Feasibility Study of Layer Separation using 2D Patterned Internal Laser Damage in Silicon

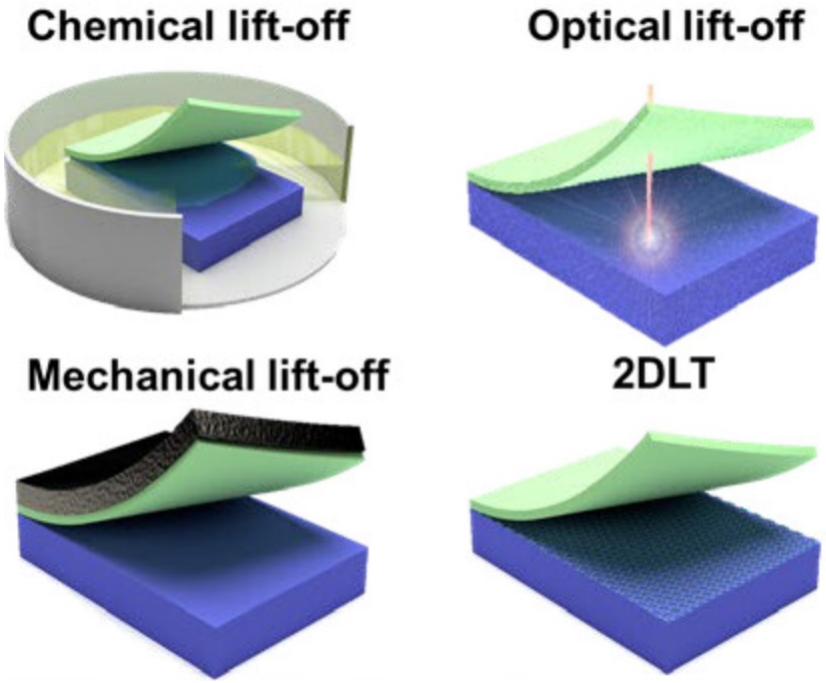
Yuan Yao† , Andrea Vergara and Shuji Tanaka

Tohoku University

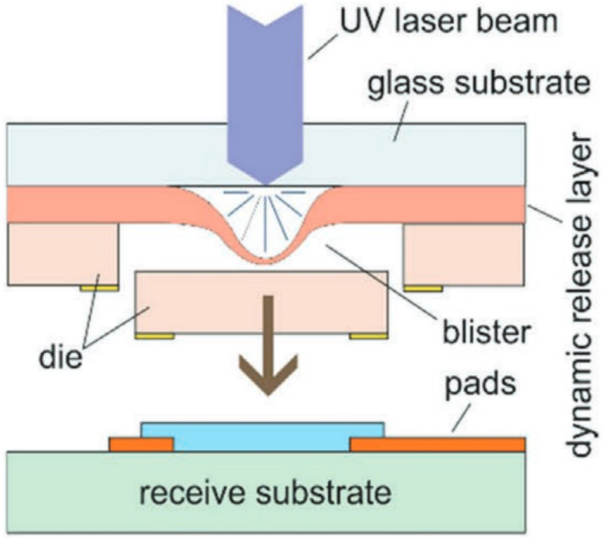
† *On leave from Jilin University, China*

Contents

Lift off technology and Laser lift-off (LLO)



Two-dimensional (2D) material-assisted layer transfer

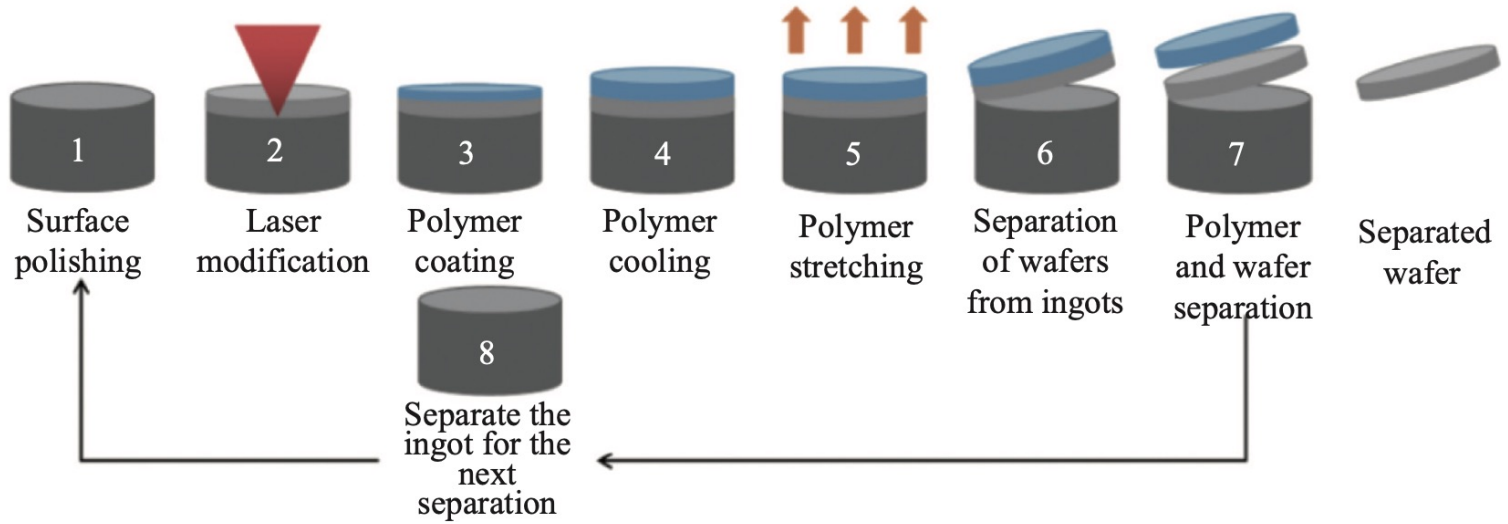


The difference of laser absorption coefficient between the substrate and the release layer is utilized

S. Han *et al.*, "Freestanding Membranes for Unique Functionality in Electronics," *ACS Appl. Electron. Mater.*, vol. 5, no. 2, pp. 690–704, Feb. 2023, doi: 10.1021/acsaelm.2c01411.

F. Wang *et al.*, "Laser Lift-Off Technologies for Ultra-Thin Emerging Electronics: Mechanisms, Applications, and Progress," *Adv Materials Technologies*, vol. 8, no. 7, p. 2201186, Apr. 2023, doi: 10.1002/admt.202201186.

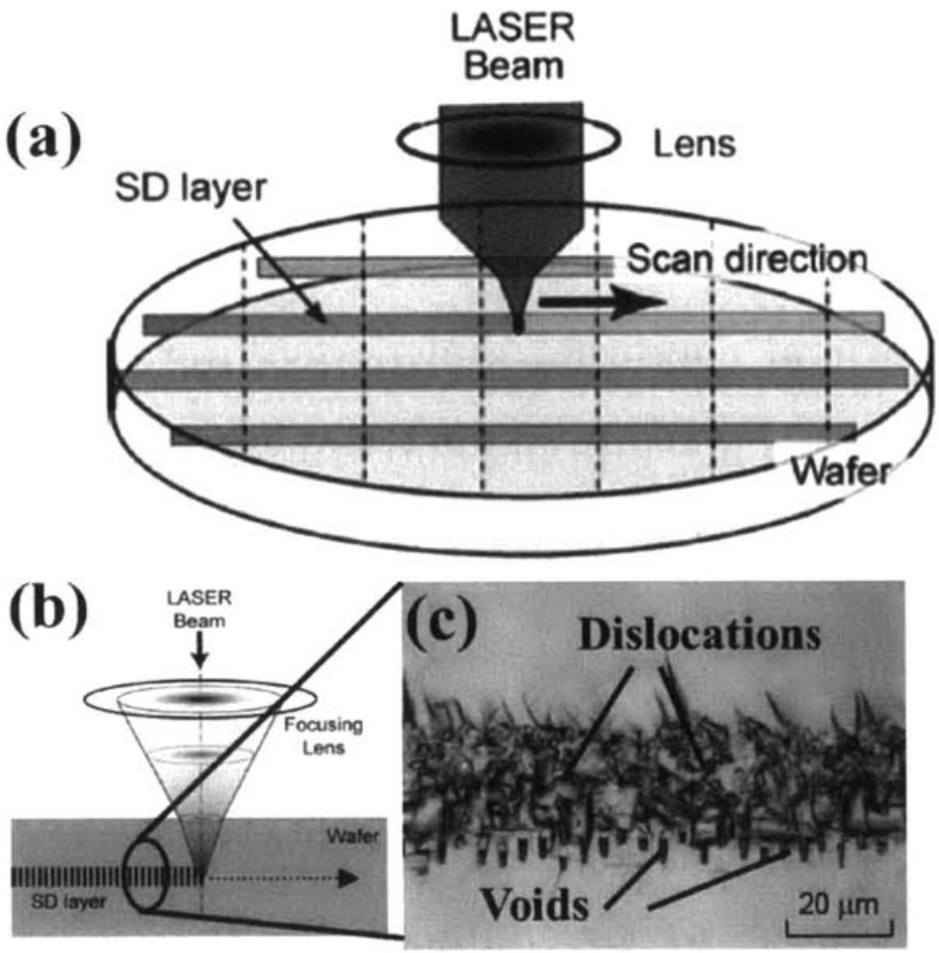
Cold cracking process



Swoboda M, Beyer C, Rieske R, et al. Laser assisted SiC wafering using cold split [J]. Materials Science Forum, 2017, 897: 403-406.

- Widely used for separating 8-inch SiC wafer
- Polymer and liquid nitrogen make it not applicable if there is device on top

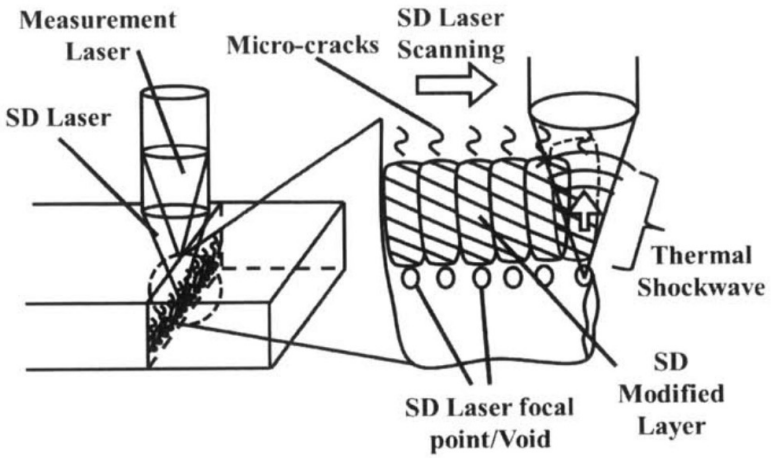
Stealth dicing

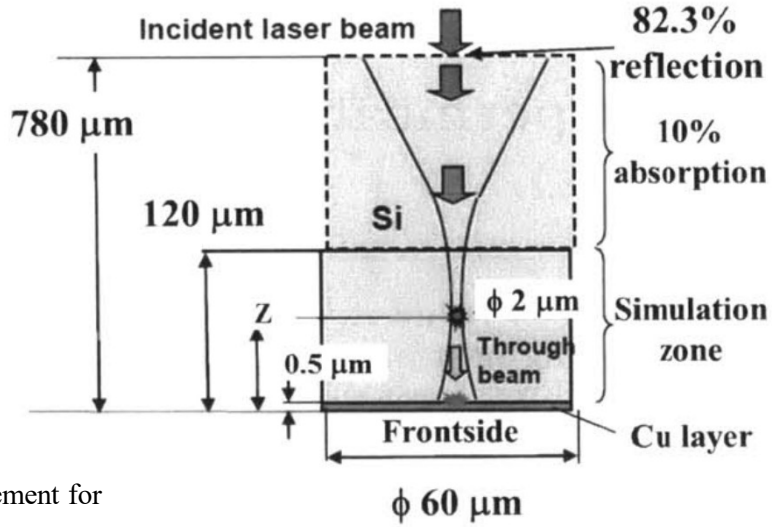


Stealth dicing technology is a technology designed by Hamamatsu Photonics K.K that focuses a laser beam of a wavelength that permeates through materials, **focus internally** and forms a stealth dicing layer(**SD layer**), then applies external stress to the wafer, separating it.

Teh, W. H. (2014). Stealth dicing characterization, optimization, integration, and operations management for ultra-thin stacked memory dies (Master dissertation, Massachusetts Institute of Technology).

Mechanism of stealth dicing





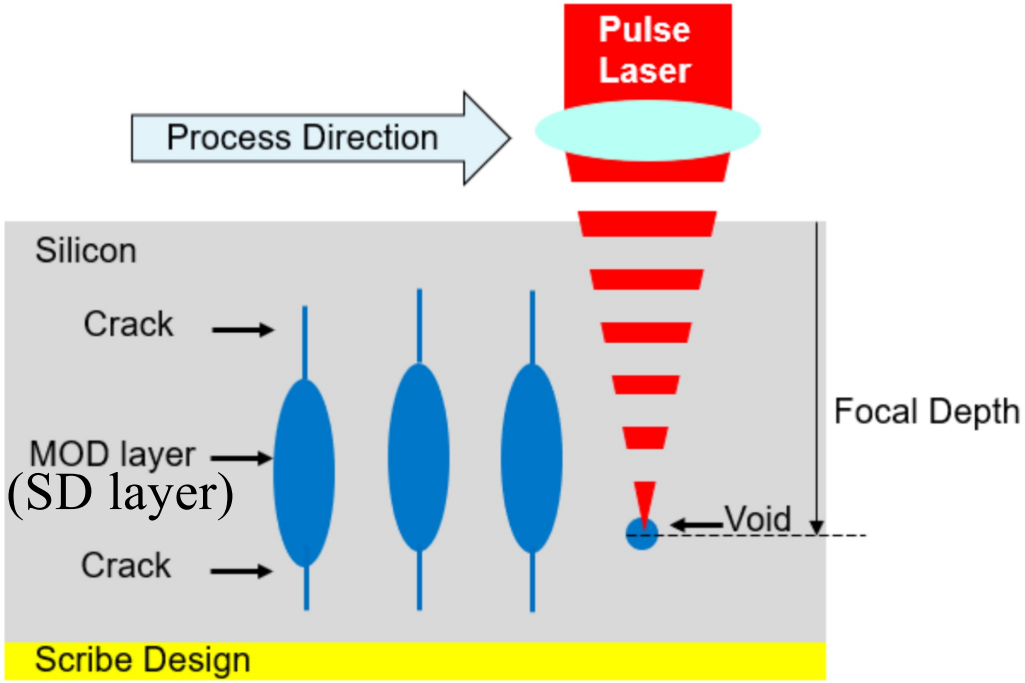
Teh, W. H. (2014). Stealth dicing characterization, optimization, integration, and operations management for ultra-thin stacked memory dies (Master dissertation, Massachusetts Institute of Technology).

1. The temperature of the laser focal point will be larger than 10000 K, silicon is melted and evaporated, **creating voids** of 1-3μm in diameter

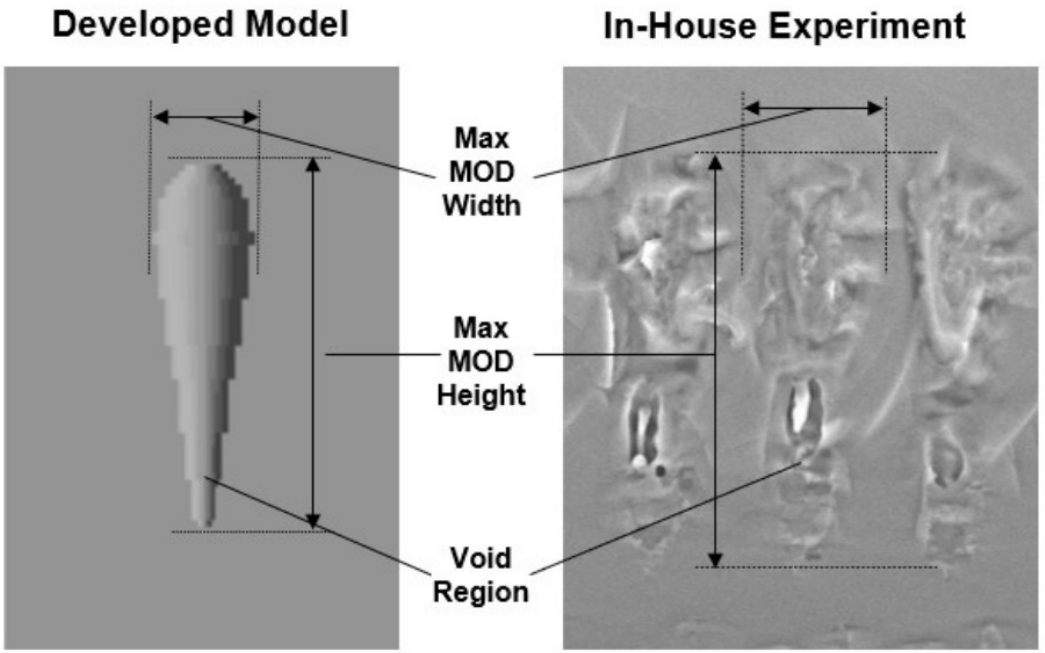
2. A thermal shockwave is generated, causing **crystal dislocations**. The continuous generation of dislocation leads to their interaction, resulting in **cracks**

3.The heat-affected zones grow mostly toward the beam incident surface because the absorption coefficient increases nonlinearly with the increasing temperature

Simulation model of stealth dicing



A simplified structure

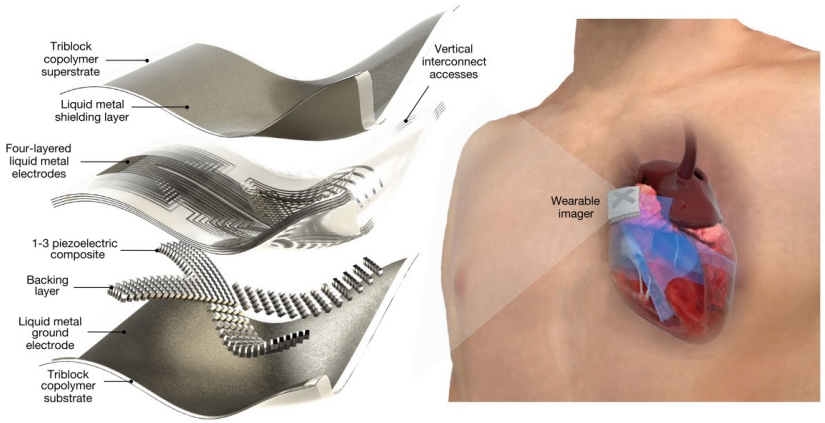


Shape of the modified layer on one point can be estimated by this simplified model

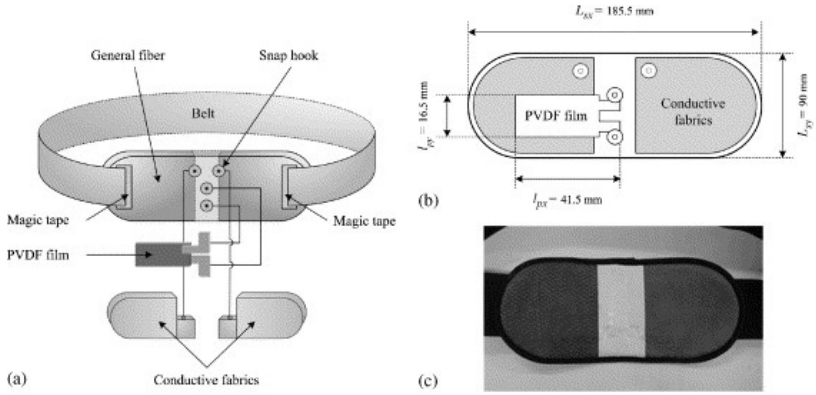
D. K. Lim, V. R. S. P. Vempaty, A. H. Shah, W. H. Sim, and H. V. Singh, "Modeling of Laser Absorption and Modification Layer Formation Within Silicon Due to Stealth Dicing," *IEEE Trans. Compon., Packag. Manufact. Technol.*, vol. 13, no. 9, pp. 1486–1493, Sep. 2023, doi: 10.1109/TCPMT.2023.3308923.

Contents

Motivation



M. Lin *et al.*, "A fully integrated wearable ultrasound system to monitor deep tissues in moving subjects," *Nature Biotechnology*, vol. 42, pp. 448-457, 2024, doi: 10.1038/s41587-023-01800-0.



S. Choi and Z. Jiang, "A novel wearable sensor device with conductive fabric and PVDF film for monitoring cardiorespiratory signals," *Sensors and Actuators A: Physical*, vol. 128, pp. 317-326, 2006, doi: /10.1016/j.sna.2006.02.012

Q: How to obtain higher performance in flexible devices?

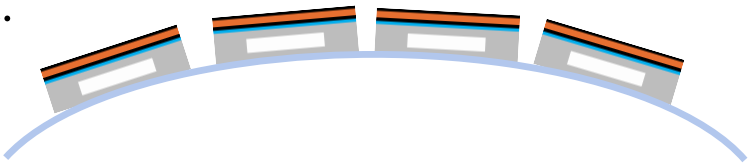
pMUT array fabricated on rigid substrate

Electrodes
Piezolayer
Buffer layer
Si substrate

A: Transfer is required.

Q: But how?

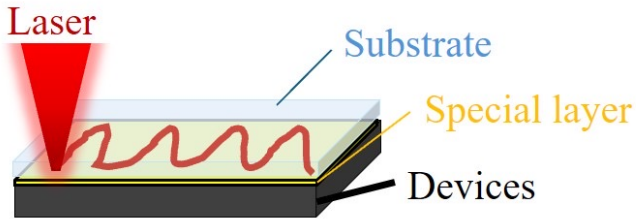
Bonding to flexible substrate after separation



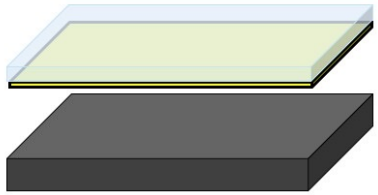
Our Answer: Next page.

Proposed idea

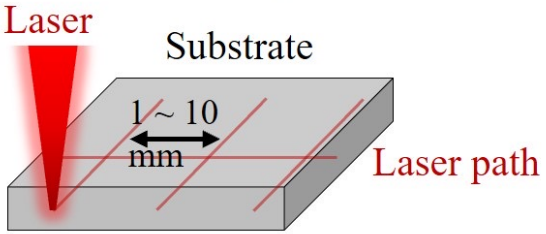
Typical laser lift-off



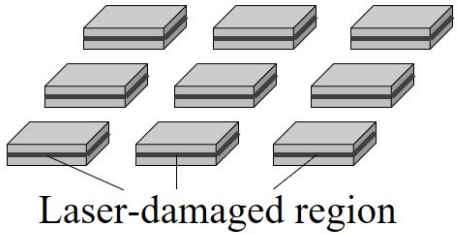
Delamination



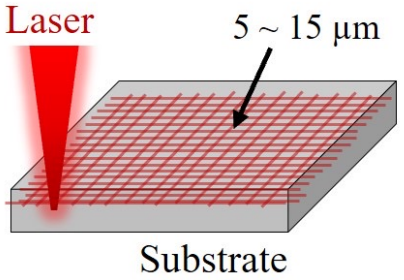
Stealth dicing



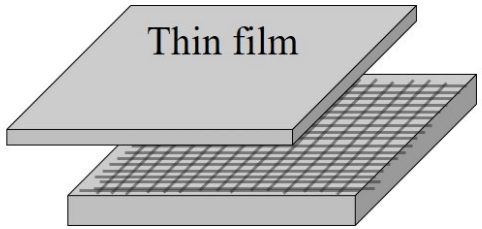
Separation by cleavage



This research



Separation by shear stress



Different materials	Single material	Single material
Layer separation	Piece separation	Layer separation

Use stealth dicing to achieve the purpose of LLO

Characteristics

Advantages:

- Special separation layer-free, **simplified** fabrication process
- More process **compatible** (e.g. tolerant to high temperature)
- **Separation height** can be set **freely** when conducting laser ablation

Disadvantages:

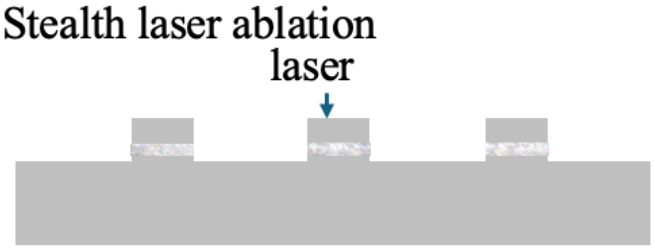
- **Time consuming** using the current setup (single point scanning)
- Lack of specialized machine or technique to **apply required shear stress** for separation

Experiment flow

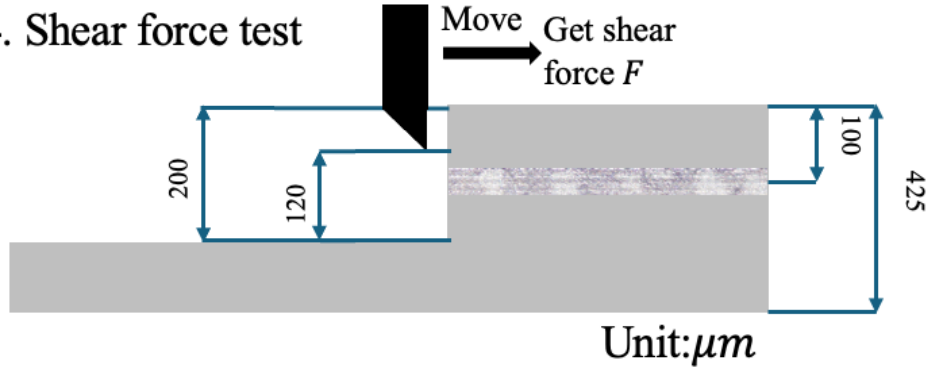
1. Initial wafer

2. Etching Si device layer(DRIE)

3. Stealth laser ablation

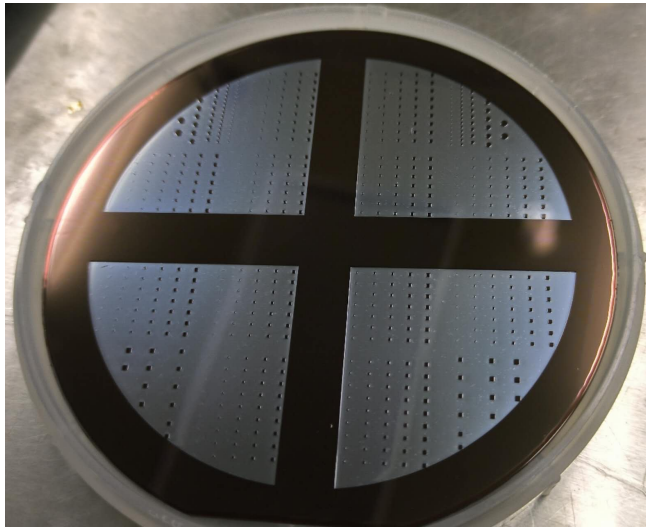


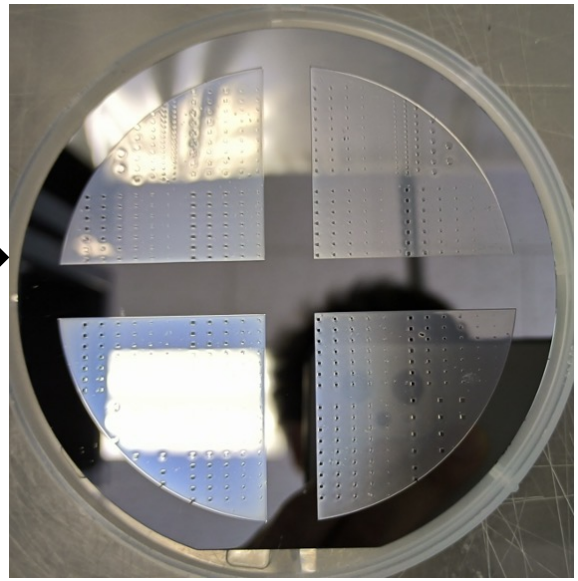
4. Shear force test

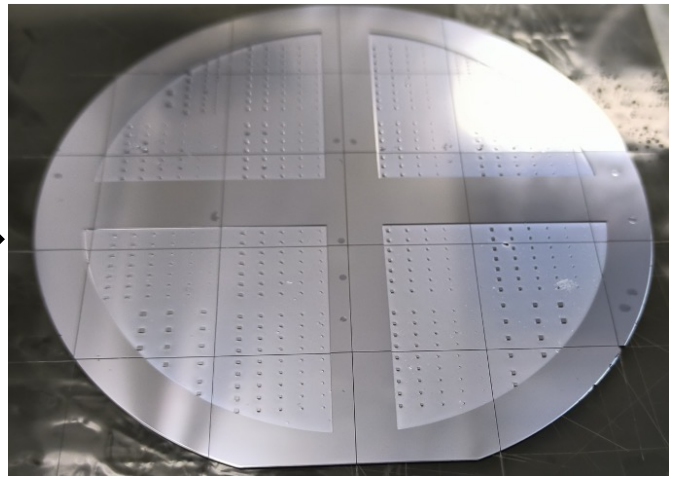


DRIE step

2. Etching Si device layer(DRIE)





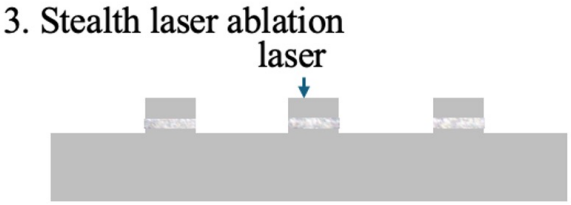


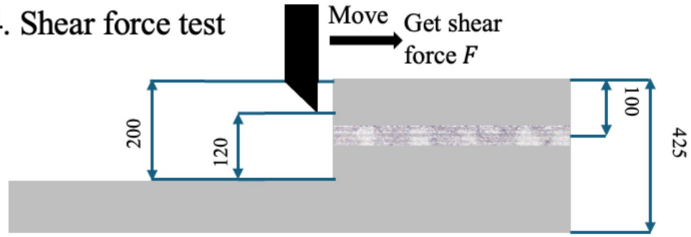
After lithography

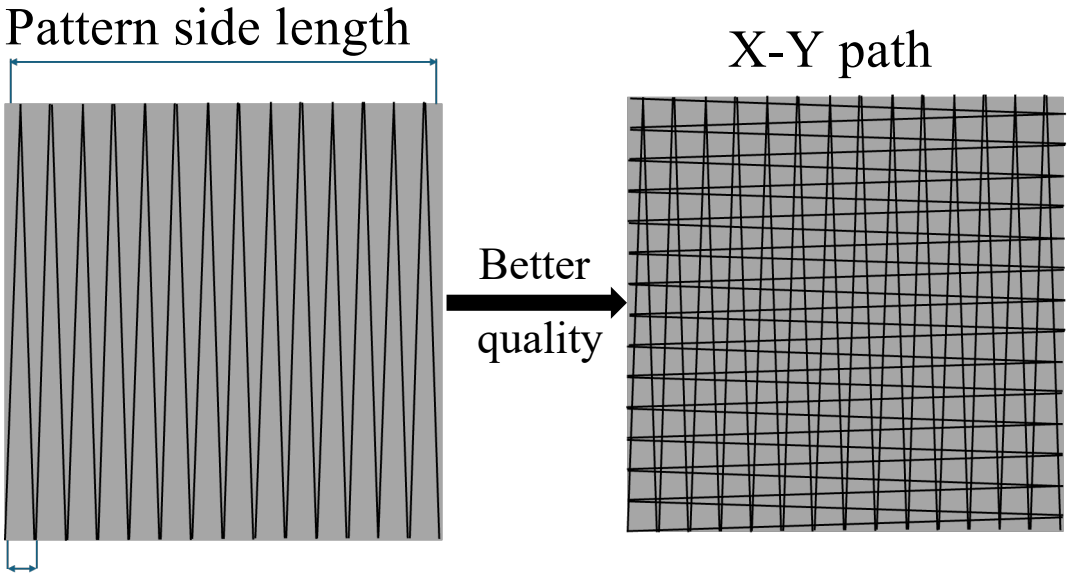
After DRIE and cleaning

After dicing

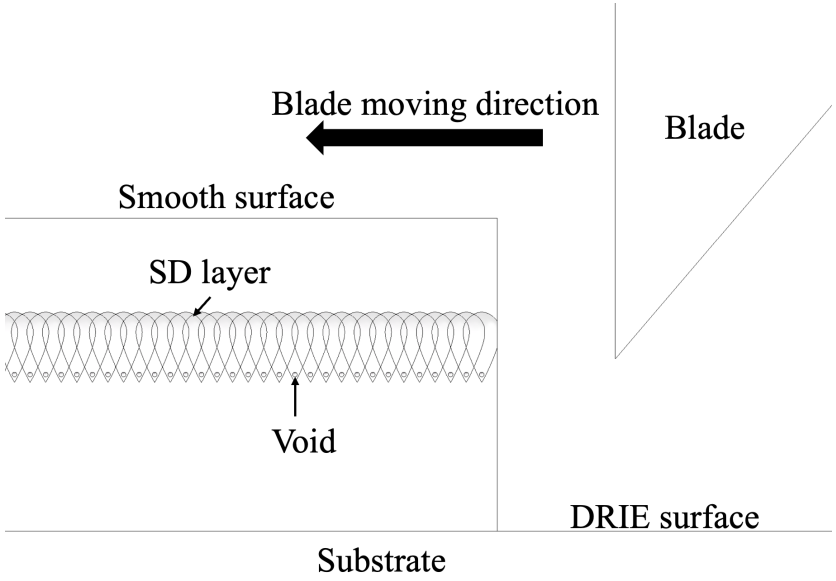
Stealth laser ablation and shear force test







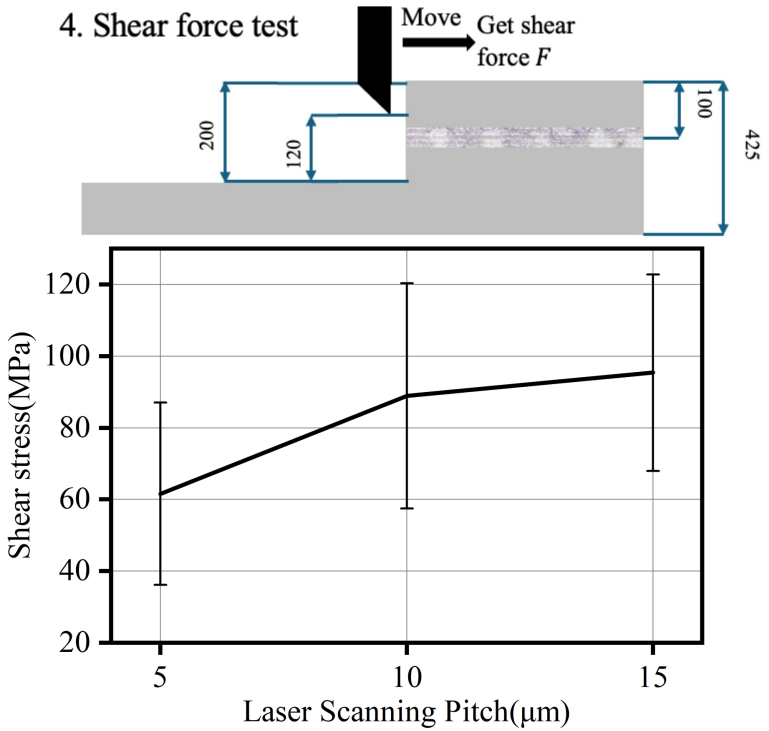
Most of the experiments were conducted following this path



Blade aligned with the SD layer applies horizontal shear stress

Contents

Shear force test

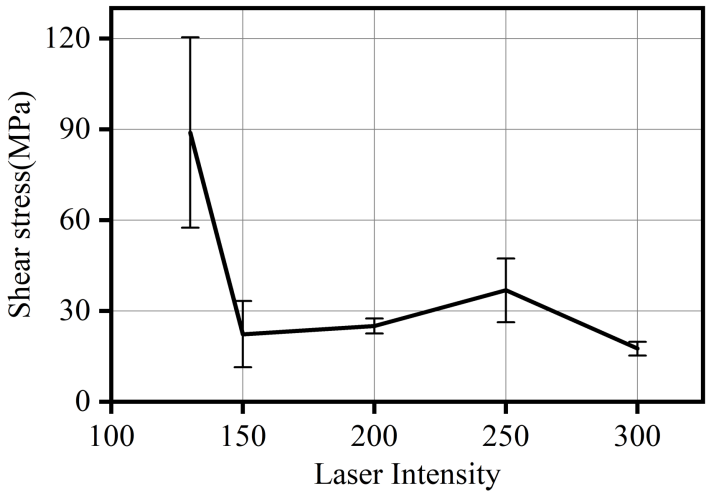


Correlation between the laser path pitch and the shear stress

Sample size= 300×300μm² Laser power=130

Recommend power: 150

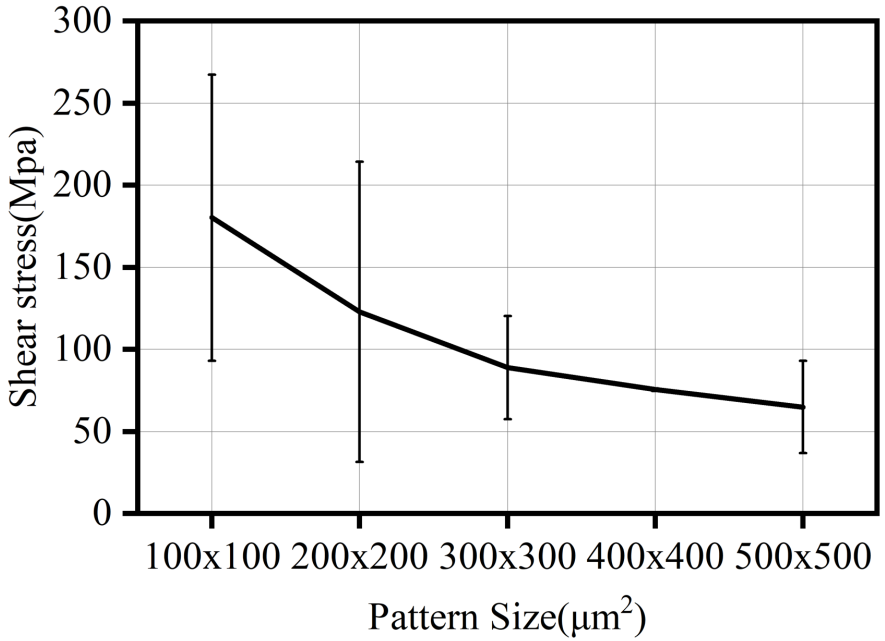
The unit of the laser intensity is percentage of power,1000 means full power(25W)



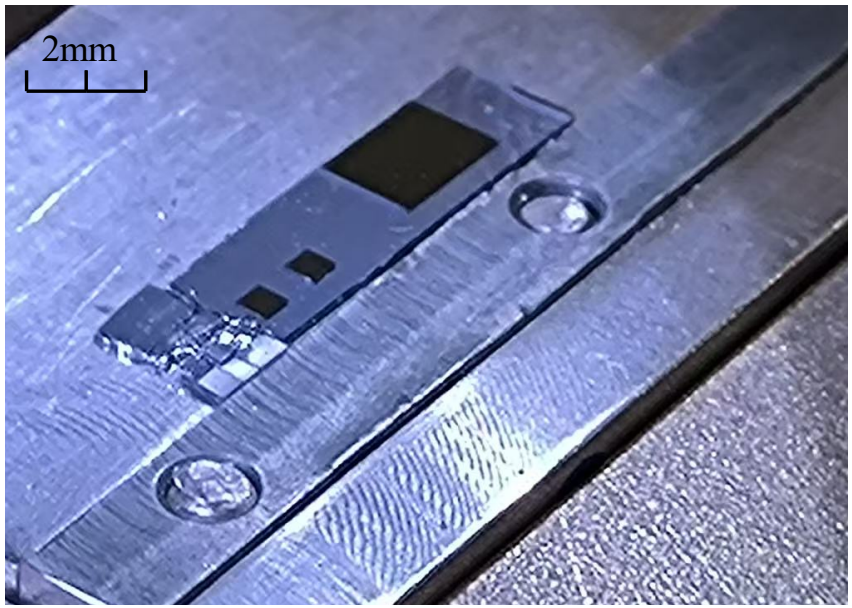
Correlation between the laser power and the shear stress

Laser path pitch=10μm, sample size=300×300μm²

Shear force test



Correlation between the pattern size and the shear stress



Any size larger than 500×500 μm² will easily cause breakage of the substrate

Laser power=130, laser path pitch=10μm

Analysis of data

- The shear stress measured was less than 100 MPa, which is typically over 1Gpa[1] without laser
- The error bars are large, one reason is the **irregular crystal dislocation**, another is the **bad alignment** of the bonding force measurement machine
- The shear strength and the laser path pitch are a trade-off in quality and time

[1]Ritchie, R. O. (2003). Failure of Silicon: Crack Formation and Propagation. Presentation. University of California, Berkeley. Retrieved from https://people.eecs.berkeley.edu/~pister/147/SiliconFailureRitchie2003.pdf

Cross section view→Top view

The cross sectional view of stealth dicing has been widely investigated

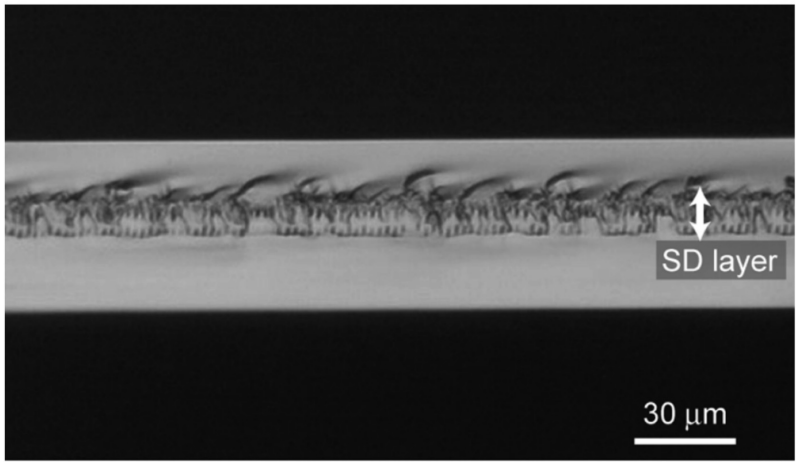
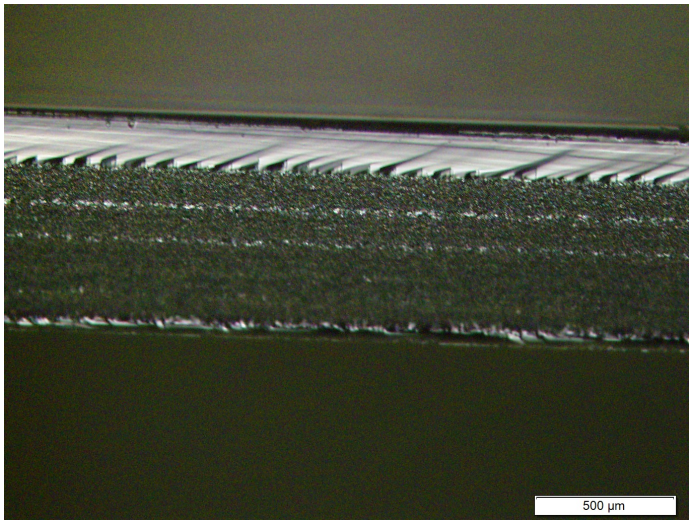


Fig. 7. Cross section of divided silicon wafer with 50-μm thickness by SD method.

M. Kumagai, N. Uchiyama, E. Ohmura, R. Sugiura, K. Atsumi, and K. Fukumitsu, "Advanced Dicing Technology for Semiconductor Wafer—Stealth Dicing," IEEE Trans. Semicond. Manufact., vol. 20, no. 3, pp. 259–265, 2007, doi: 10.1109/TSM.2007.901849.

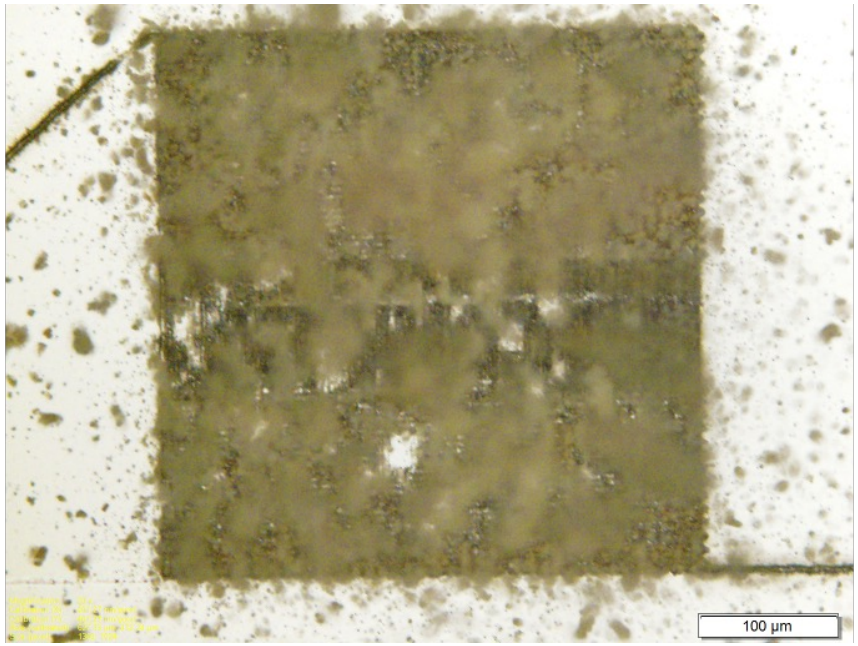
My sample

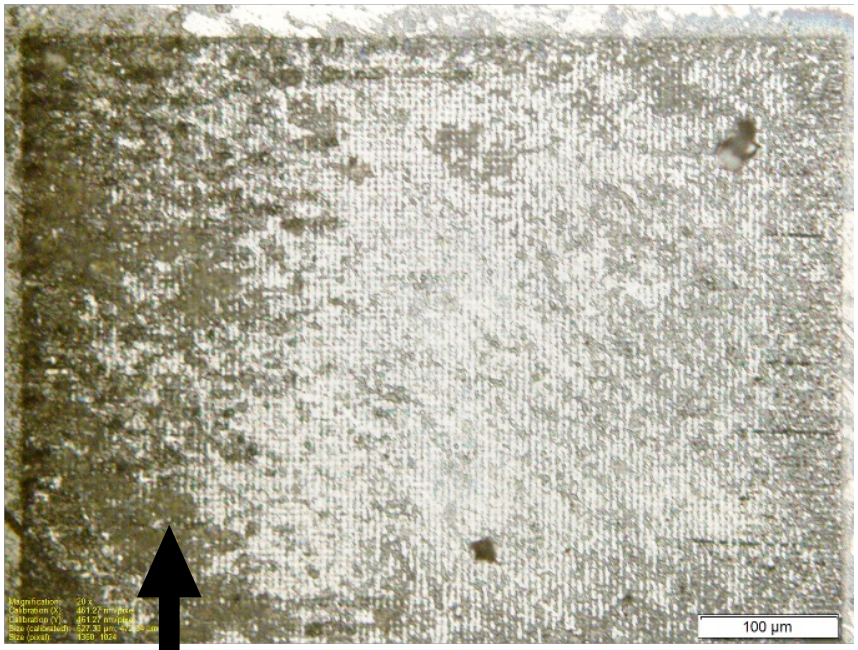


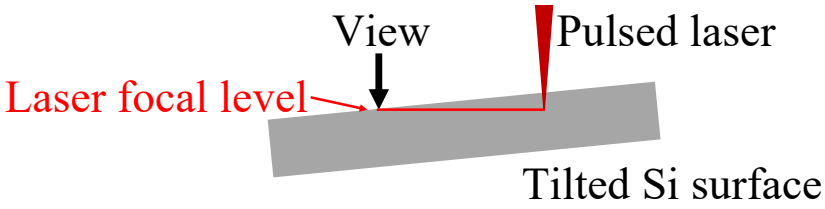
However, there are no report about SD layer from the **top side** as it is invisible in the former research

Laser modified layer on smooth surface

Focus laser **on the plain Si surface**



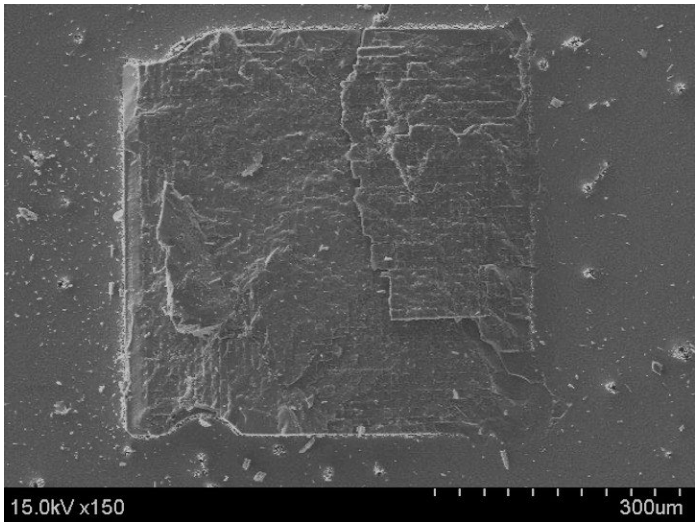


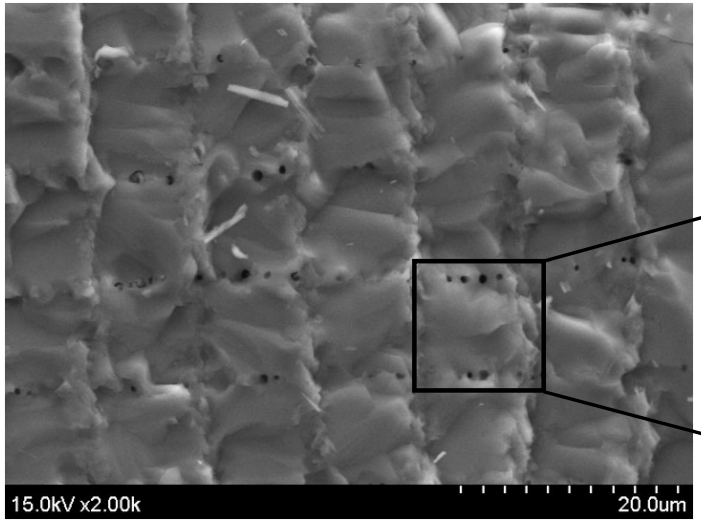


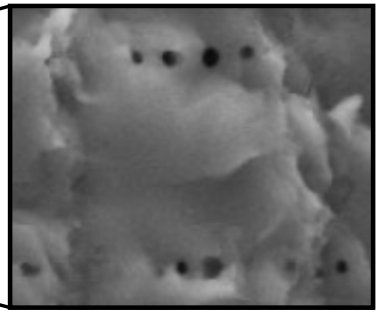
Morphology change due to the uneven surface on either stage or chip

Pictures of the substrate

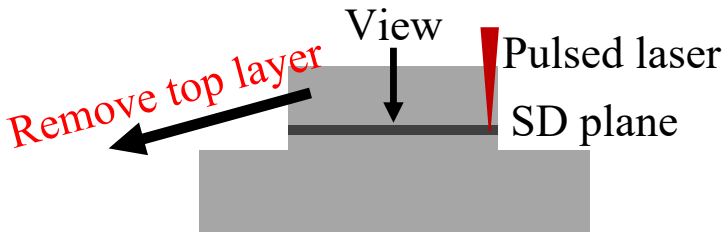
Substrate **after the shear force test**



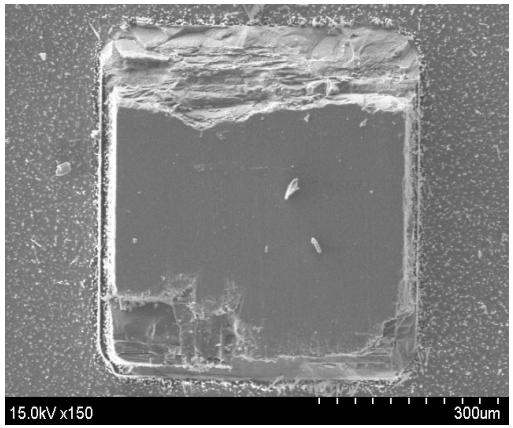


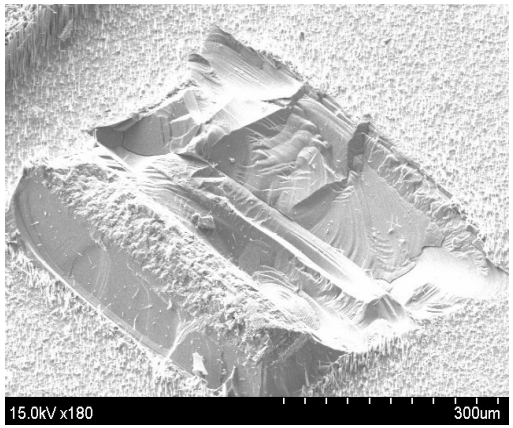


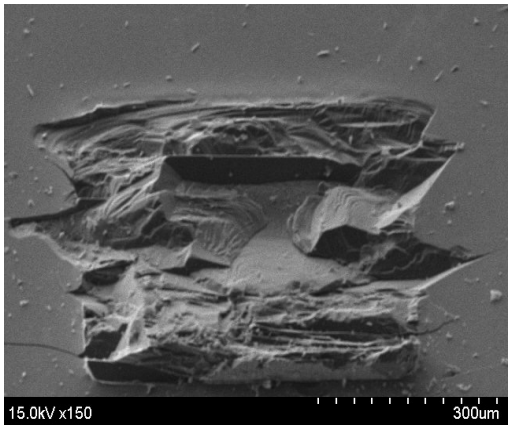
The voids(focal points of the laser)

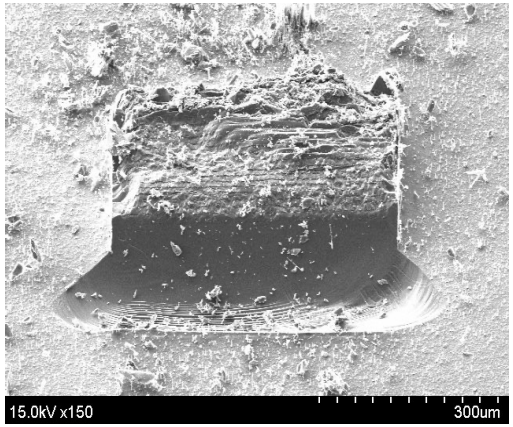


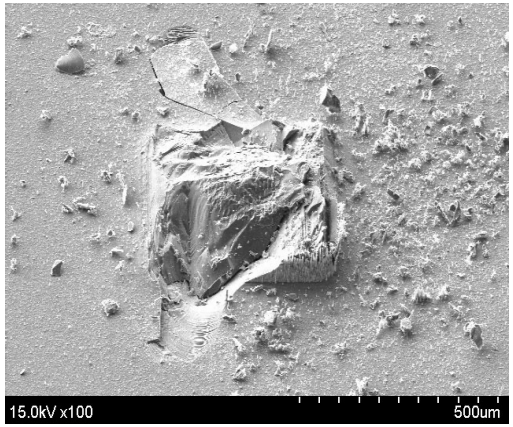
Failure examples

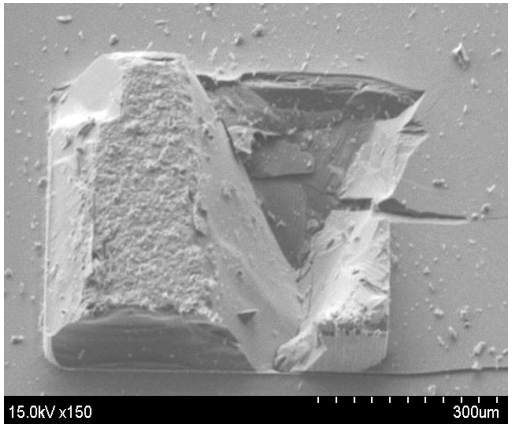






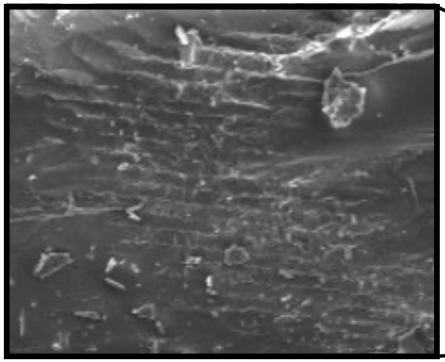


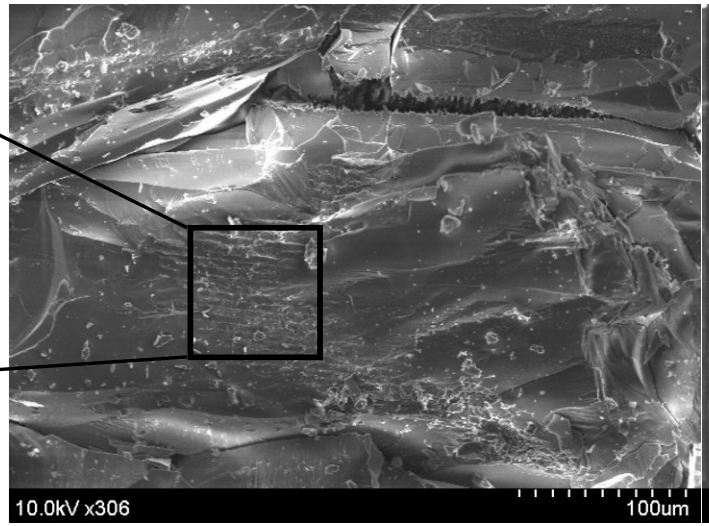


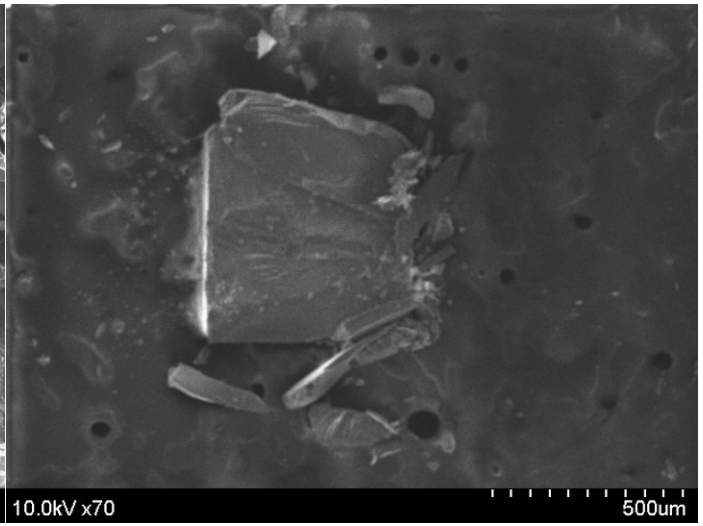


The layer removed by shear force test

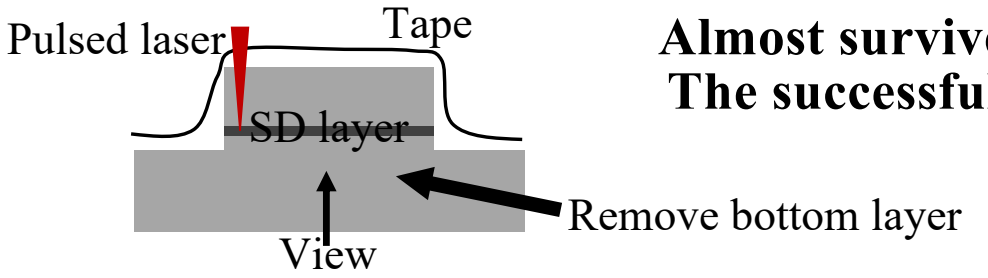
Adhesive tape is applied to the surface prior to conducting the shear force test







Only slight laser path can be observed because of the asymmetric effect of the laser



Almost survived the separation
The successful rate is very low

Summary

- The **feasibility** of this new laser lift-off technology was **verified**
- The shear strength can be **lowered** by **narrowing the laser path pitch, enlarging the pattern size and using larger laser power**

In the future

- Parameters can be optimized more to find the best separation condition
- A suitable separation technique is required for practical use

Thank you for your attention!

Yuan Yao , Andrea Vergara and Shuji Tanaka