Tech Briefing 2022

December 2022

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Future of Wafer Singulation Technology

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Major Singulation Technologies at DISCO

- Other than blade dicing technology, laser dicing and plasma dicing technologies are also part of our lineup.
- Here are the characteristics of each technology using Si dicing as an example.

	Blade	Laser Ablation	Laser Stealth Dicing	Plasma Dicing
Image	Blade	Focus lens Short pulse laser Wafer	Focus lens Short pulse laser Wafer Modified layer	Fluorine plasma
Processing method	Material is cut using a blade.	Laser is focused on the wafer surface and the material is sublimated and evaporated.	Laser is focused inside the workpiece to form a modified layer. Singulated using external force.	Material is removed using plasma etching gas.
Cross-sectional view		SEM×400 Wafer thickness：50μm	SEM×500 Wafer thickness：100μm	
Characteristics	･Highly versatile. Can handle various materials by changing the type of blade. ･Industrially proved, established technology.	･Non-contact processing and mechanical load is low. ･Can handle materials that are difficult to process with blade dicing.	･Processing particles are low because it is an internal process. ･Dry processing without water.	･Entire wafer surface is processed all at once. For micro die. ･Processing damage is low with high die strength.
Use	･Majority is IC/LSI	･To remove the insulating film with low mechanical strength (Low-k film) used in high-speed logic IC.	･MEMS devices with micro mechanical structure. ･Image devices where particles are not allowed.	･RFID, etc.

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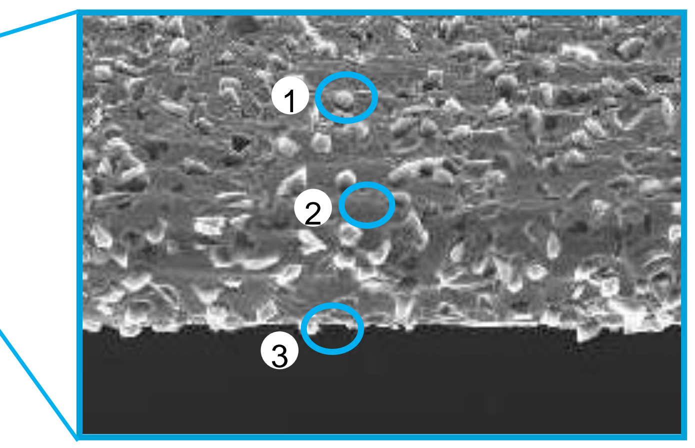
Blade Dicing Process

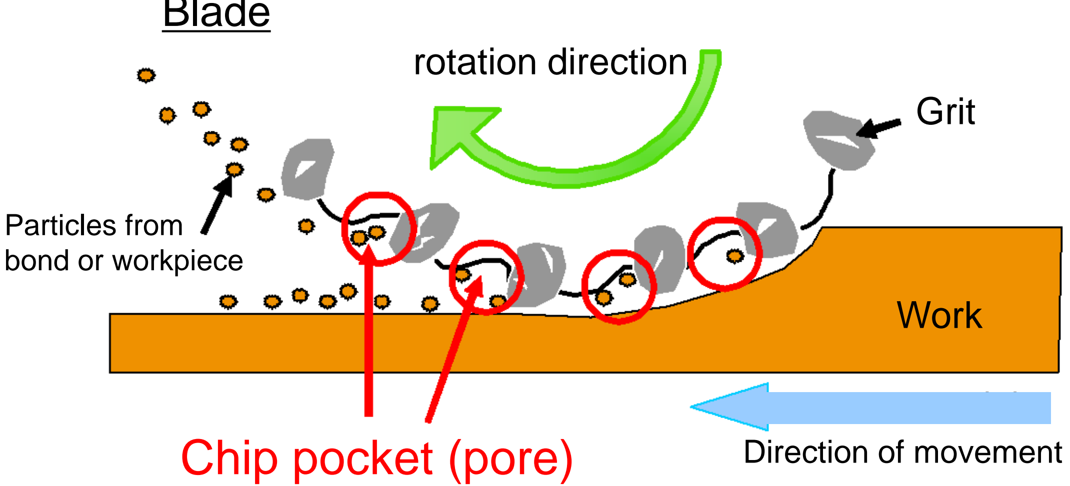
- Dicing process using the self-sharpening characteristics of a blade

The 3 major factors of a blade

Grit	Performs the actual processing
Bond	Holds the diamond grit together
Chip pocket (pore)	Catches the processing particles and the cutting water for a cooling effect

Dicing blade





- **The chip pockets catch the particles generated during cutting.**
- **In addition, water also accumulates in the pockets, cooling the processing point.**

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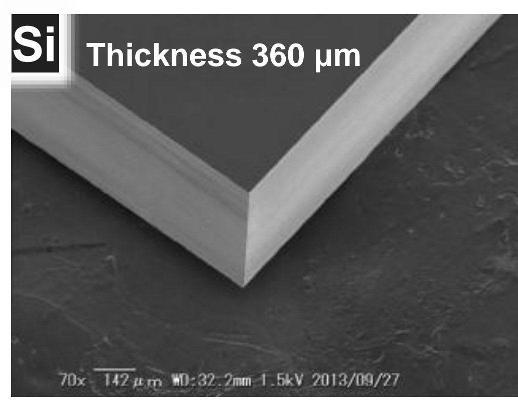
Examples of Applying Blade Dicing Equipment

- Used widely in cutting semiconductor IC, LSI, and various precision parts.
  - However, demands for processing technology are becoming advanced due to structural evolution and material change.

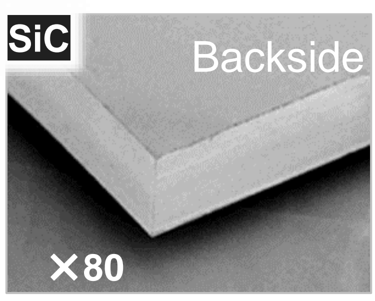
Change in shape and structure

Category	Device	Tendency of changes	Current
Semiconductors	DRAM	Lower profile substrate (thinner)	Si thickness: 50-150 μm
	NAND	Increase in layers for cell transistors Lower profile substrate (thinner)	Si thickness: < 50 μm
	Logic	Circuit miniaturization, high integration Lower profile substrate (thinner)	Si thickness: < 50 μm
	RFID	Miniaturization of die size	Die size < 1 mm
Electrical components	Ceramic capacitor	Multi-layer for internal circuit Miniaturization of die size	Capacitor size 0.2 x 0.4 mm
Medical devices	Ultrasonic probe (PZT)	Higher frequency	Frequency 2 – 12 MHz



Change in material (conventionally Si wafer)

Category	Device	Tendency of changes	Increasingly used materials
Semiconductor	Power device	Energy saving Miniaturization	SiC GaN
Electrical components	SAW filter	Higher frequency	LiTO3 LiNbO3



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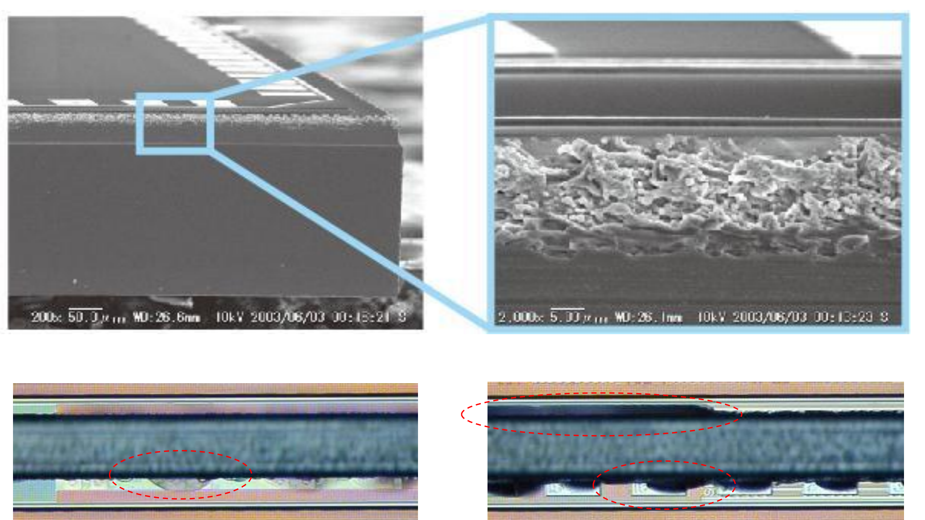
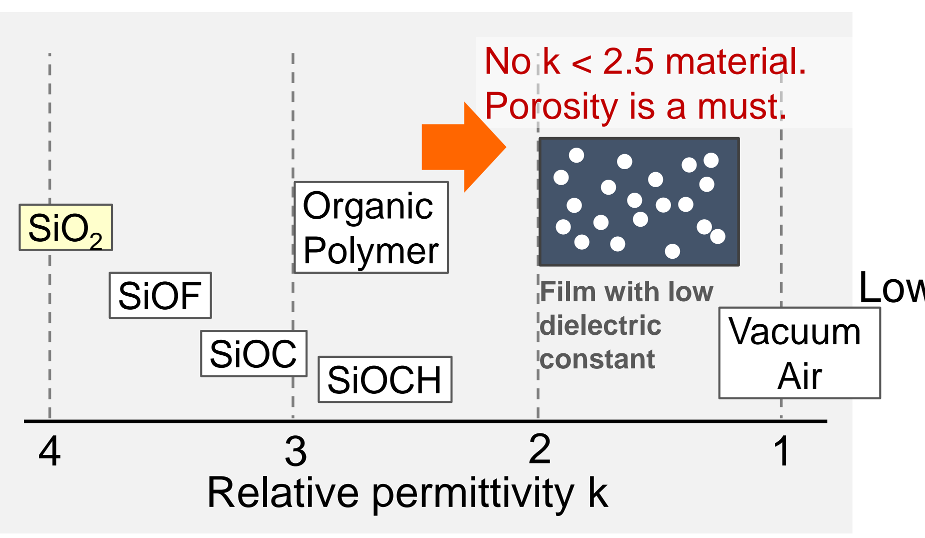
Challenges of Low-k Processing

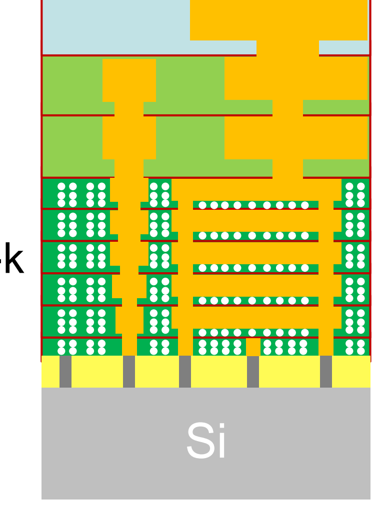
- LSI miniaturization and multi-layer wiring
- Low dielectric material (low-k) adopted for interlayer dielectrics (ILD)
- Layer peeling occurs as mechanical strength of the layer is weak



In order to reduce the permittivity, nano-level cavities are created on the entire film. Mechanical strength declines.



Cross-sectional view of wiring layer



Low-k layer in the middle moves downwards due to mechanical processing

Processing with low mechanical load is required

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- Two main processing methods are provided

Process	Laser ablation	Stealth dicing
Processing method	Laser is focused on the surface Short pulse laser Focus lens Workpiece	Laser is focused inside the material Short pulse laser Modified layer Focus lens Modified layer Workpiece SDE Stealth Dicing Engine inside! HAMAMATSU
Advantage	Can be applied to a wide range of applications	Narrow kerf Dry process
Disadvantage	Debris	Workpieces that can be processed by SD are limited (E.g.: Material, die size, with or without metal layer film)
Major device	Logic Controller BSI (image sensor) LCD driver	MEMS NAND flash memory Line sensor

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Laser Ablation Processing Principle

- Laser is absorbed by the target material and vaporized at the surface
- Laser head with a good laser absorption with regard to the workpiece is required

Image of Processing Phenomenon

Time taken for the phenomenon to occur in one pulse: 1 / 500,000 sec.

Laser

Melted area

Plasma

Shock wave

Debris

Si

Si surface is melted using laser irradiation

Plasma formation and expansion creates a pressure in the surrounding area

A shock wave occurs and the melted particles (debris) scatter

Melted area on the surface continues to scatter

Example of Si processing: A case where the pulses do not overlap

Energy is focused on the wafer surface → Possible to handle various materials

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Combined with Blade Dicing

- Wiring layer is removed using a laser that does not directly come into contact
- No interlayer dielectrics (ILD) peeling as no mechanical processing load is added from processing

HogoMax
TEG
Low-k layer
Metal wiring
Silicon
Tape
Debris
Laser
No debris
No delamination
Blade

Protective film coating → **Laser grooving** → **Spinner cleaning** → **Blade dicing**

Blade half cut	Laser grooving
Blade half cut (#1500 resin blade)	Laser grooving
Blade half cut + Blade full cut	Laser grooving + Blade full cut

Film peeling from blade dicing

No film peeling, no debris

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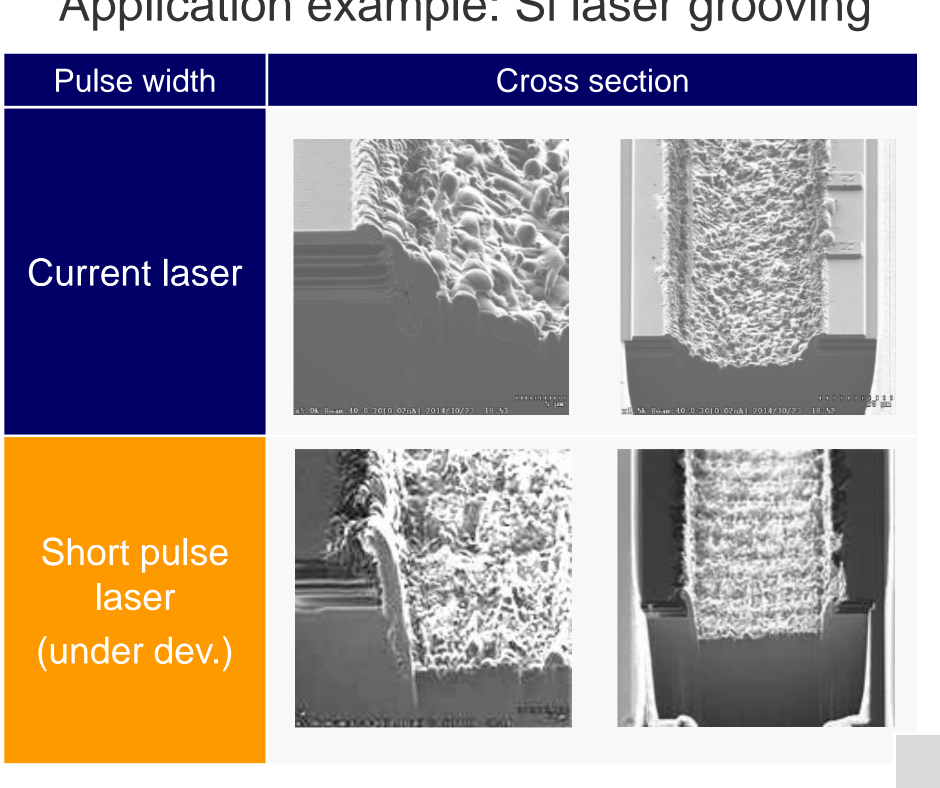
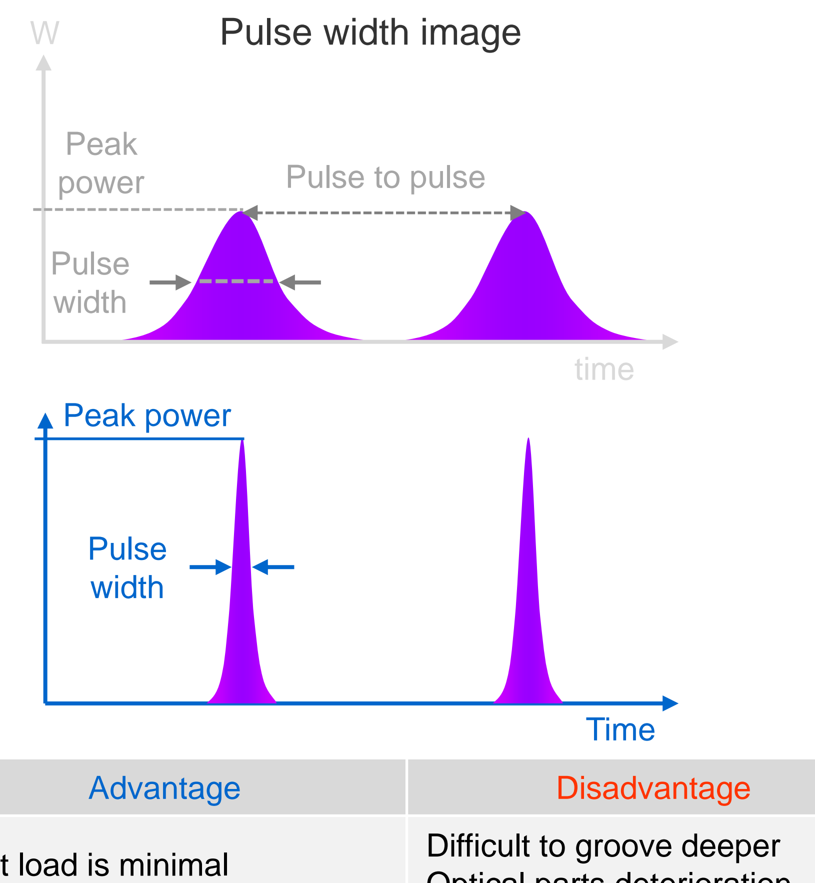
The Direction That Laser Development is Proceeding in

- Laser processing with minimal heat damage
  - Compared to the conventional laser, the duration of one pulse is shorter and melting during processing is minimal.
  - Optics design is critical as laser head is outsourced.

Application example: Si laser grooving





Advantage	Disadvantage
Heat load is minimal	Difficult to groove deeper Optical parts deterioration

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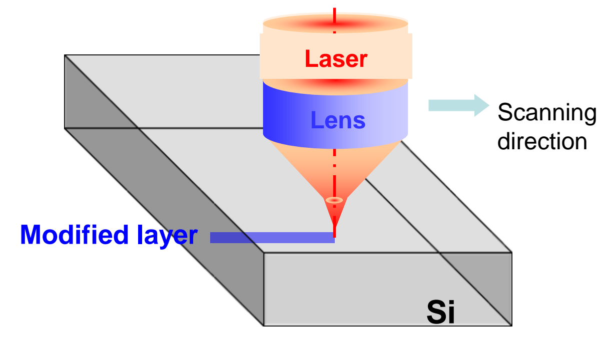
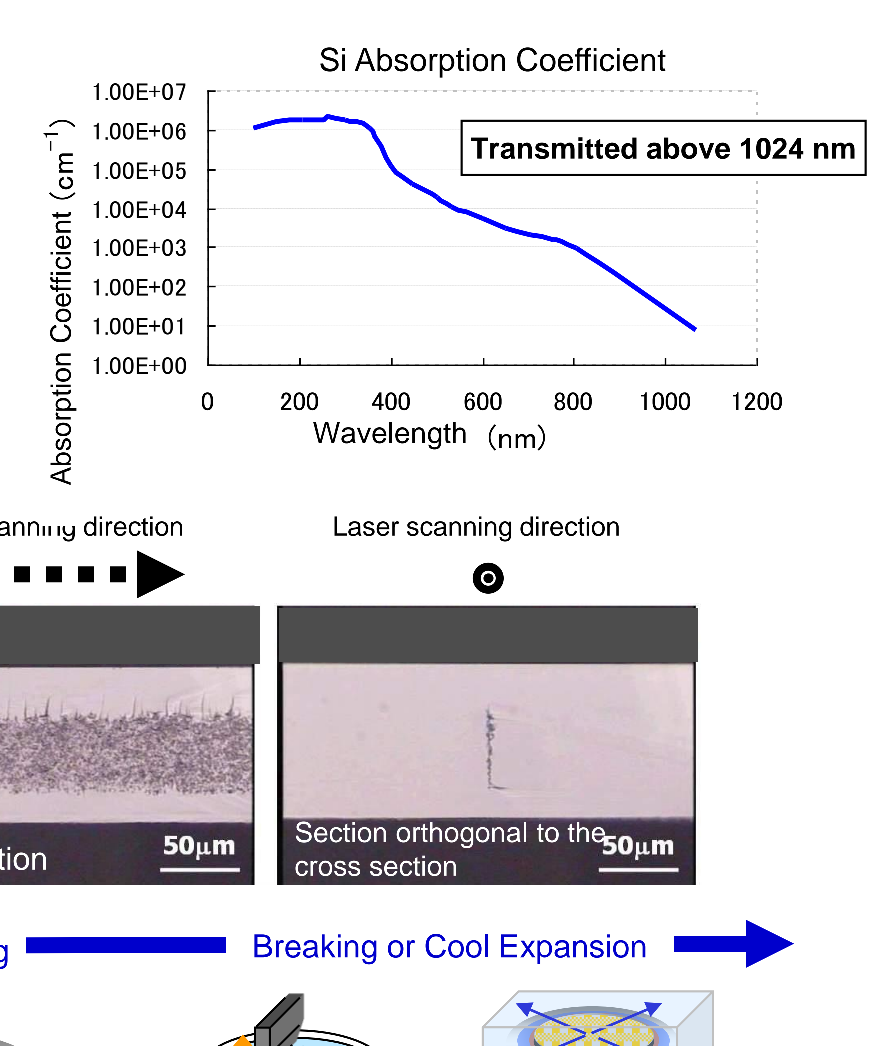
- SD Process Flow
  - Modified layer formation
    - By focusing a laser beam that can be transmitted through Si, nonlinear absorption occurs.
      - No damage other than at the focus point
  - Modified layer formation





Mounted on expandable tape

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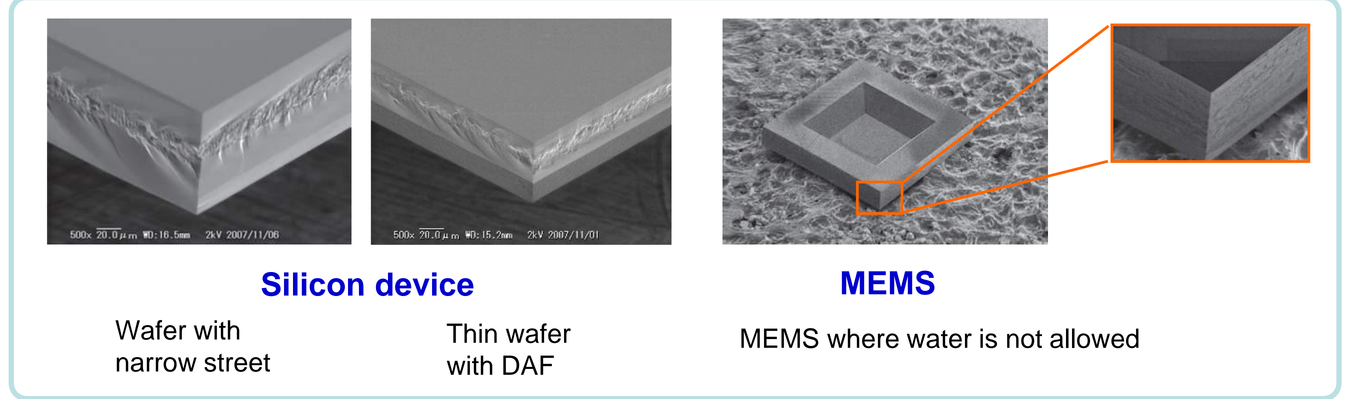
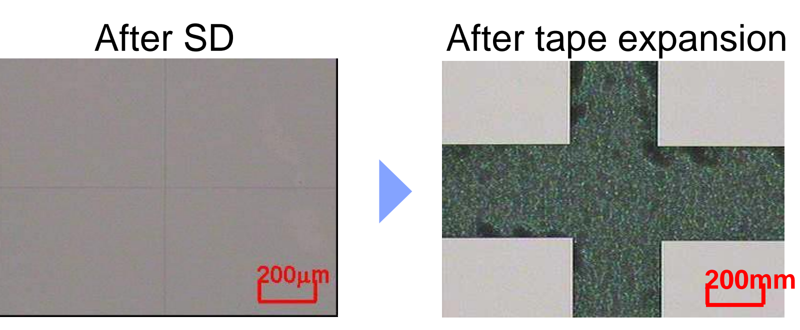
Characteristics of Stealth Dicing

Compared to a dicing saw, 10 times the water of a 25 m pool can be saved

- Dry process without using water
  - Possible to process MEMS wafers, where water is not allowed, without any damage
- No mechanical load on the workpiece during processing
  - Possible to process thin wafer/MEMS with low strength



- No contamination generation
  - No processing particles are generated as modification occurs inside the workpiece
- Almost no kerf width
  - As kerf width can be made extremely narrow, the die obtained per wafer increases



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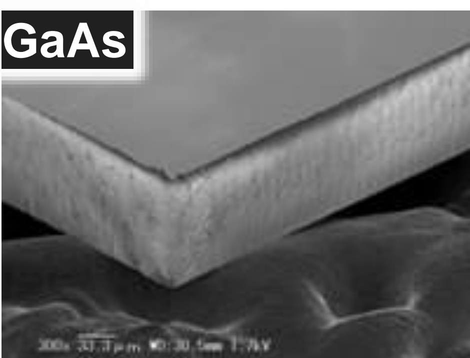
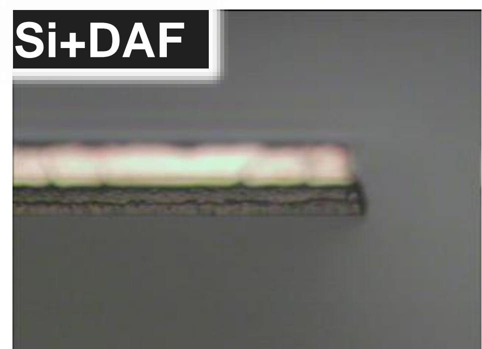
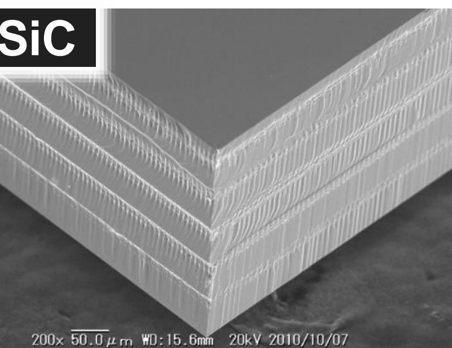
Laser Processing Examples

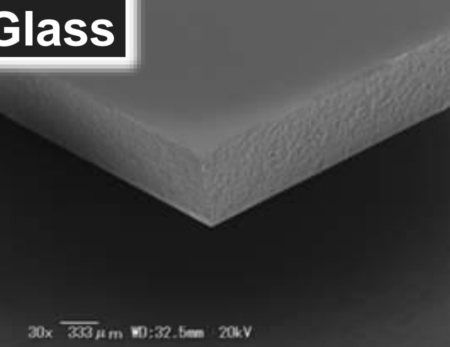
- Ablation
  - Devices that use an insulating film (low-k) between circuits
    - Logic
    - Controller
    - BSI
    - LCD driver
  - Analog device
    - RFIC
  - Power device
    - IGBT
  - Others
    - DAF cut





- SD
  - Water is not allowed
    - MEMS (Si microphone)
  - Ultra-thin device
    - NAND flash
  - Long or small die
    - Line sensor
  - Viscous material
    - SAW device
  - Illumination
    - Blue LED
  - Others
    - Multi-layer DRAM
    - Si-photonics





Adopted in many areas due to the superiority of laser processing
→ Mostly to complement blade dicing or for areas that cannot be handled by blade dicing

No mechanical load, but this does not mean that there is no damage

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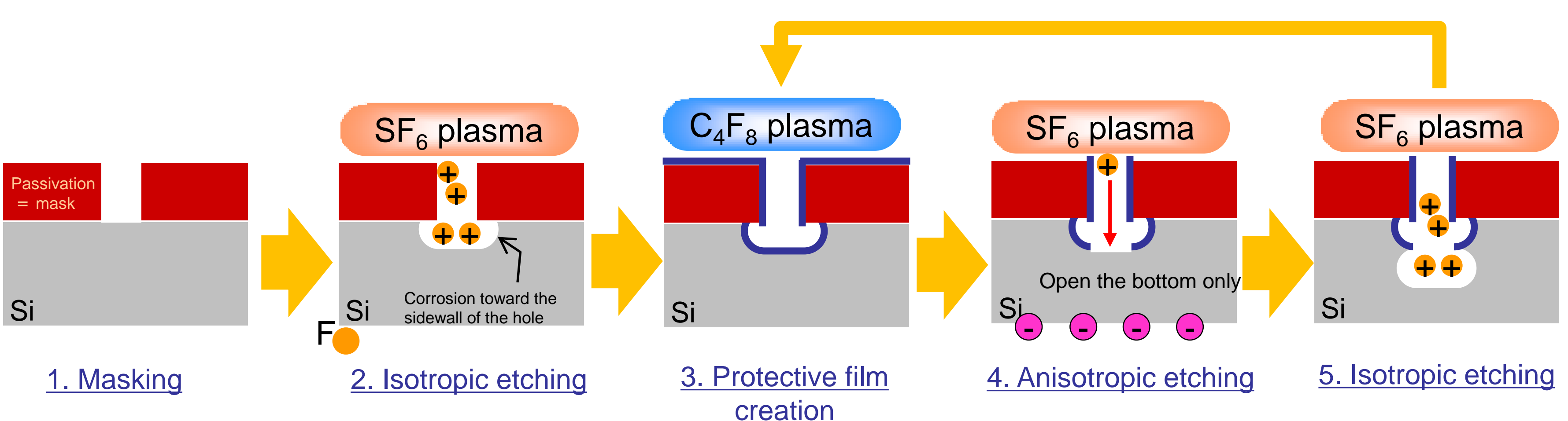
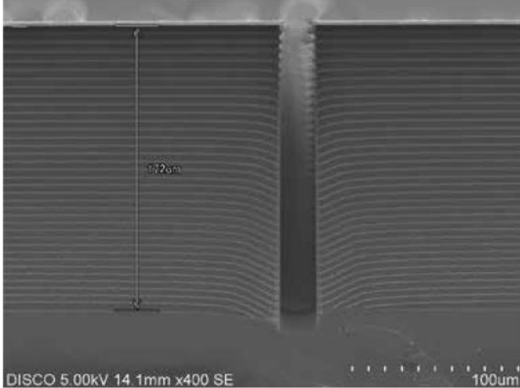
- Basic principle is dry etching using reactive gas
  - When making thin and deep holes using standard etching, corrosion occurs toward the sidewalls (Fig.2)
  - For this reason, the Bosch Process is used (process developed by the German company Robert Bosch in 1992)
  - By repeating the “etching” and “deposition” processes alternatively, it is possible to dig a deeper hole

Bosch Process:



Processing example



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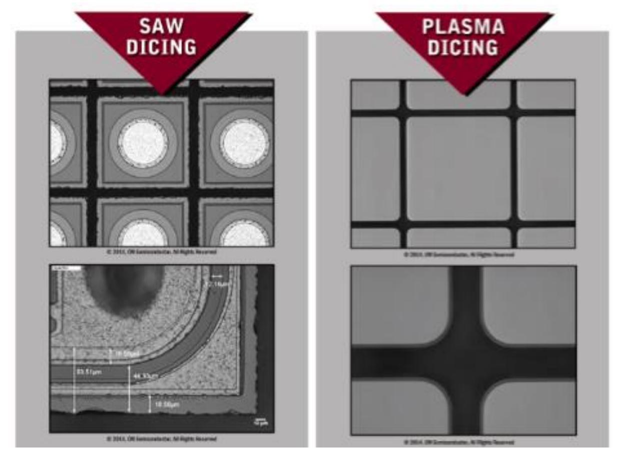
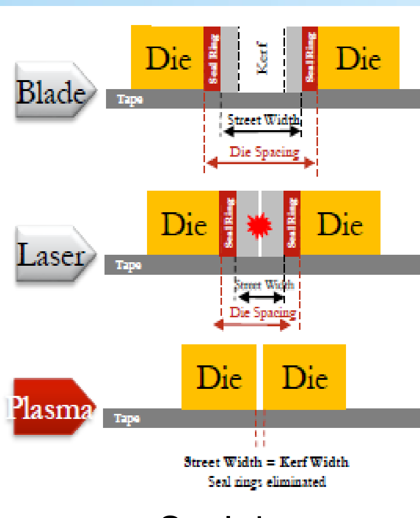
Characteristics of Plasma Dicing

- Die strength improvement
  - Possible to achieve no cracks or chipping
  - No physical or thermal damage
- High UPH
  - Surface processing allows separation of all lines at the same time

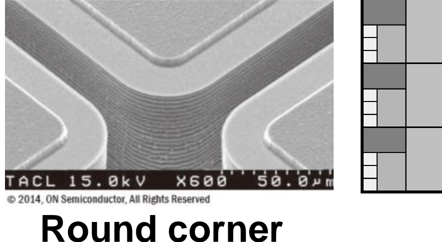


Die strength

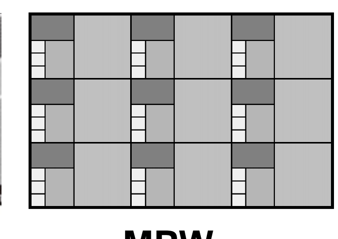


Seal ring

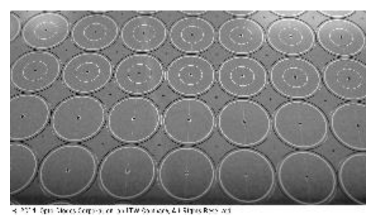
- No. of die per wafer can be increased by making the street width narrower
  - Narrow kerf due to dry etching
  - Seal ring is not required as there is no chipping
  - No cut shift
- Can process irregular shapes
  - Round corners
  - Hexagonal shapes
  - MPW, round shapes, etc.



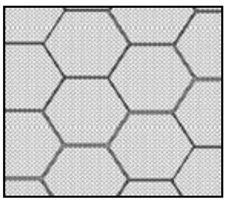
Round corner



MPW



Round



Hexagon

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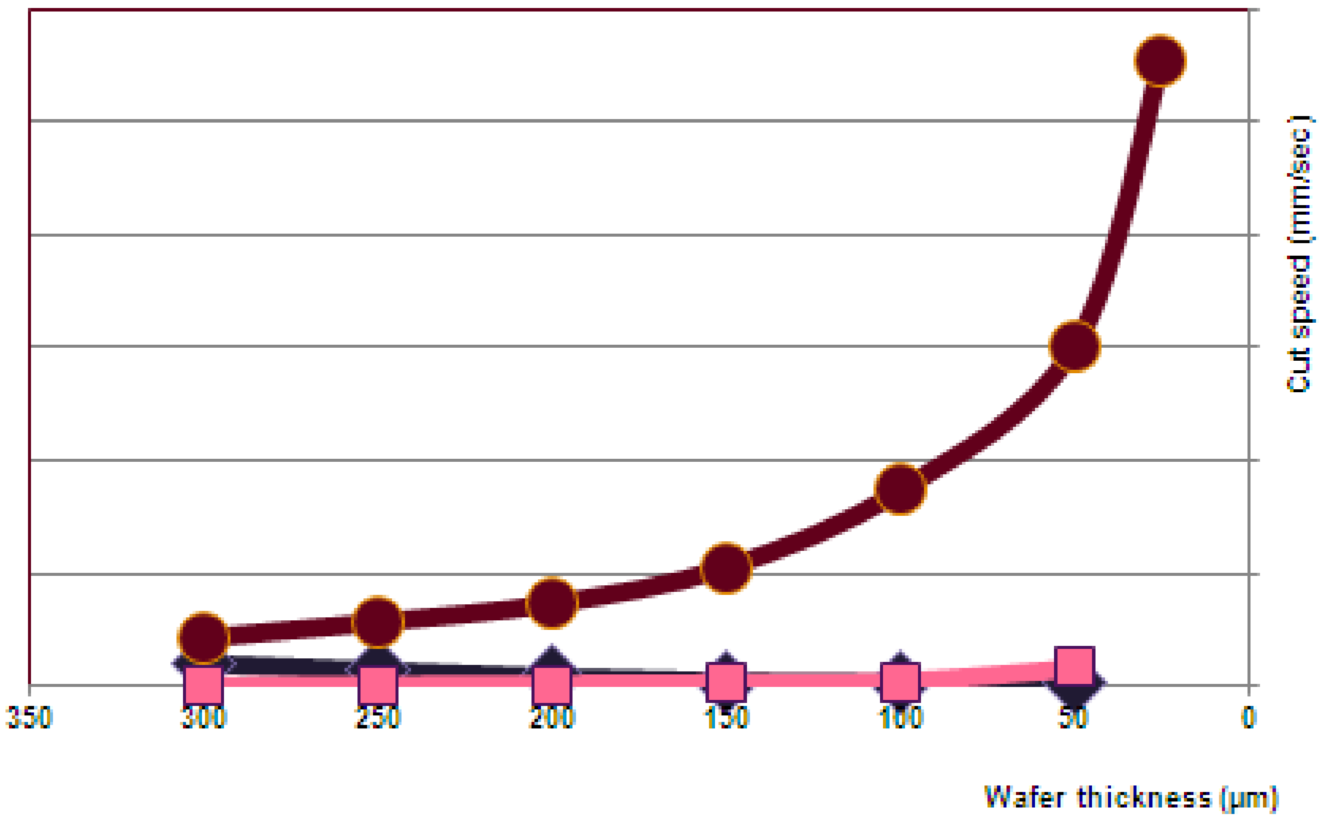
UPH Compared to Other Processes

- UPH drastically increases as the wafer becomes thinner
  - Plasma dicing is not suitable for thick devices



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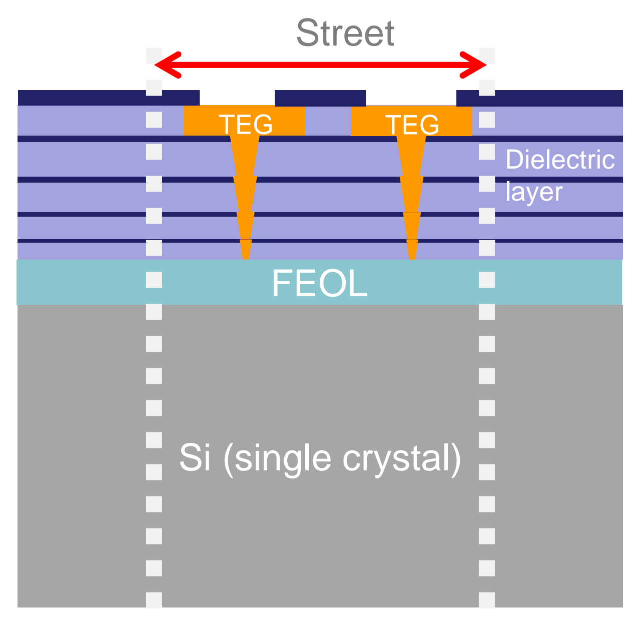
Structure of Dicing Area (Street)



Street (dicing area):

Circuit layer: SiN, SiO2, interlayer dielectrics (ILD), circuit metal

FEOL layer: p-type Si, n-type Si, oxide film, contact metal

Si substrate: single crystal (physical property changes based on dopant amount)

Blade	Various materials can be processed. As long as blade loading does not occur, processing is possible. It is not suitable for mechanically delicate materials.
Laser	Laser wavelength and material used (absorption rate) need to be matched. Material is not sublimated but melted instead, so processing quality deteriorates.
Plasma	If the material is suitable for plasma, high processing quality can be achieved, but there is no versatile etching gas. It tends to be high cost because of mask processing and exhaust gas processing.

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Comparison of Processes

- Process flow comparison (singulation after thinning)

Process	Process flow
Blade dicing	Simple with not many processes Blade dicing
Laser ablation	No. of processes and consumables increases HogoMax coating → Laser grooving → HogoMax removal → Blade dicing
Stealth dicing	Materials that can be processed are limited Stealth Dicing → Tape remount → Tape expansion
Plasma dicing	No. of processes and consumables increases. Gas processing facility is required. Suitable materials are limited. Resist coating → Laser grooving → Remote plasma → Resist removal

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Cost Comparison (Image)

- There are advantages and disadvantages for each application.
- Plasma dicing is a good method if the device is suitable for plasma dicing.
  – For needs that place emphasis on safety such as automotive devices
  – For thin φ300-mm Si with small die: High added value

Image:

	Blade dicing	Laser ablation	Stealth dicing	Plasma dicing
Equipment price (fully automatic)	1	3 to 5 or more	4 to 7 or more	6 to 10 or more
Consumables/year	1	1 to 5 or more	1	2 to 6 or more
Water, air, electricity	1	0.1 or less	0.1 or less	5 ?
# of wafers processed/h	1	1 to 5 (depends on material)	5 or more (depends on material)	10? (if suitable)
Thickness that can be full cut	70 to 775 μm	150 μm or less	50 to 775 μm	775 μm (lower UPH as wafer thickness increases)
Unsuitable materials	Metal, viscous materials (GaAs, SiC, LT), multi-layer structure	Thick materials (if too much heat is applied, molten substances may be generated)	Metal, ceramic, materials with film, materials that do not allow inner laser focusing	Materials other than Si

*May differ from the above depending on various conditions

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Sales Transition of Laser Equipment

- First equipment was released in 2002
  - Laser equipment did not compete with blade dicing equipment, and sales increased for both
  - Laser equipment progressed to being an application that supports materials that are not suited for blade dicing
- It is difficult for a new process (plasma dicing) to completely exterminate the others

Trend of Dicing Saw Shipment Amount

45%
40%
35%
30%
25%
20%
15%
10%
5%
0%

FY05 FY06 FY07 FY08 FY09 FY10 FY11 FY12 FY13 FY14 FY15 FY16 FY17 FY18 FY19 FY20 FY21

Blade dicer
Laser saw
Percentage of laser made up for by dicer

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Summary

- Blade dicing is a stable process with many past results
  - It can be applied to a wide range of applications and devices
- Laser dicing was developed to handle high-performance semiconductors
  - By combining blade and laser, the applicable devices increased
  - Some areas that are not suited for blade dicing are covered by laser alone
- Plasma dicing makes it possible to achieve damage-less processing
  - However, many obstacles exist for the application of plasma dicing
  - For stable processing, combination with laser is being considered
- Demands for versatile blades will continue in the future as well

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KKM for Power Devices

- From wafer making to device manufacturing -

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Agenda

- What is a power device?
  - Types/market
  - Difference from general-purpose IC
  - Advantages of SiC
- DISCO's KKM for power devices
  - Solutions for Si
    - Wafer making
    - Device thinning: TAIKO
  - Solutions for SiC
    - Wafer making: KABRA
    - Device thinning
    - Device singulation: Ultrasonic dicing, Stealth Dicing

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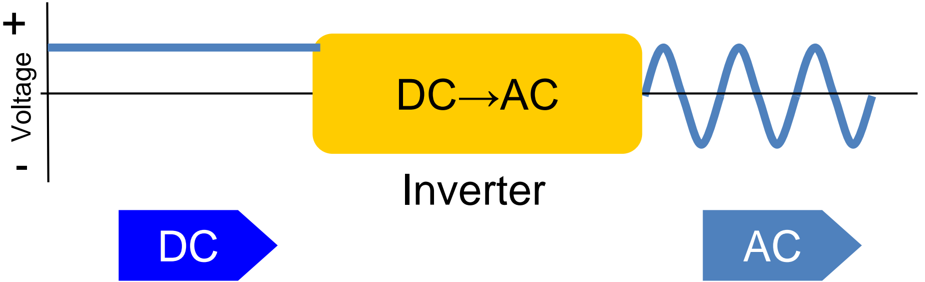
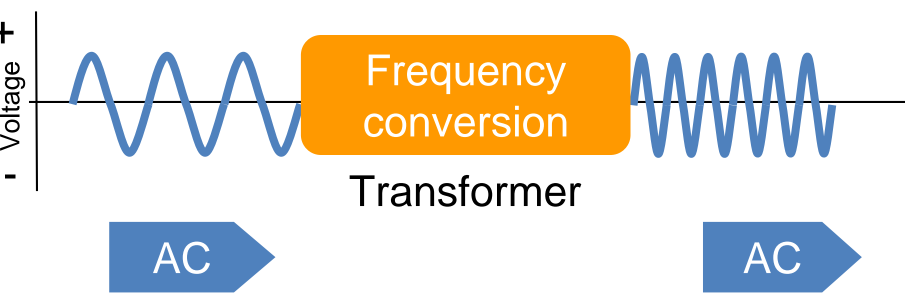
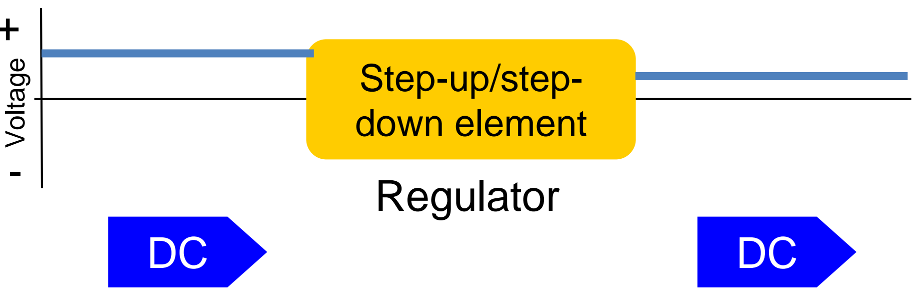
What is a Power Device? - Types

- Power devices are semiconductor electrical components used for power control
  - DC ⇔ AC conversion inverter/converter
  - Amplification element, step-up/ step-down element







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What is a Power Device? - Market

High-voltage devices

Power generation facilities

Transmission facilities

Mid-voltage devices

Trains

Factory facilities

Social infrastructure

HV, EV, electric vehicles

Low-voltage devices

PC routers

General electronics

PC-related equipment

Household solar cells

Servers

AC adapters

Rated current value (A): 10k, 5k, 1k, 500, 100, 50, 10, 5

Rated voltage value (V): 10, 50, 100, 500, 1k, 5k, 10k, 50k, 100k

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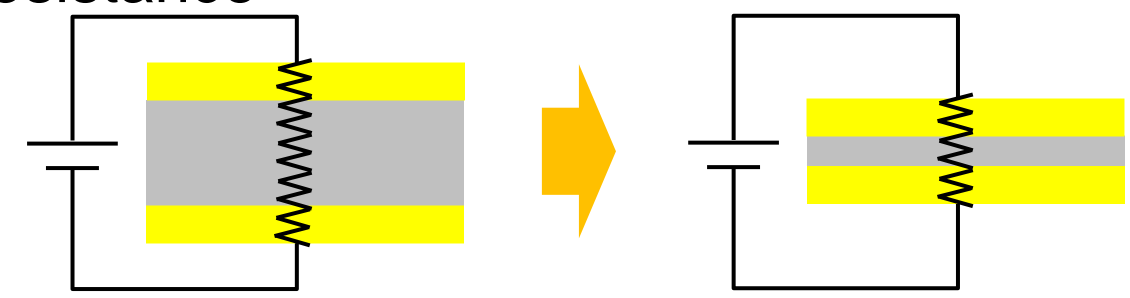
What is a Power Device? - Difference from General-purpose IC

	Power device	General purpose IC
Function	Power control	Data processing
Structure	Vertical structure	Horizontal structure
Reason for thinning	Reduction of internal resistance	Final product thinning and die stacking

- Reason for thinning: reduction of internal resistance
  - Reduced power loss
    Output Power = V^2 / R, or larger
  - Faster switching speed



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What is a Power Device? - Difference from General-purpose IC

	Power device		General purpose IC	
Structure	Vertical	Current	Horizontal	Current
Processing method	Substrate (Si, SiC, etc.)	Wafer	Substrate (Si)	Wafer
	Front-end process	Pattern	Front-end process	Pattern
	Substrate thinning		Substrate thinning	
	Backside process (metal deposition, etc.)	Pattern		
	Singulation			

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Advantages of SiC

- SiC surpasses Si in the following characteristics, especially in having high voltage resistance

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  - Solutions for SiC
    - Wafer making: KABRA
    - Device thinning
    - Device singulation: Ultrasonic dicing, Stealth Dicing

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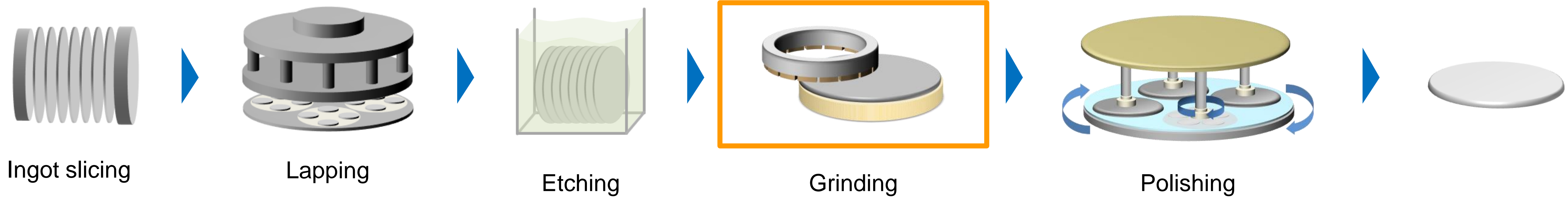
Si Wafer Making

- DISCO's KKM for Si wafer making

[Example of the general process flow (not limited to power devices)] *The process differs depending on the manufacturer



  - High-precision, small-volume grinding ⇒ Reduced load in the next process and improved flatness of the final wafer using shape adjustment

- Change in wafer diameter for power devices
  - NAND memory chip size: 10 mm x 10 mm, relatively large
    ⇒ 300 mm wafers are common in order to increase the number of die per wafer
  - The chip size of power devices is relatively small (few mm x few mm)
    ⇒ 8 inch wafers used to be mainstream, but 300 mm wafers are starting to increase

Calculated with

- 8 inch wafer
  10 mm x 10 mm approx. 270 die
  1 mm x 1 mm approx. 2,700 die
- 300 mm wafer
  10 mm x 10 mm approx. 640 die
  1 mm x 1 mm approx. 6,200 die

Edge exclusion 2 mm
Street width 50 μm

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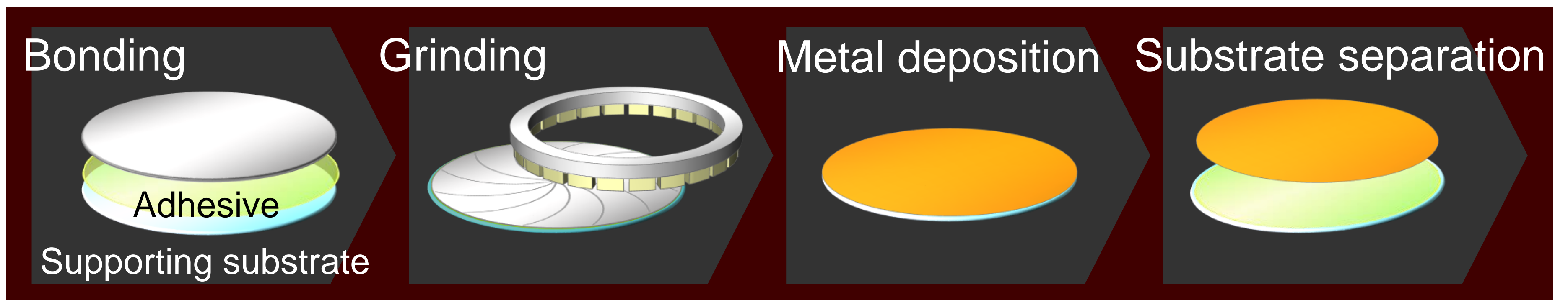
Device Thinning: TAIKO

- Easy wafer handling is required for power devices due to the backside process after thinning.

[Hard substrate method]



– Increased costs due to additional materials, outgassing due to high-temperature processes such as metal deposition

[TAIKO] A technology that leaves an edge area on the outermost circumference of the wafer and grinds only the inner circumference to make it thinner

φ300 mm×50 μm

Reduced handling risk of thin wafers
- Improved wafer strength
- Reduced wafer warpage

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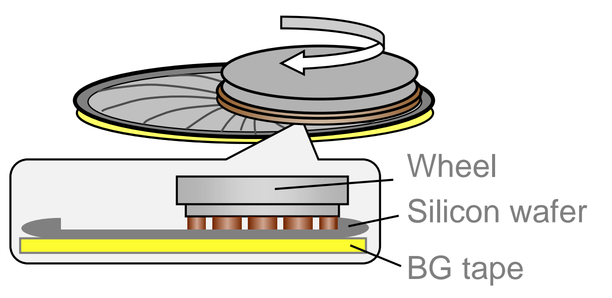
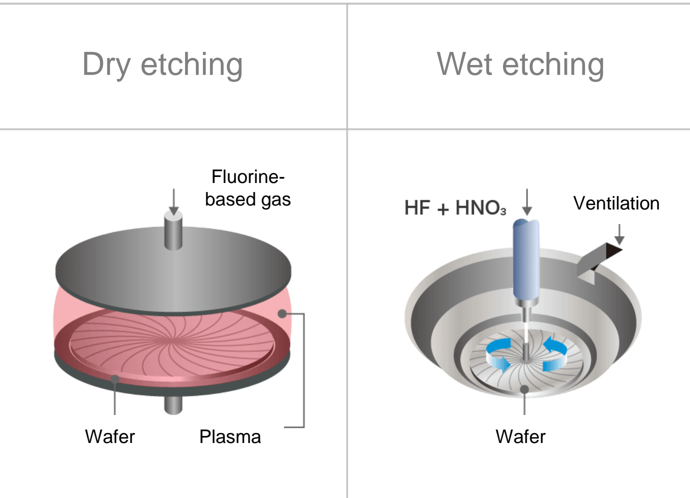
Device Thinning: TAIKO

BG tape lamination

TAIKO grinding



Stress relief Dry/wet



BG tape peeling

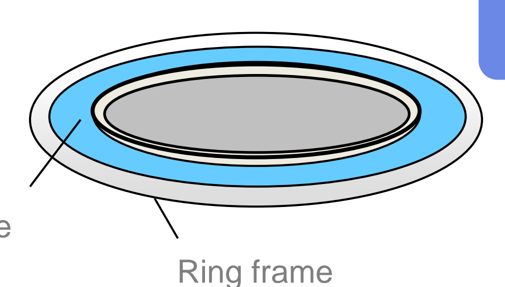
Backside process

- Ion implantation
- Annealing
- Backside metal deposition
- Wafer testing, etc.

Dicing tape mounting

Ring removal

Dicing



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Agenda

- What is a power device?
  - Types/market
  - Difference from general-purpose IC
  - Advantages of SiC
- DISCO's KKM for power devices
  - Solutions for Si
    - Wafer making
    - Device thinning: TAIKO
  - Solutions for SiC
    - Wafer making: KABRA
    - Device thinning
    - Device singulation: Ultrasonic dicing, Stealth Dicing

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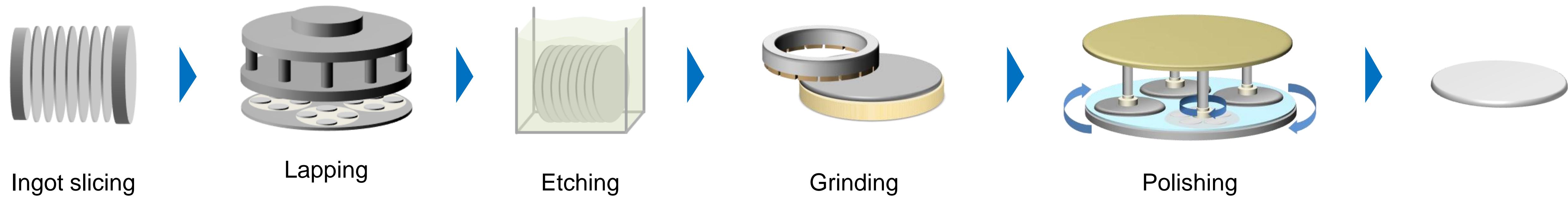
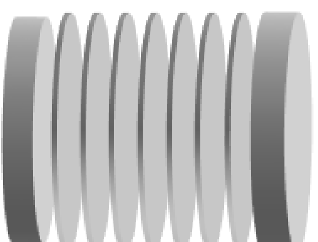
SiC Wafer Making: KABRA

- Conventional process (same as Si)

*The process differs depending on the manufacturer



  - Higher density and harder than Si ⇒ Lower productivity during processing and increased costs
  - Higher material cost than Si ⇒ Material loss during processing is an issue



Ingot slicing: conventional process using a wire saw

Processing time: 100 hours (approx. 3.1 hours per wafer)
*When producing 350 μm thick wafers from a 6 inch, 20 mm thick ingot

Material loss: 180 μm
*The ratio of material loss is large for a wafer thickness of 350 μm

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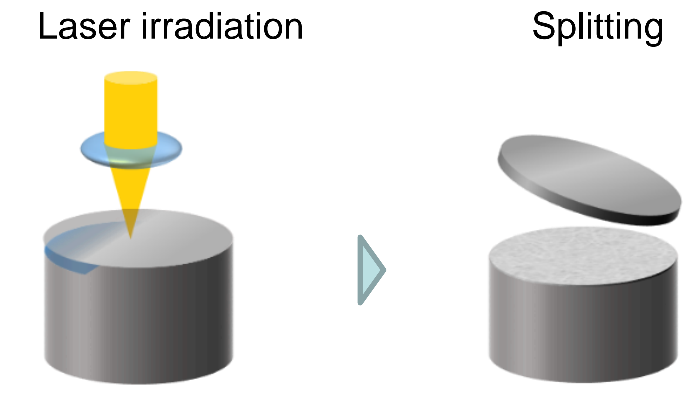
SiC Wafer Making: KABRA

- New SiC ingot slicing technology using laser
  - Significant reduction in processing time,1.4 times increase in wafer production volume

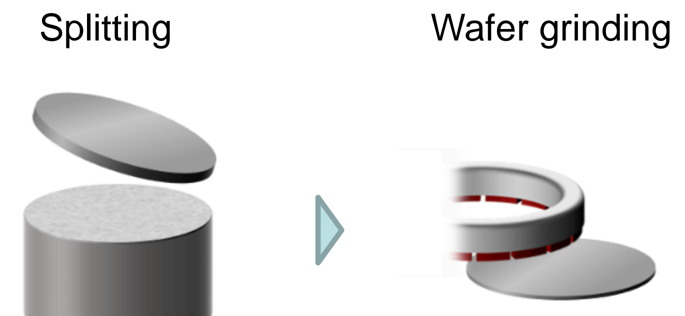


Processing time: 10 min per wafer (conventional: 3.1h)
*When producing 350 μm thick wafers from a 6 inch, 20 mm thick ingot

*When laser irradiation, peeling, and ingot grinding are done in parallel for multiple ingots

Material loss: 80 μm (conventional: 180 μm)
The number of wafers obtained per ingot is 1.4 times that of the conventional process

  - No lapping process necessary



Conventional:
Lapping is necessary to remove wafer undulation caused by wire saw

KABRA:
Wafer undulation can be suppressed, so lapping is unnecessary

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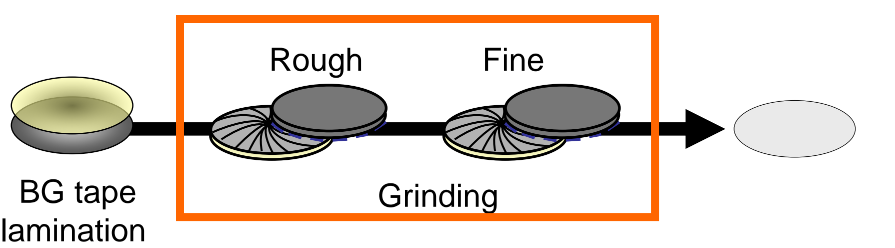
SiC Device Thinning

- Various processes according to processing quality and productivity
  - 2-axis grinding



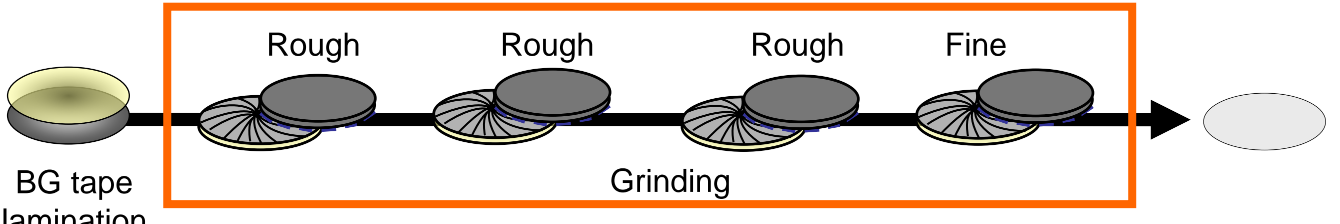
DFG8540
General-purpose 2-axis grinder

High-power spindle for SiC grinding

DFG8640
High-precision 2-axis grinder

Optimized processing point layout and installation of various functions make high-precision grinding, including SiC, possible

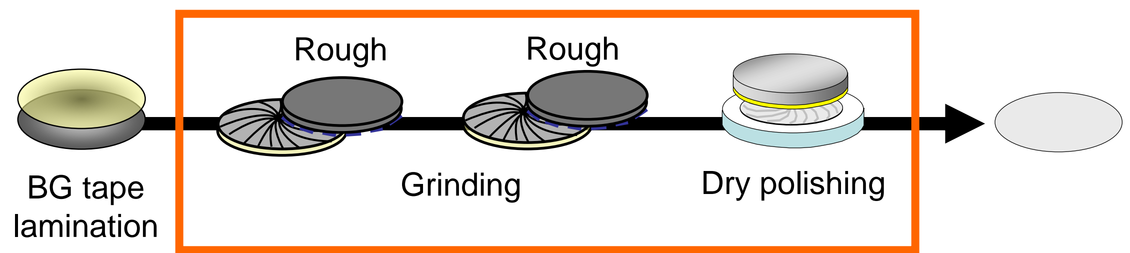
  - UPH improvement with 4-axis grinding



DFG8830
4-axis grinder

Improved productivity by mounting optimal wheels on four axes

  - Quality improvement by dry polishing (DP)



DGP8761
Grinder/polisher with 2-axis grinding, 1-axis polishing

From thinning to polishing in a single unit

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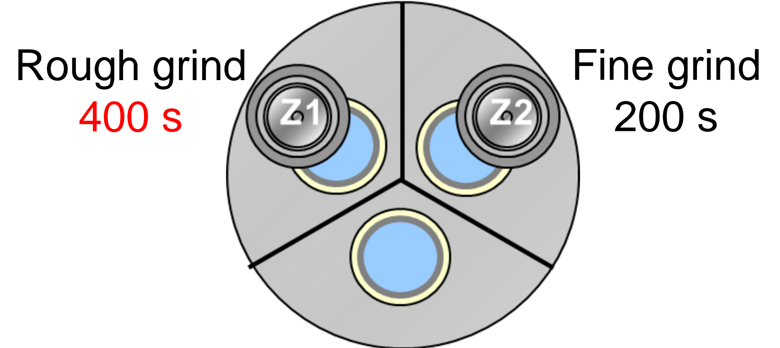
Device Thinning

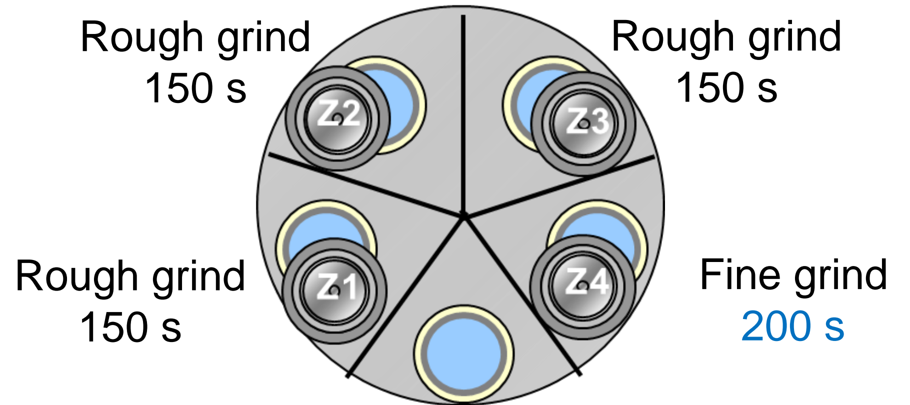
- Improved productivity with 4-axis grinding

*The processing times are reference values and differ from the actual processing times

– 2-axis grinding: rate determining time 400 s



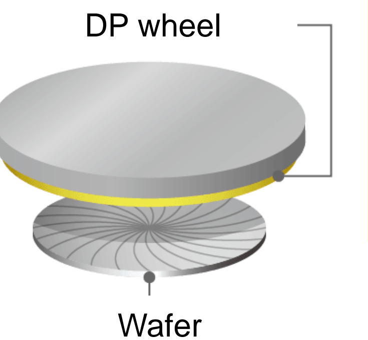
– 4-axis grinding: rate determining time 200 s



- Improved quality with dry polishing

– DISCO's original dry polishing

- Environmentally friendly process that does not use water or slurry

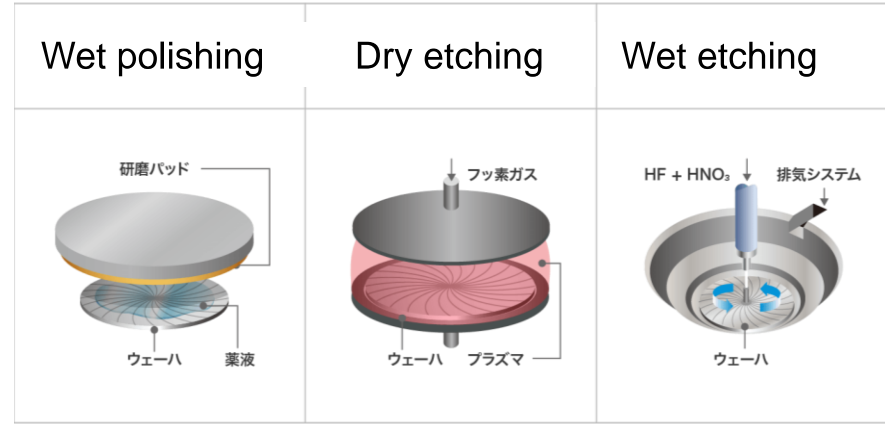


Removal of grinding damage

– Higher die strength

– Less wafer warpage

【Other polishing examples】



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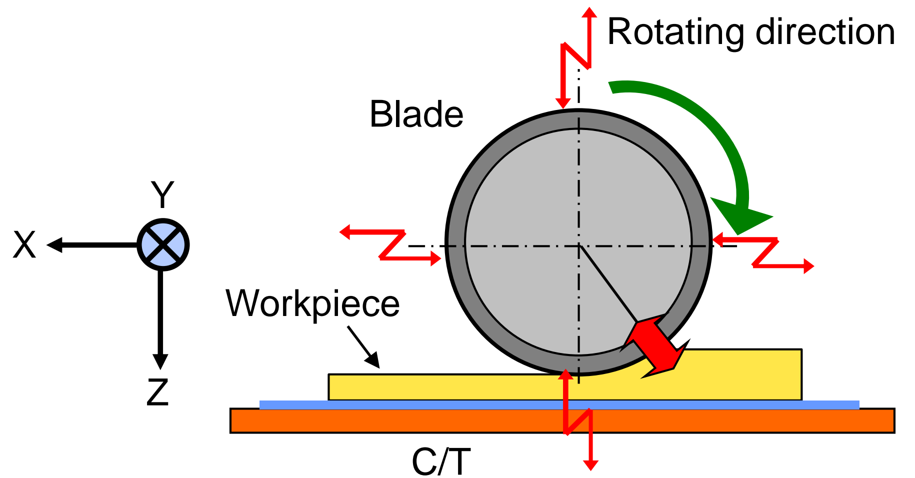
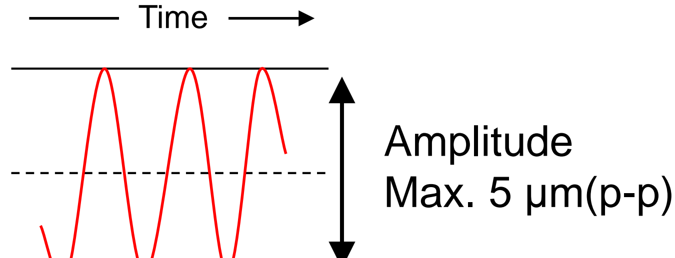
SiC Device Singulation: Ultrasonic Dicing, Stealth Dicing

DISCO

- UltraSonic (US) dicing
  - Improved processing speed and quality
  - Burr reduction for ductile materials

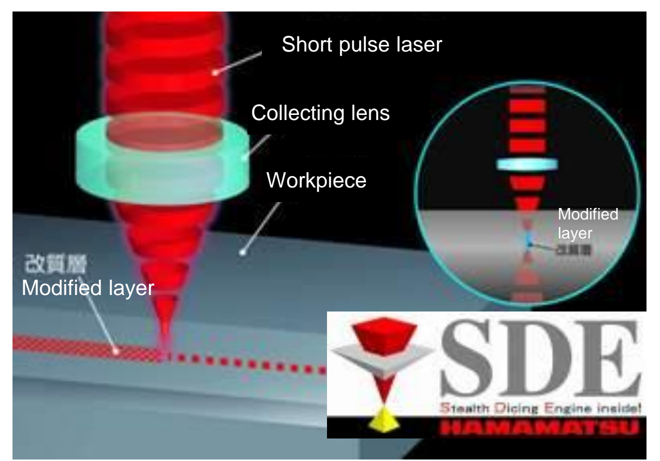


Amplitude of ultrasonic waves



Amplitude
Max. 5 µm(p-p)

- Stealth Dicing (SD)
  - Completely dry process that does not use water
  - High throughput processing using laser
  - Narrow kerf due to modified layer inside wafer



SD

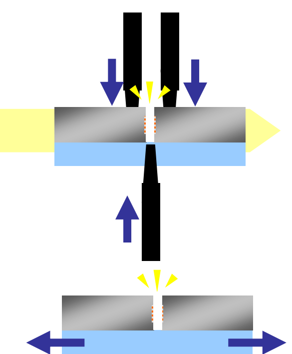
Forming modified layer

SiC
Tape

Die Separation

3-point breaking

Tape expansion



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SiC Device Singulation: Ultrasonic Dicing, Stealth Dicing

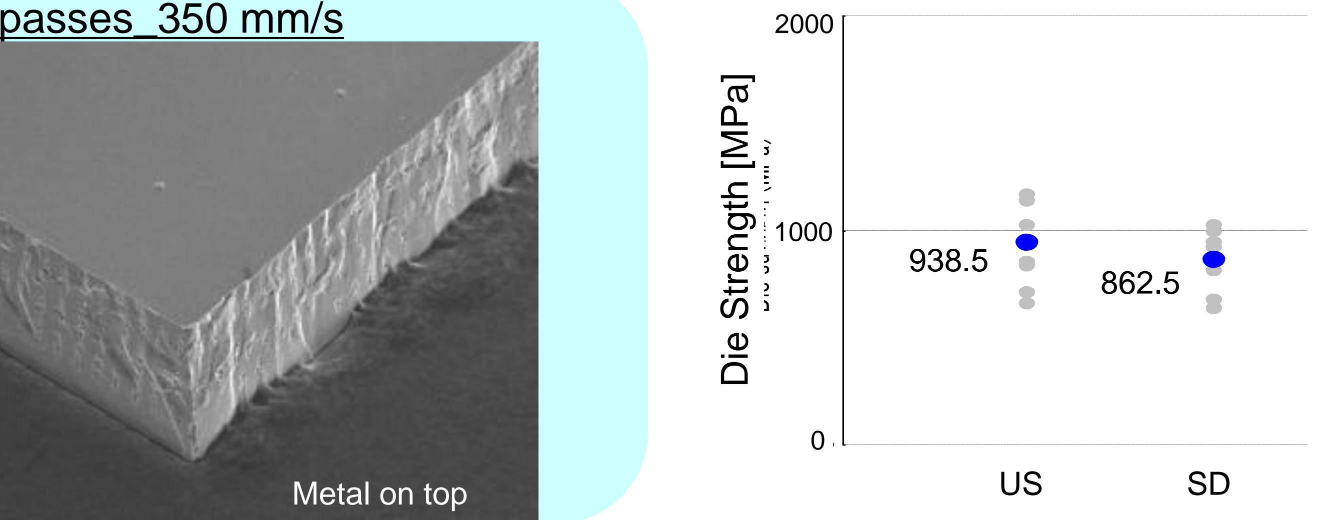
- Processing example: SEM photo, die strength

t = 110 µm

US_1 pass_10 mm/s

Metal on top

SD_3 passes_350 mm/s



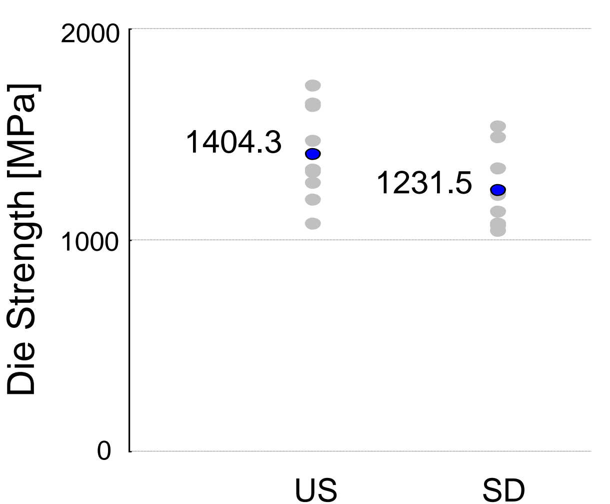
t = 350 µm

US_1 pass_10 mm/s

Metal on top

SD_6 passes_350 mm/s

Metal on top



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SiC Device Singulation: Ultrasonic Dicing, Stealth Dicing

- UPH comparison

Die size (SQ)	t =110 μm: US:10mm/s 1 pass	t =110 μm: SD:600mm/s 3 passes	t =350 μm: US:10mm/s 1 pass	t =350 μm: SD:600mm/s 6 passes
3 mm	5.1	18.6	5.1	9.1
5 mm	8.5	26.8	8.5	14.1
10 mm	16.1	38.1	16.1	23.0

UPH (axis 0–40); Die size (SQ) and thickness

4H-SiC, 4inch

The UPH of SD depends on the thickness, so thinner substrates and smaller die sizes are advantageous

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