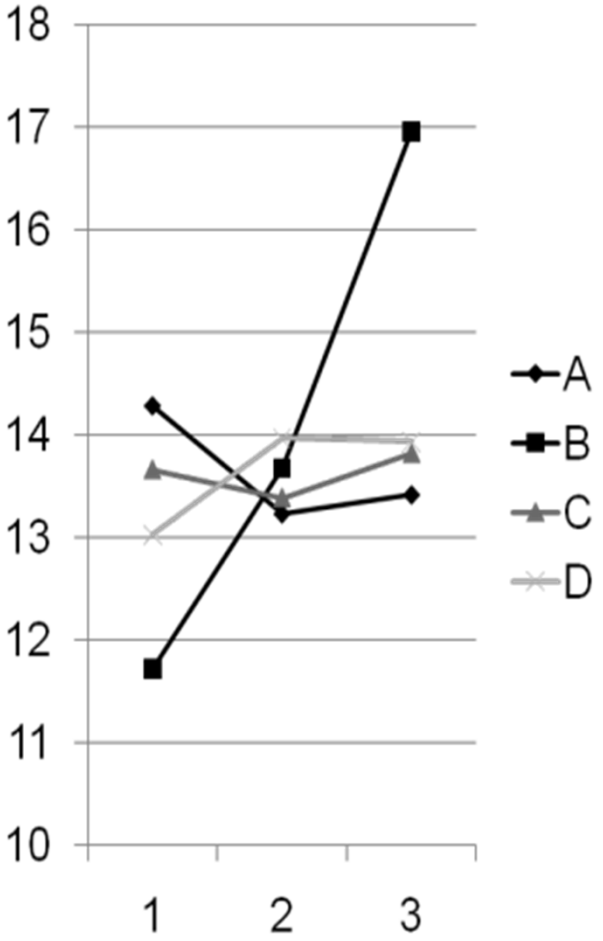
Factor	Level 1	Level 2	Level 3
A Repetition Rate	4MHz	6MHz	10MHz
B Power	5W	10W	15W
C Speed	150mm/s	300mm/s	600mm/s
D Passes	2 passes (overlap 20%)	2 passes (overlap 50%)	2 passes (overlap 100%)

	A	B	C	D
1	L1	L1	L1	L1
2	L1	L2	L2	L2
3	L1	L3	L3	L3
4	L2	L1	L2	L3
5	L2	L2	L3	L1
6	L2	L3	L1	L2
7	L3	L1	L3	L2
8	L3	L2	L1	L3
9	L3	L3	L2	L1

No.	Depth（um）		Average(um)
1	3.82	3.9	3.86
2	5.35	5.21	5.28
3	10.67	10.39	10.53
4	3.49	4.03	3.76
5	4.22	4.61	4.415
6	6.74	7.24	6.99
7	4.05	3.85	3.95
8	4.96	4.86	4.91
9	5.56	5.8	5.68

Factor	Level 1	Level 2	Level 3
A Repetition Rate	4MHz	6MHz	10MHz
B Power	5W	10W	15W
C Speed	150mm/s	300mm/s	600mm/s
D Passes	2 passes (overlap 20%)	2 passes (overlap 50%)	2 passes (overlap 100%)

	A	B	C	D
1	14.27885	11.71896	13.66322	13.02729
2	13.23299	13.67703	13.38505	13.9639
3	13.41772	16.95501	13.82254	13.93504



Optimization：A1B3C3D3　(4MHz, 15W, 600mm/s, overlap 100%)

Results

- Laser Grooving

Item	Specification	Industrial Standard	Experimental Work
1	Heat affect analysis（Debris）	< 5 μm	3.57μm
2	Top side chipping	Not allow	<0.005μm
3	Passivation peeling	Not allow	<0.005μm
4	Laser groove depth	>10 μm	15.786μm
5	Wafer scratch	Not allow	<0.005μm
6	Die crack	Not allow	<0.005μm
7	Wafer broken	Not allow	None
8	Laser total kerf width	Target ± 3um	± 2.73μm
9	Laser kerf shift	± 2um	± 1.96μm

Item	Specification	Industrial Standard	Experimental Work
1	Heat affect analysis（Debris）	< 5 μm	3.57μm
2	Top side chipping	Not allow	<0.005μm
3	Passivation peeling	Not allow	<0.005μm
4	Laser groove depth	>10 μm	15.786μm
5	Wafer scratch	Not allow	<0.005μm
6	Die crack	Not allow	<0.005μm
7	Wafer broken	Not allow	None
8	Laser total kerf width	Target ± 3um	± 2.73μm
9	Laser kerf shift	± 2um	± 1.96μm

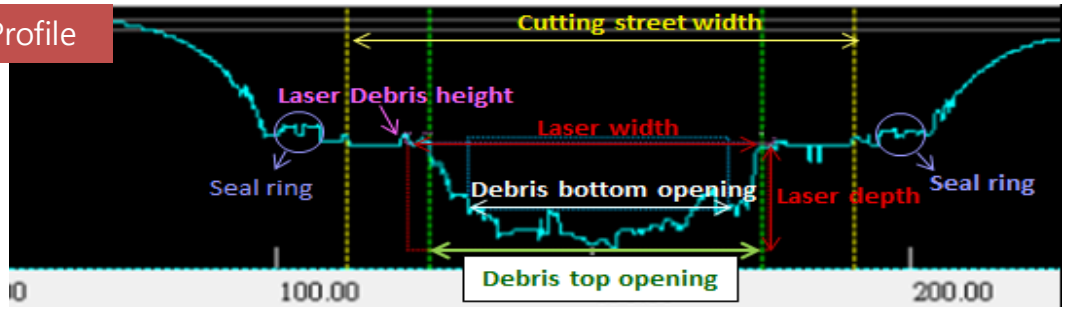
- Recipe for 28 nm low-k wafer

Stage	Type	Power(w)	Frequency (kHZ)	Index (um)	Defocus (mm)	Speed (mm/s)
Laser Saw	BSS6	1st 2.7 2nd 3.7 3rd 2.8	1st 200 2nd 40 3rd 60	1st 47 2nd 50 (mask) 3rd 50 (mask)	1st 0 2nd 0 3rd 0	1st 300 2nd 125 3rd 300

- measure the dimension of laser grooving

OM Photo

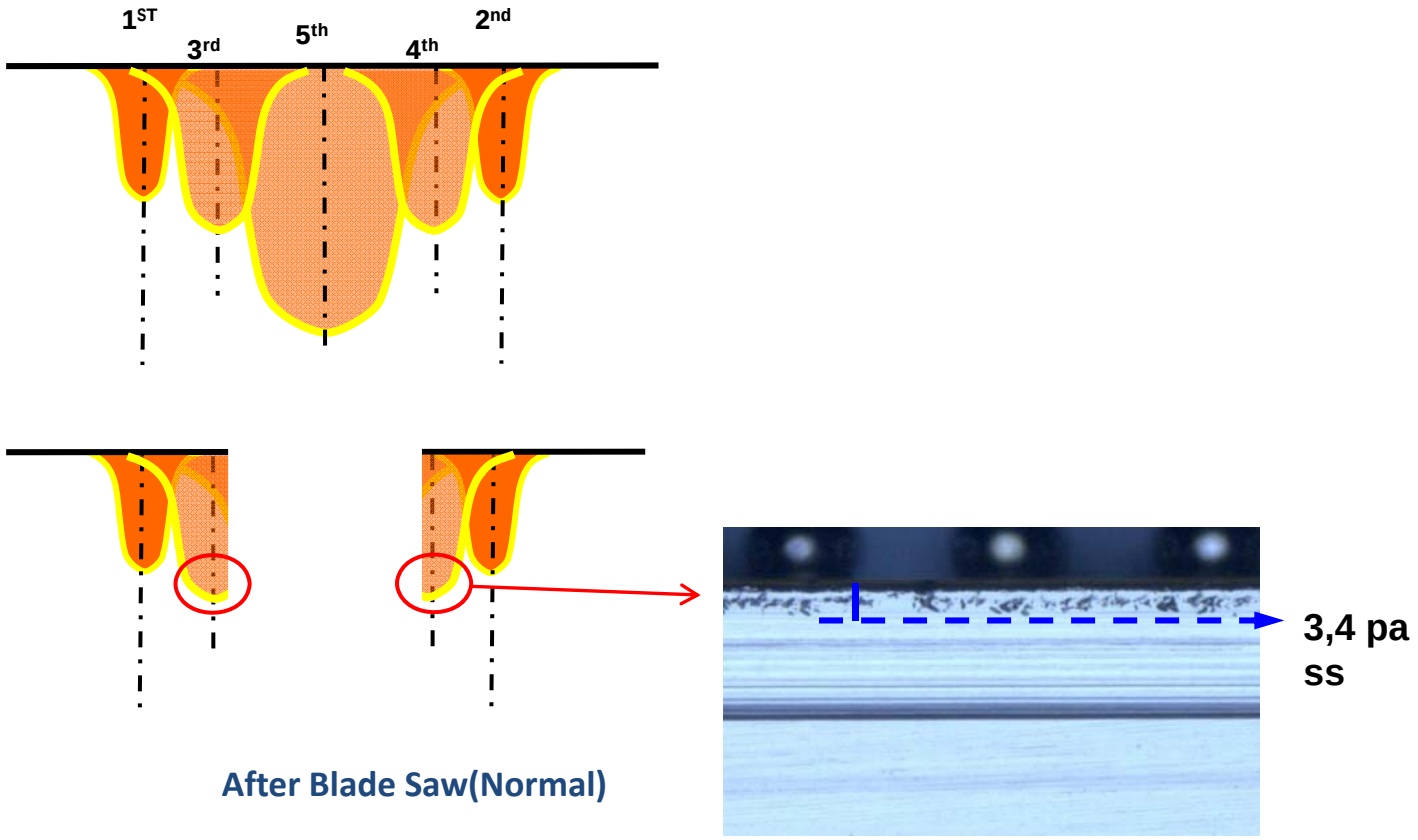
Laser Profile



- quality index

Index	criteria	Method	Min.	Max.	Avg.	STD.	CPK
Metal residue	Not allow	OM	No Metal Residue				
Kerf width	55±5 um	Laser Profile scanner	52.90	57.50	55.75	0.61	2.33
Debris top opening	50±5 um		49.16	51.75	50.63	0.85	1.71
Debris bottom opening	42.5±7.5 um		38.52	41.11	39.36	0.45	3.24
Laser Depth	14±4 um		14.31	16.36	15.18	0.32	2.90
Laser Debris	<5um		2.71	4.26	3.36	0.16	3.37

- Sidewall void for 45 nm low-k wafer

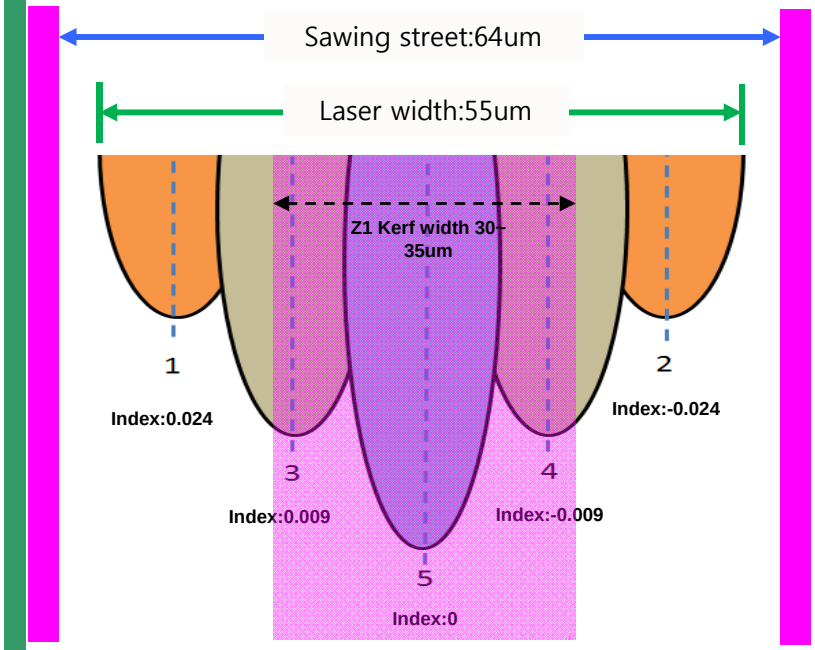


After Blade Saw(Normal)

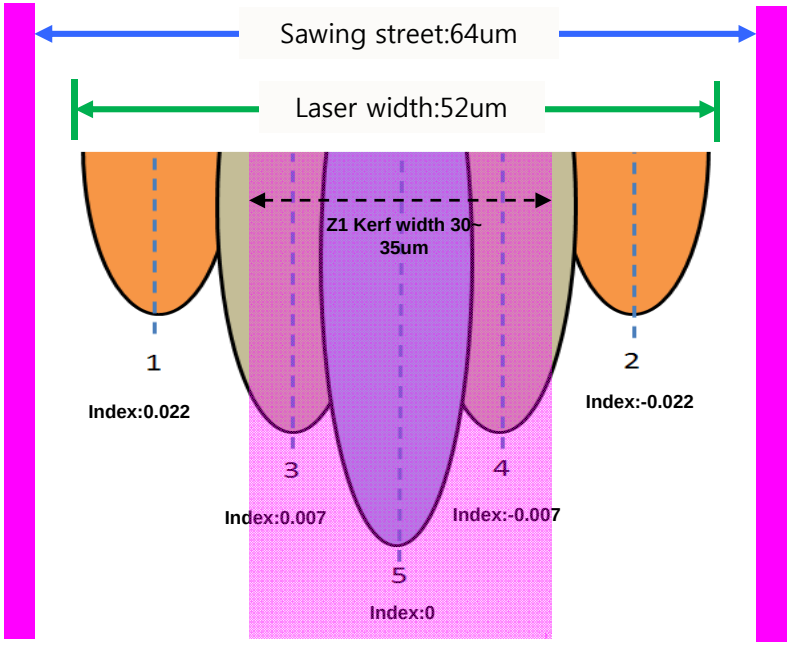
- Laser Grooving Parameter

Laser Grooving	Pass	Power (W)	Frequency (kHZ)	Speed (mm/s)	Defocus (mm)	Index (mm)
DOE1 Kerf width 55	1	1.4	200	450	0	0.024
	2	1.4	200	450	0	-0.024
	3	3.5	60	200	0.14	0.009
	4	3.5	60	200	0.14	-0.009
	5	4.5	40	200	0.2	0
DOE2 Kerf width 52	1	NC	NC	NC	NC	0.022
	2	NC	NC	NC	NC	-0.022
	3	NC	NC	NC	NC	0.007
	4	NC	NC	NC	NC	-0.007
	5	NC	NC	NC	NC	0
DOE3 Kerf width 47	1	NC	NC	NC	NC	0.02
	2	NC	NC	NC	NC	-0.02
	3	NC	NC	NC	NC	0.005
	4	NC	NC	NC	NC	-0.005
	5	NC	NC	NC	NC	0

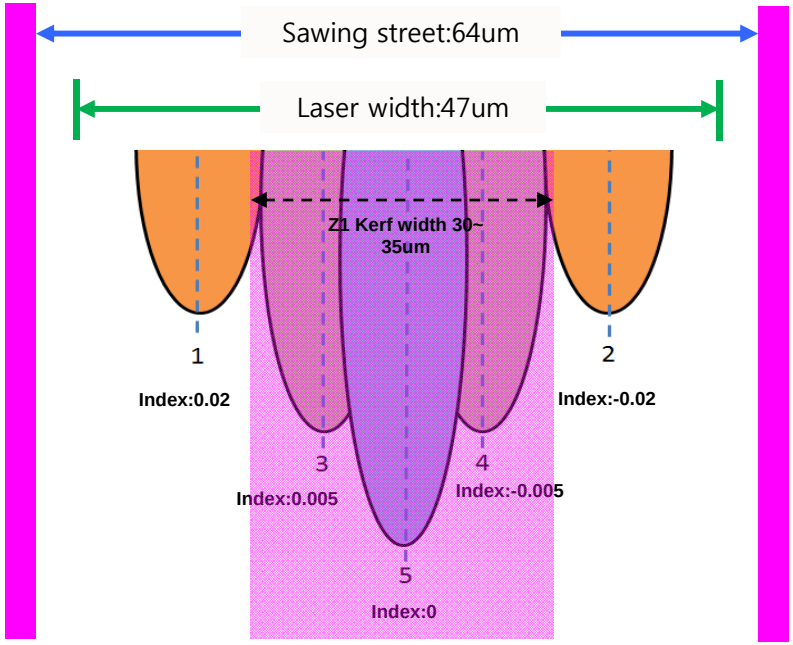
NC : same as DOE1


Sawing street:64um
Laser width:55um
Z1 Kerf width 30~35um
1
Index:0.024
2
Index:-0.024
3
Index:0.009
4
Index:-0.009
5
Index:0

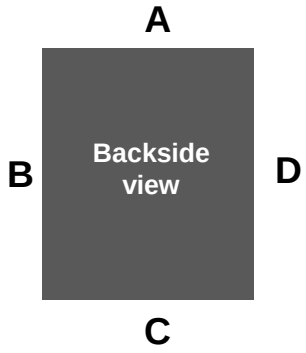
DOE 1

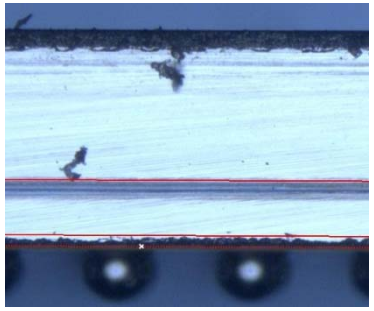

Sawing street:64um
Laser width:52um
Z1 Kerf width 30~35um
1
Index:0.022
2
Index:-0.022
3
Index:0.007
4
Index:-0.007
5
Index:0

DOE 2


Sawing street:64um
Laser width:47um
Z1 Kerf width 30~ 35um
1
Index:0.02
2
Index:-0.02
3
Index:0.005
4
Index:-0.005
5
Index:0

DOE 3

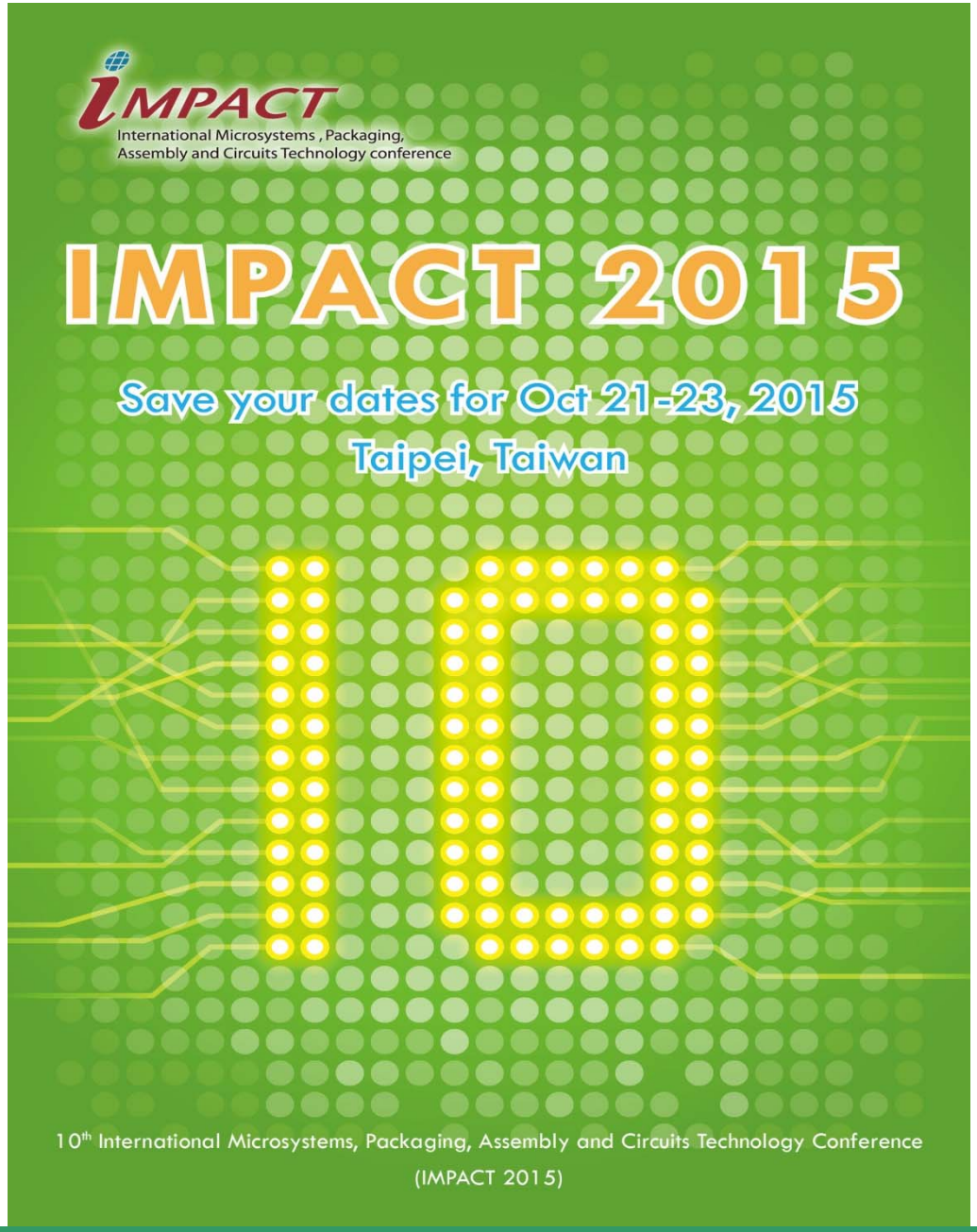




- For all 4-side, only DOE 3 eliminate sidewall voids.

Summary

- A 30W 10 ps green (515 nm) mode-locked fiber laser was successfully applied to 3D IC packaging.
- The cutting speed at 800mm/sec and 50 % of power can satisfy most of the requirement.
- For laser grooving, excellent performance has been satisfied industrial standard.


IMPACT
International Microsystems , Packaging,
Assembly and Circuits Technology conference
IMPACT 2015
Save your dates for Oct 21-23, 2015
Taipei, Taiwan
10th International Microsystems, Packaging, Assembly and Circuits Technology Conference
(IMPACT 2015)

kmeps

End of presentation

Thank you for your attention!