Alternative Approach to Die-to-Wafer Bonding Utilizing Atmospheric Plasma Cleaning

Daniel Pascual

ONTOS Equipment Systems

Hybrid Bonding in the News!

EETimes

As Classic Moore's Law Dims, Heterogeneous Integration Steps Into the Limelight

By Nirmalya Maity 04.20.2022 0

IEEE Spectrum FOR THE TECHNOLOGY INSIDER

Hybrid Bonding Plays Starring Role in 3D Chips

› Tech makes millions of connections in a square millimeter of silicon

BY SAMUEL K. MOORE | 04 JUN 2024 | 7 MIN READ |

Samuel K. Moore is IEEE Spectrum's semiconductor editor.

SEMICONDUCTOR ENGINEERING
DEEP INSIGHTS FOR THE TECH INDUSTRY

Gearing Up For Hybrid Bonding

1k Shares 59 351 563

Toolsets are starting to meet the stringent cleanliness, flatness and placement accuracy specs, but doing all of that at lower temperatures isn't possible yet.

OCTOBER 23RD, 2023 - BY: **LAURA PETERS**

EP&T
ELECTRONIC PRODUCTS & TECHNOLOGY

Demand for AI optimized chipsets to spur hybrid bonding

By Dr. Seung Kang, VP of semiconductor strategy, Adeia May 6, 2024

Hybrid Bonding Moves Into The Fast Lane

1.6k Shares 109 303 1k

Companies are speeding ahead to identify the most production-worthy processes for 3D chip stacking.

JULY 21ST, 2022 - BY: **LAURA PETERS**

3DInCites

Hybrid Bonding: The Time has Come

Book Reviews, Resource Library
May 02, 2024 · By Dr. Dongkai Shangguan

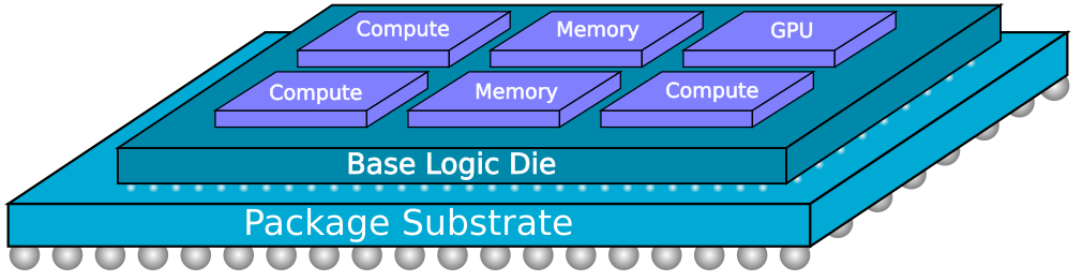
ECTC 2024: Advanced Packaging Engineers to the Rescue!

Blogs, Francoise in 3D
Jun 01, 2024 · By Francoise von Trapp · advanced packaging, ASE, Kiterocket, KLA, LQDX

3D-IC and Heterogeneous Integration



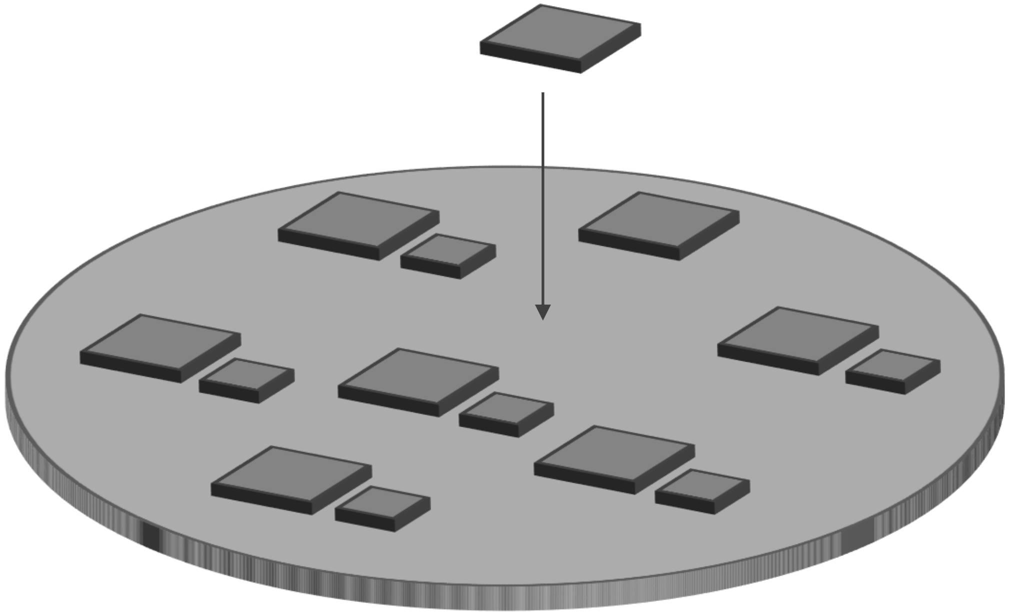
"The most advanced processors today are no longer a single piece of silicon. Instead, they are multiple "chiplets" bound together by advanced packaging techniques that do their best to make it seem as if everything really is one big chip." – Samuel K. Moore, IEEE Spectrum's semiconductor editor



Die-to-Wafer bonding for Heterogeneous Integration of "Chiplets"

Benefits

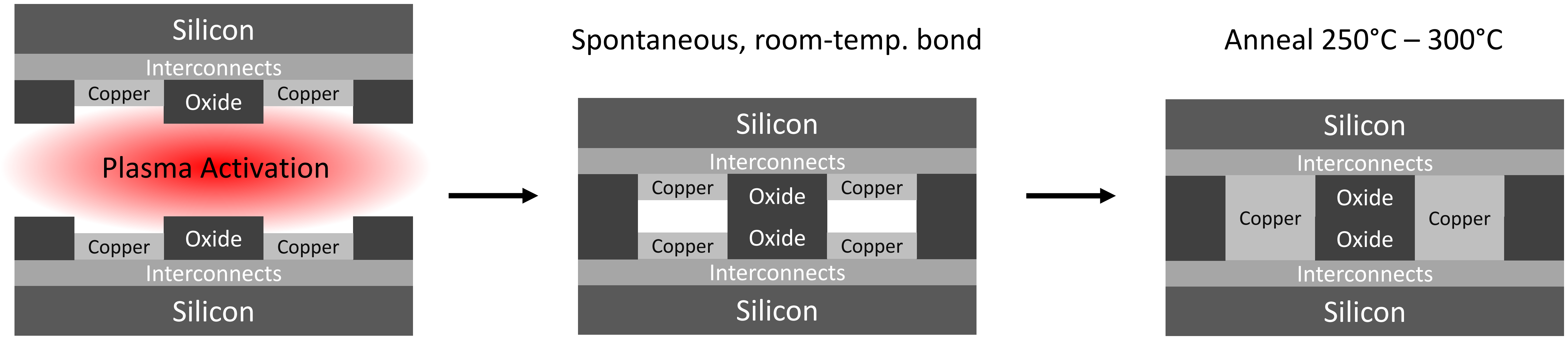
- Increase Yield: Use only known good die
- Most flexible: Die can be different size, thickness, material, supplier etc.



Challenges

- How to prepare diced chips for bonding?
- Need to manage contamination from equipment and handling.

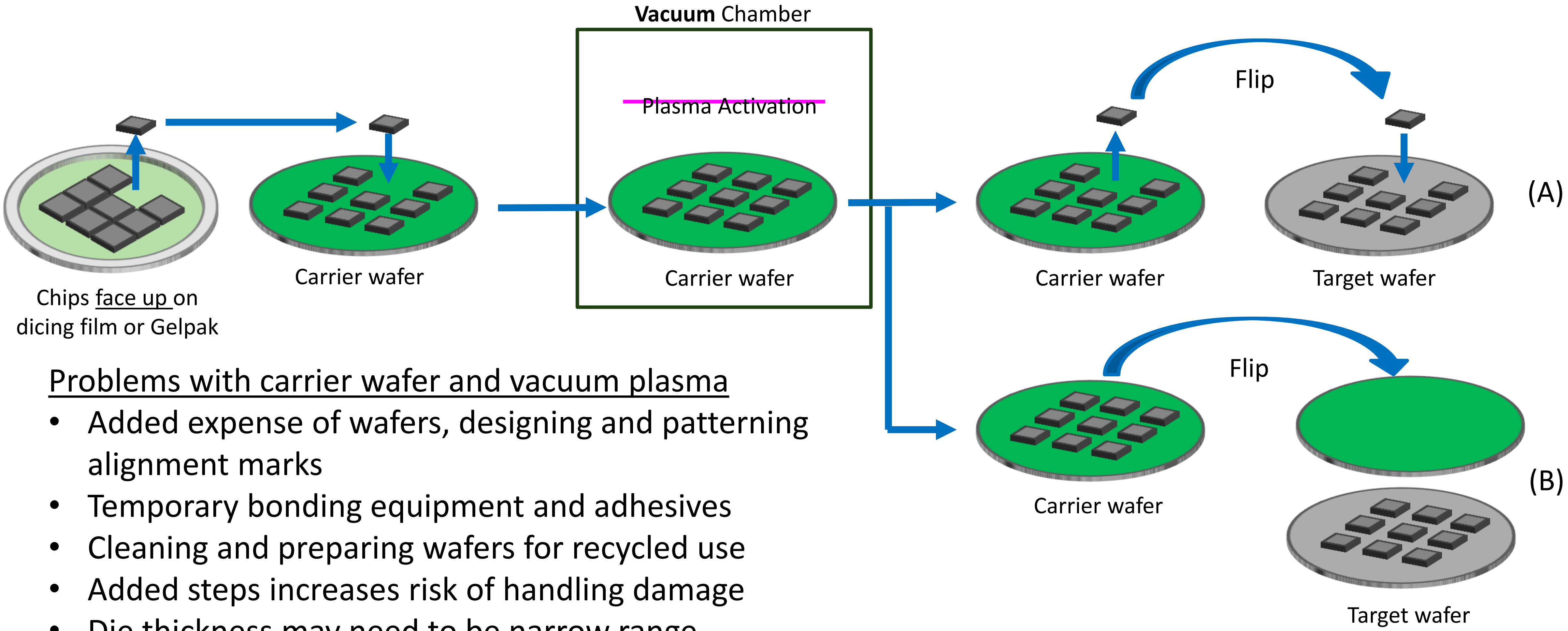
Hybrid Bonding



Hybrid Bonding ideal for Die-to-Wafer applications

- Higher interconnect density, better heat conduction, faster signals, more reliable, ….
- Simultaneous bonding of dielectric (typically SiO2) and metal (typically Cu)
- Requires plasma treatment of the bonding surfaces to increases surface energy and clean contaminants such as metal oxides and organic residue, resulting in a strong mechanical and electrical connection.
- Challenge: How to activate die (and wafer) before bonding?

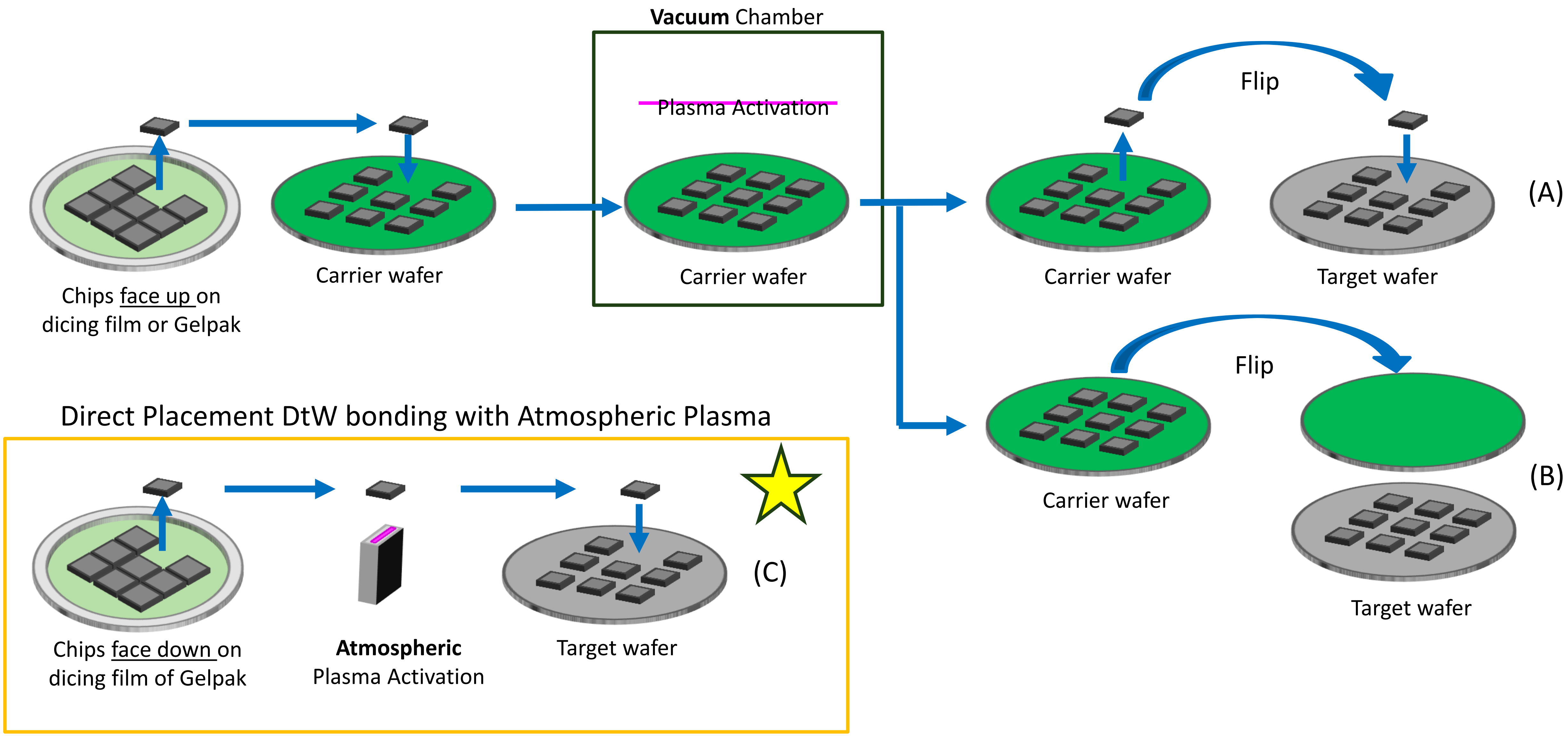
Approaches to DtW Bonding



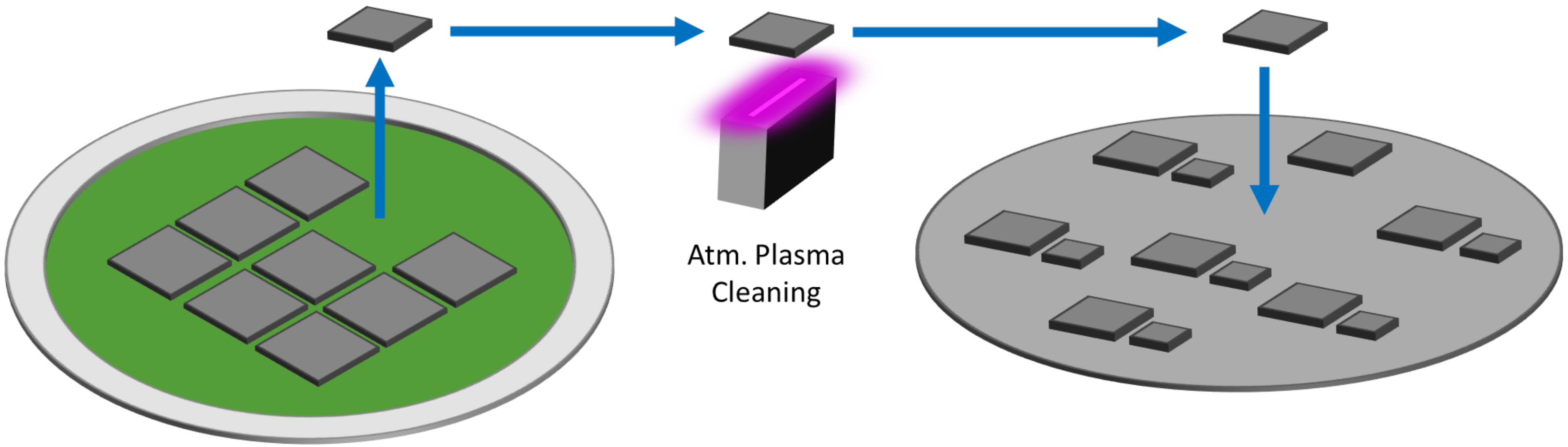
Problems with carrier wafer and vacuum plasma

- Added expense of wafers, designing and patterning alignment marks
- Temporary bonding equipment and adhesives
- Cleaning and preparing wafers for recycled use
- Added steps increases risk of handling damage
- Die thickness may need to be narrow range
- Error stack up of misalignment
- Vacuum plasmas can roughen and damage bonding surface

Approaches to DtW Bonding



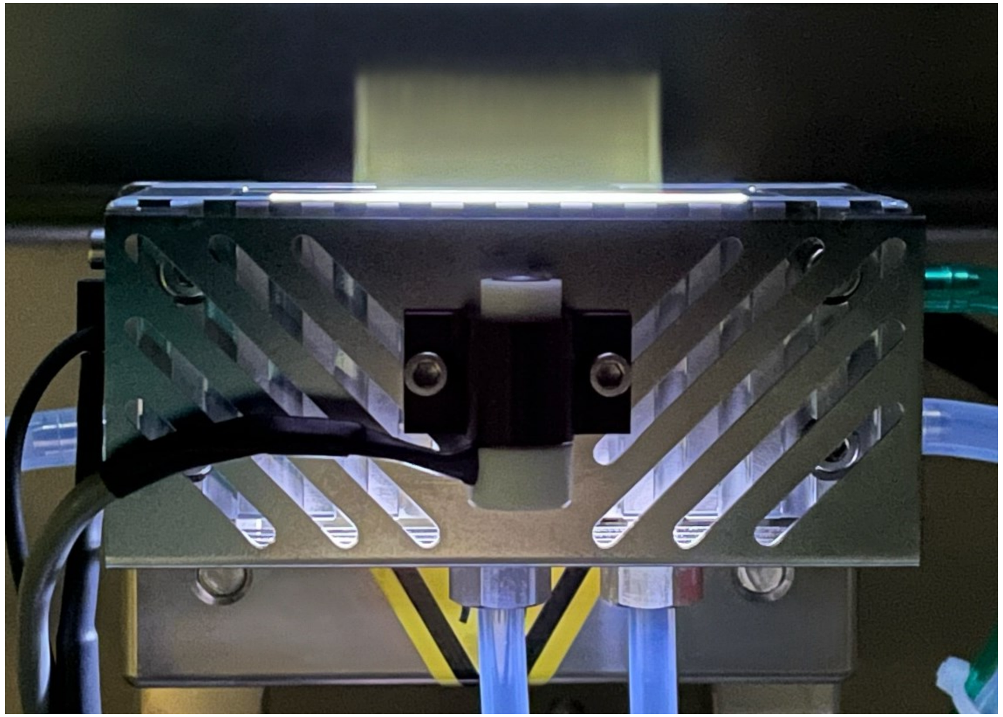
Direct Placement DtW Bonding with Atmospheric Plasma



Benefits

- Avoids ALL of the problems of carrier wafers and vacuum plasma already described
- Simple, cost effective, fast, and on-demand for optimal bonding strength
- Can be used for treatment of dies and wafer
- Since dies are face down, dicing film can act as protective film during shipment
- Cleans and activates SiO_2 and Cu surfaces simultaneously

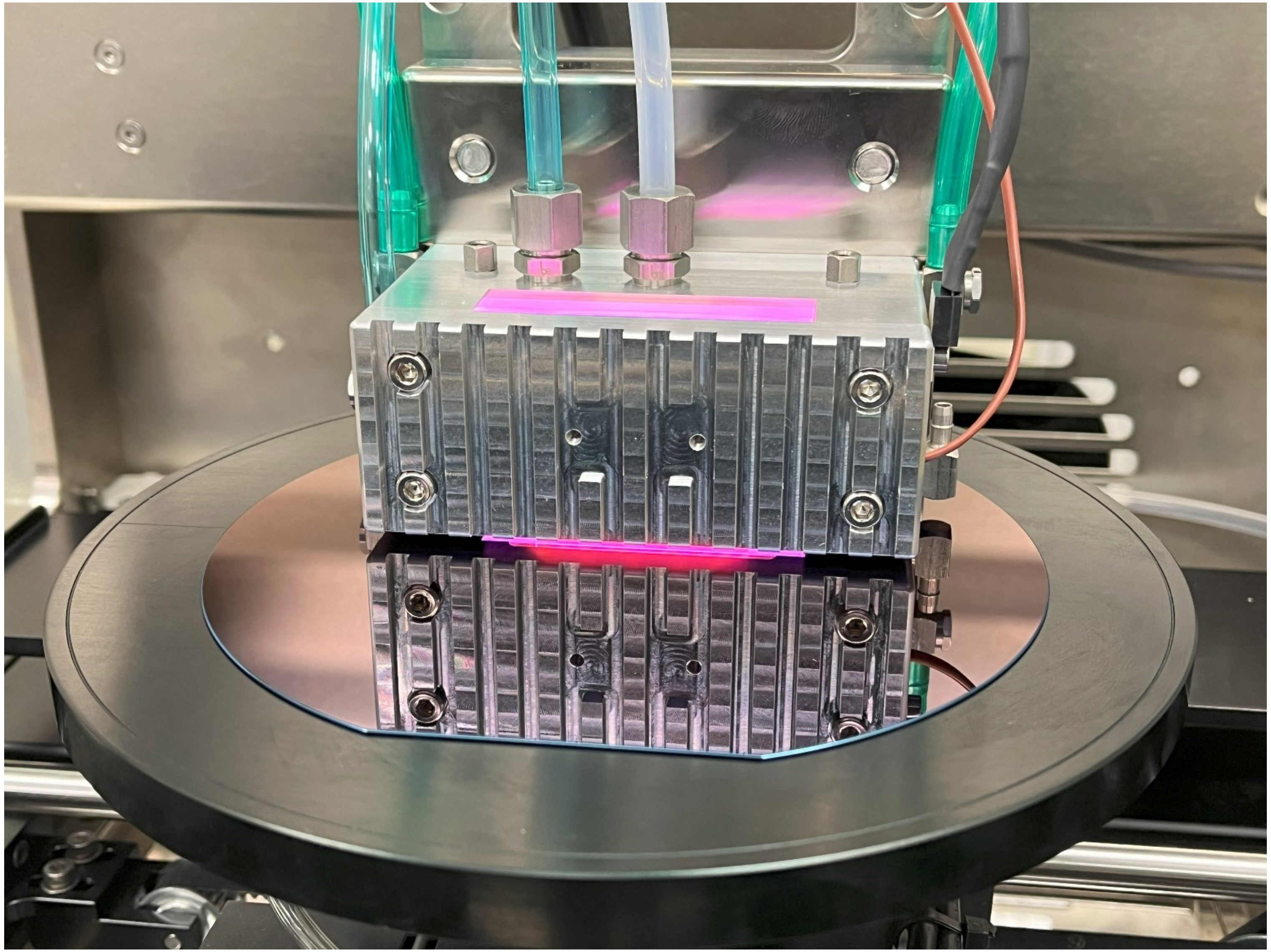
Atmospheric Plasma System



- **Simple** process - no vacuum chamber, inline capable
- **Effective** surface cleaning and activation
  - Increases surface energy for hybrid bonding
  - Cleans organic residue
  - Reduces metal oxides
- **Fast** – completes die treatment in seconds
- **Ultra-clean –** no particle adders or contamination.
- **Safe** for devices and personnel
  - Low Temperature ~35°C
  - Radical chemistry only
  - No arc discharges, No ion bombardment,
  - No re-deposition or cross contamination.
  - Semiconductor safe.
  - Non-toxic gases including He, Ar, H_2 (1%-5%), O_2, and N_2

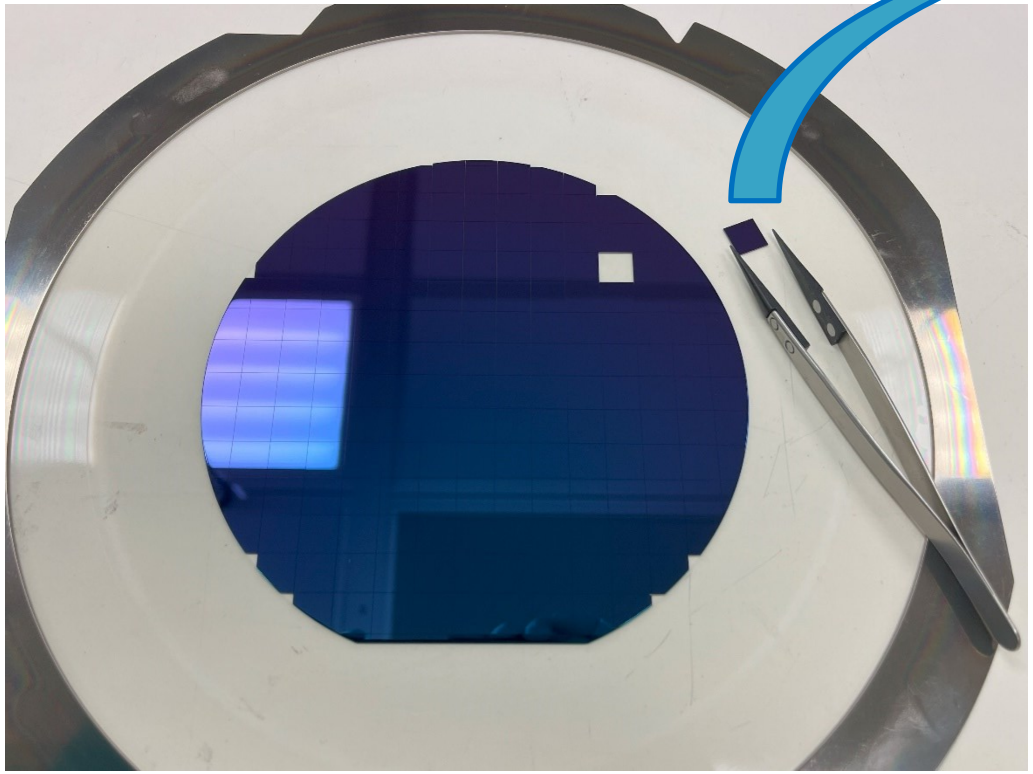
Demonstration of Direct Placement DtW Bonding with Atmospheric Plasma

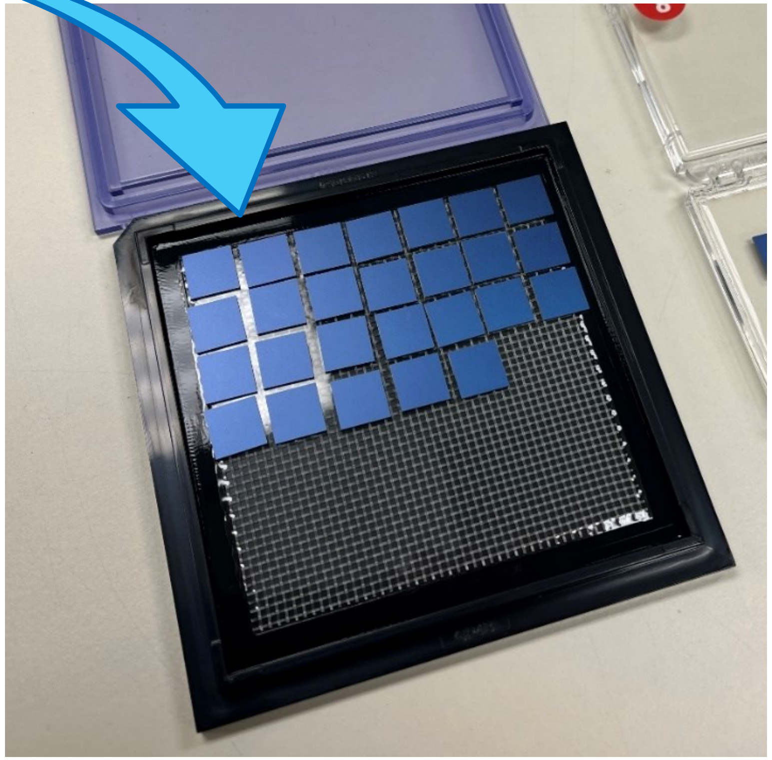
Wafer Activation



- Full wafers of can be treated by scanning over the surface with atmos. Plasma head.
- 150mm wafer shown here.

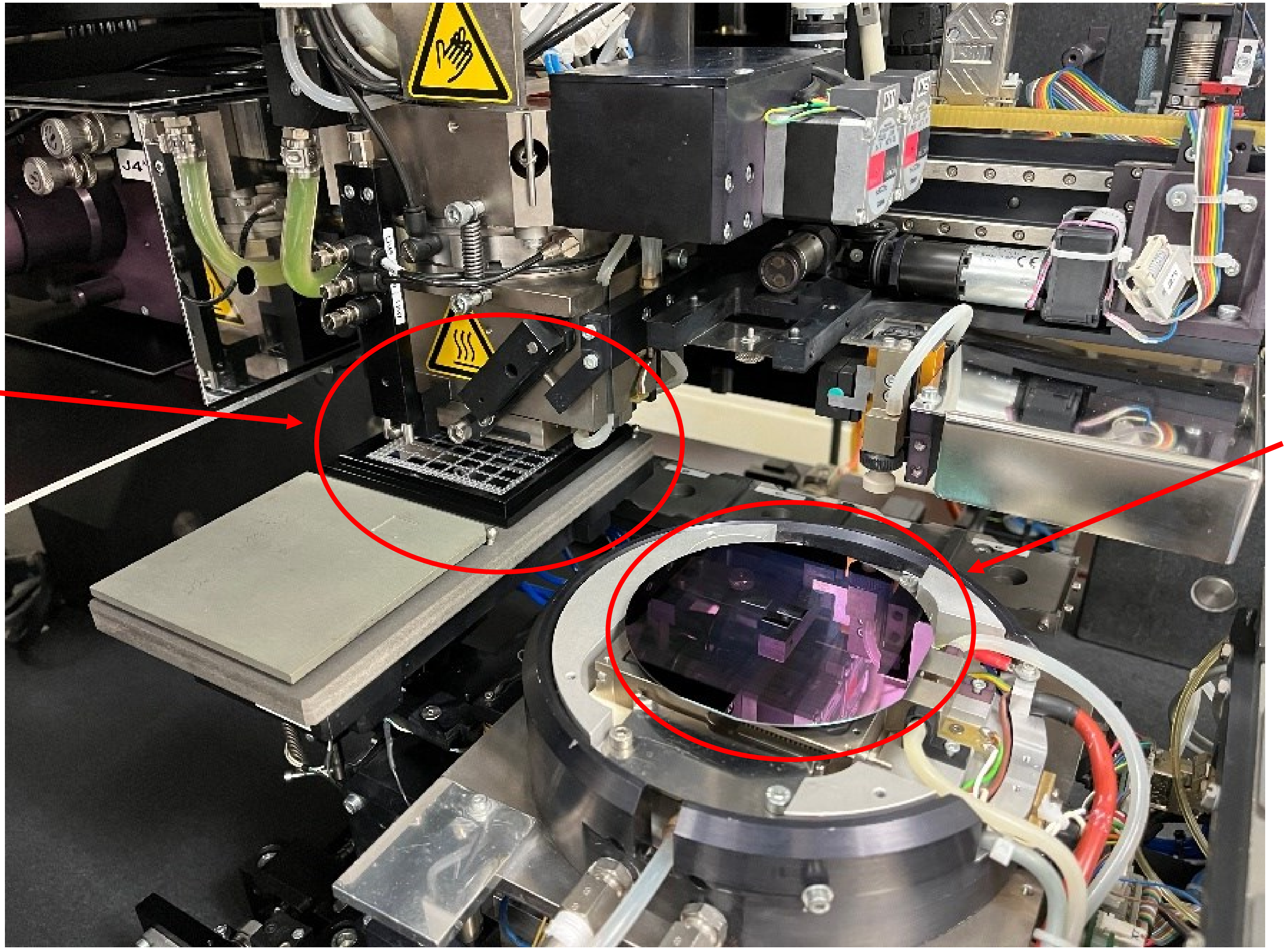
Die placed face-down onto Gel-Pak tray





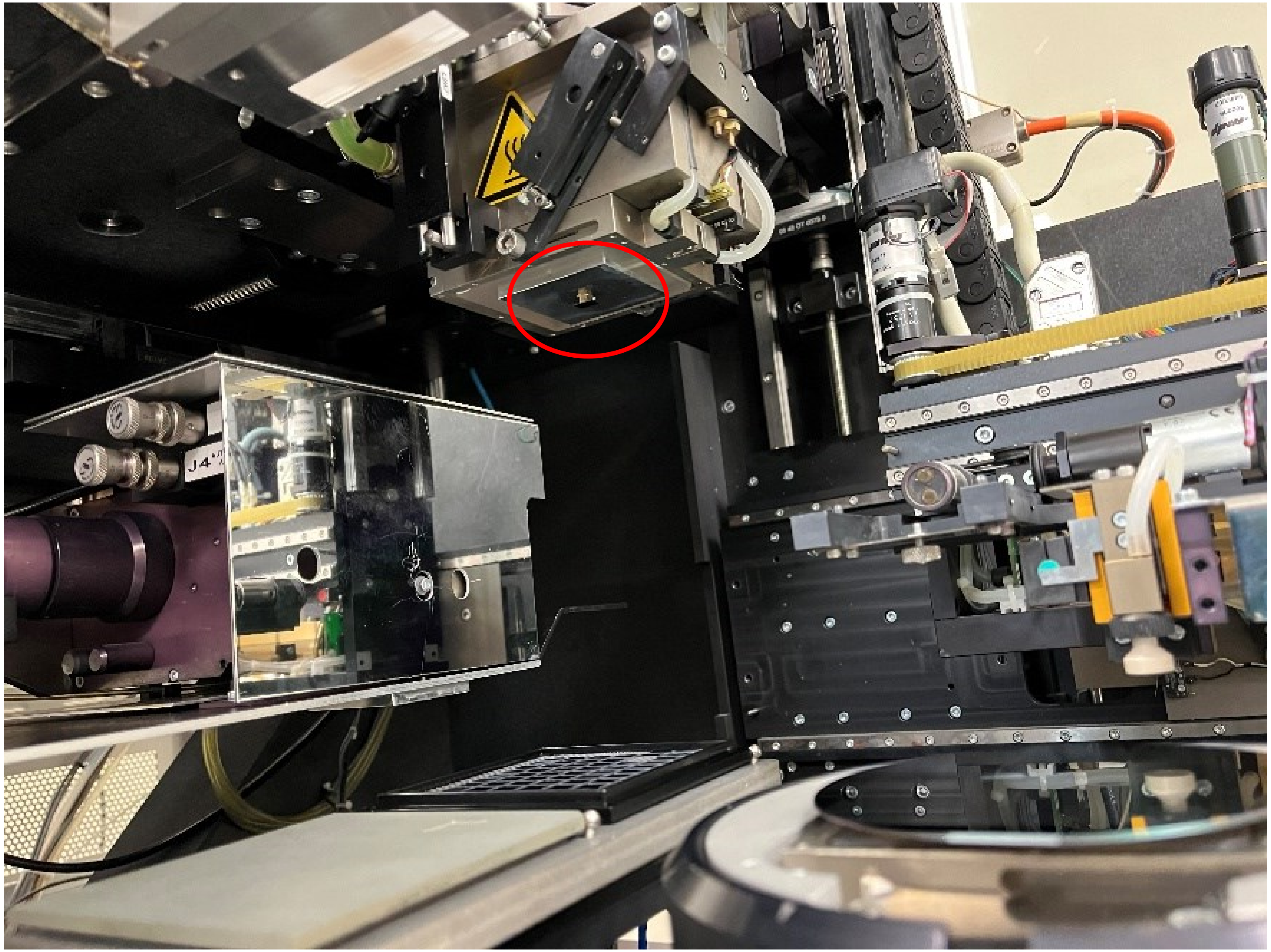
Pick up die and position wafer on chuck

Bond arm picking up die from Gel-Pak Tray

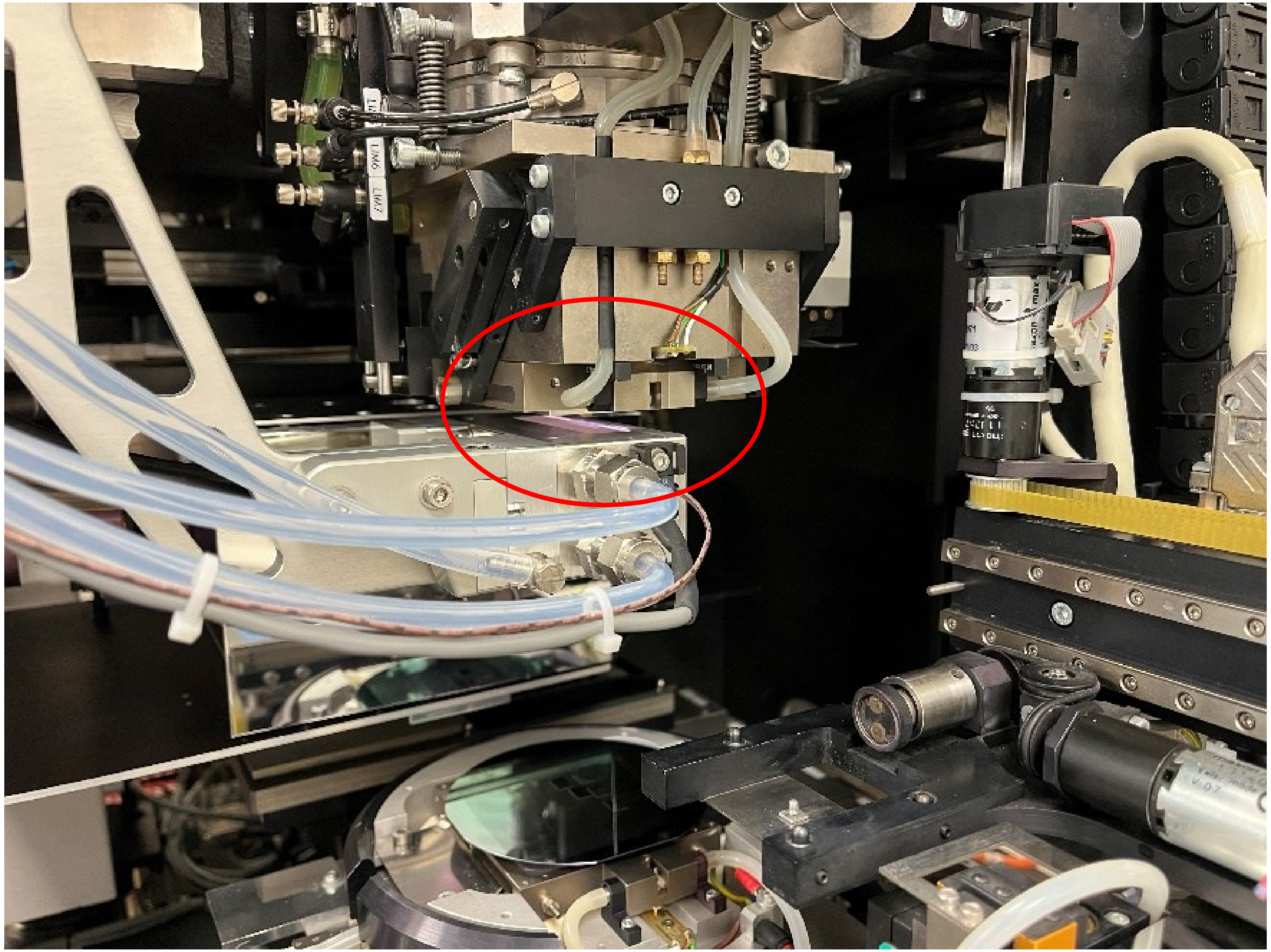


Landing wafer on chuck

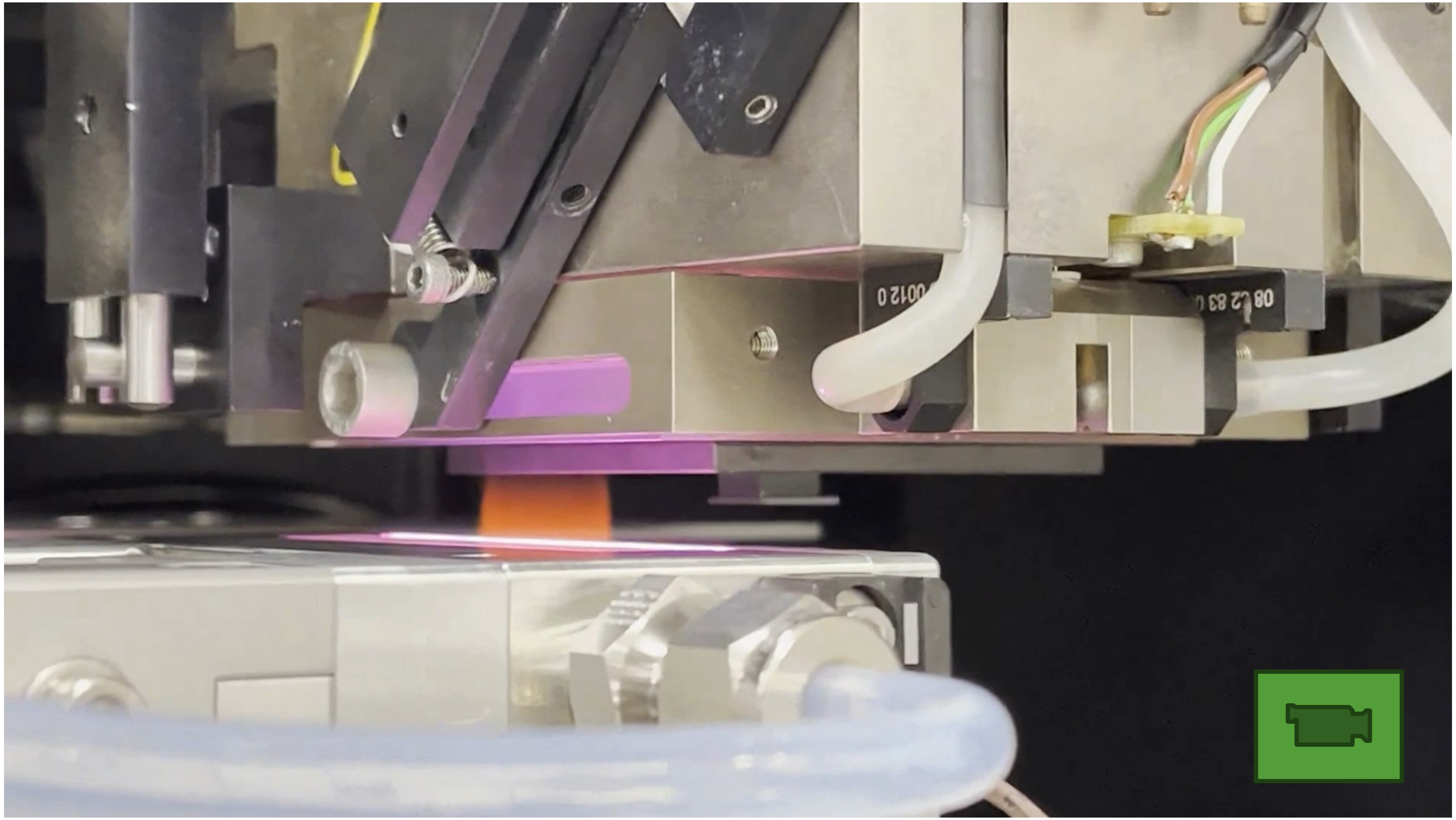
Die on Bonding Arm



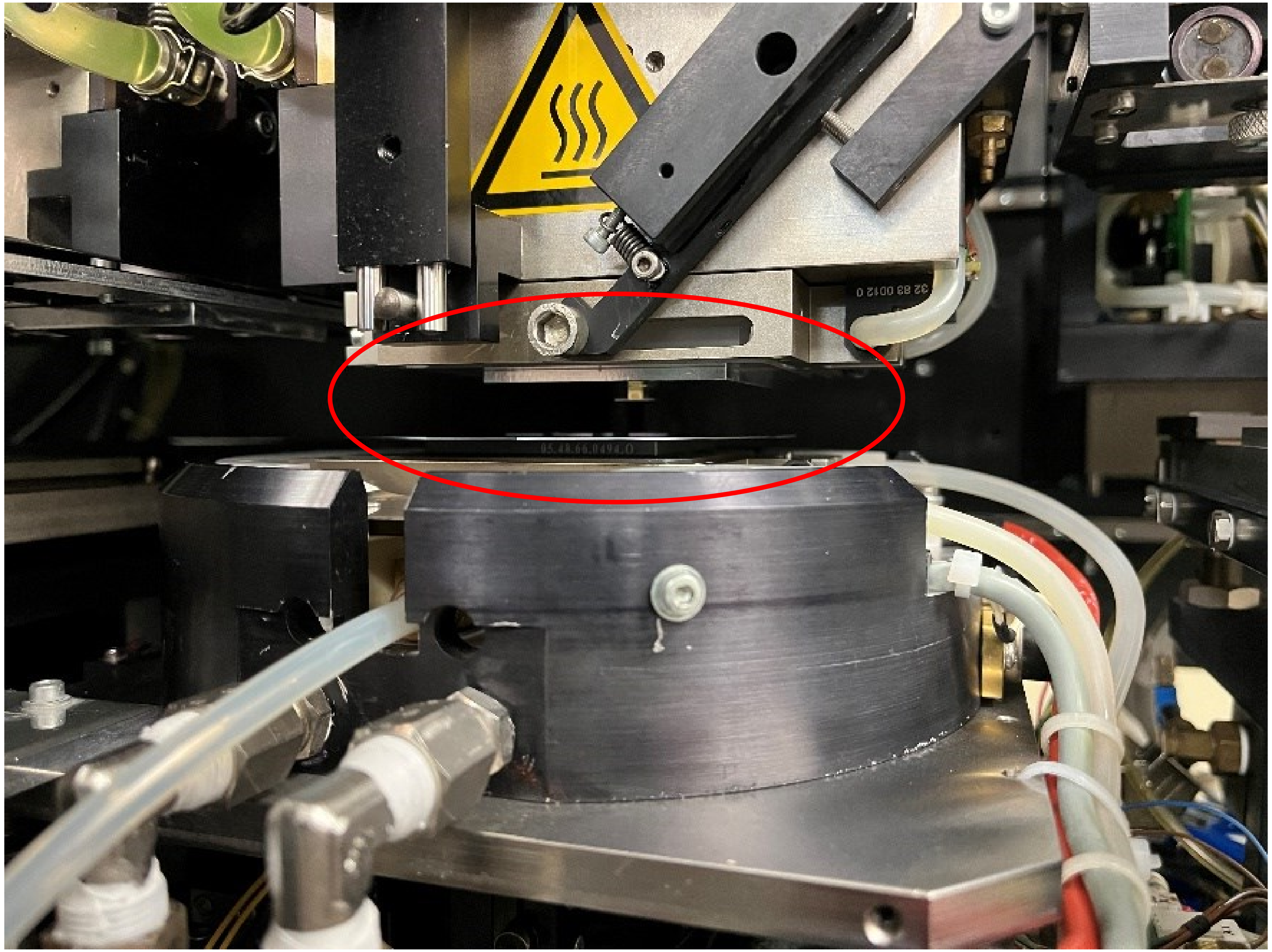
Atmospheric Plasma Treat Die



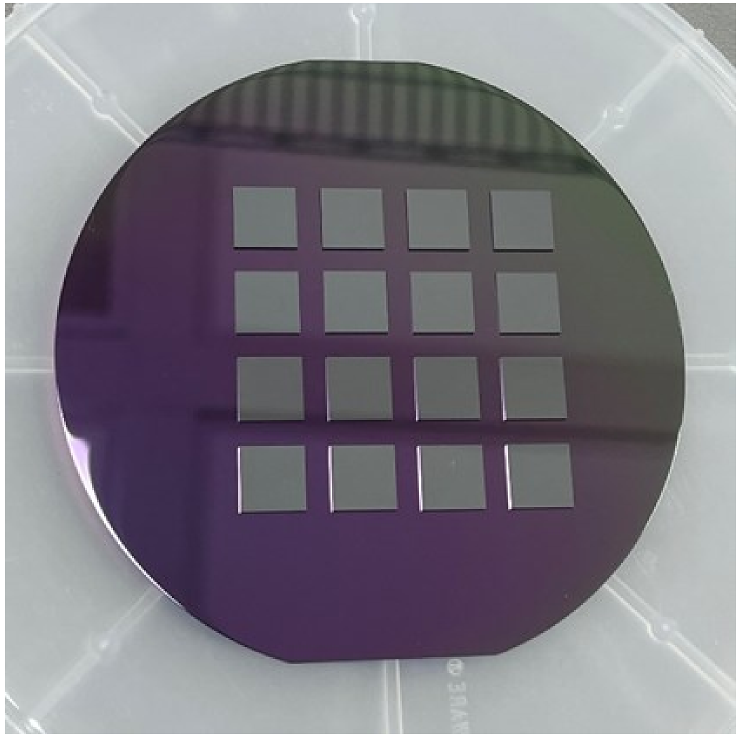
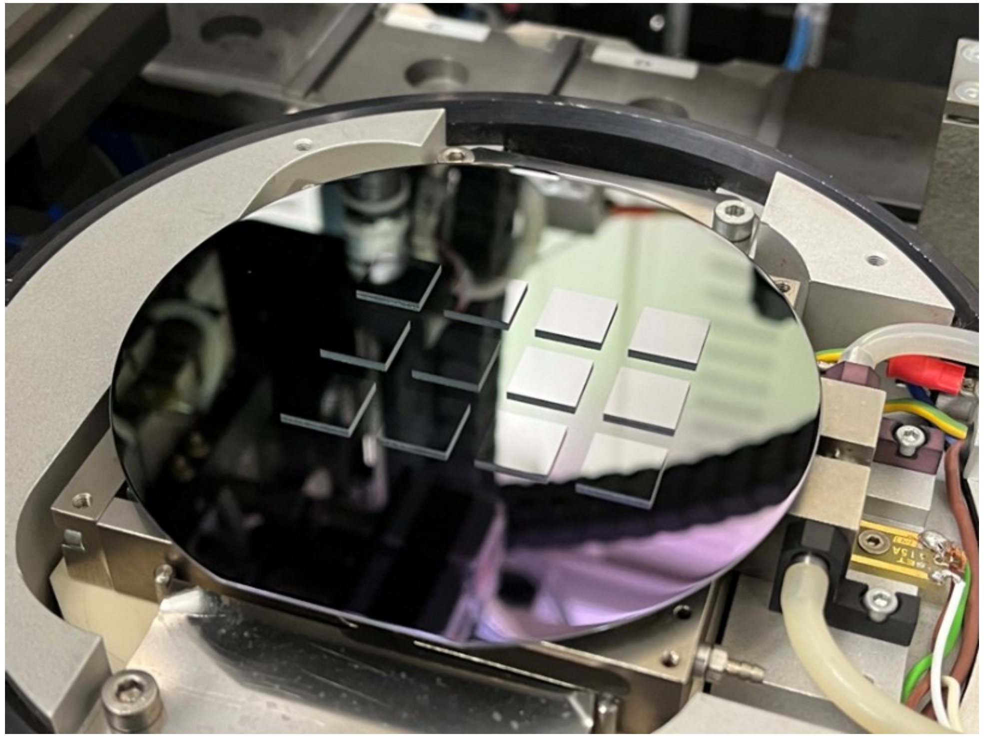
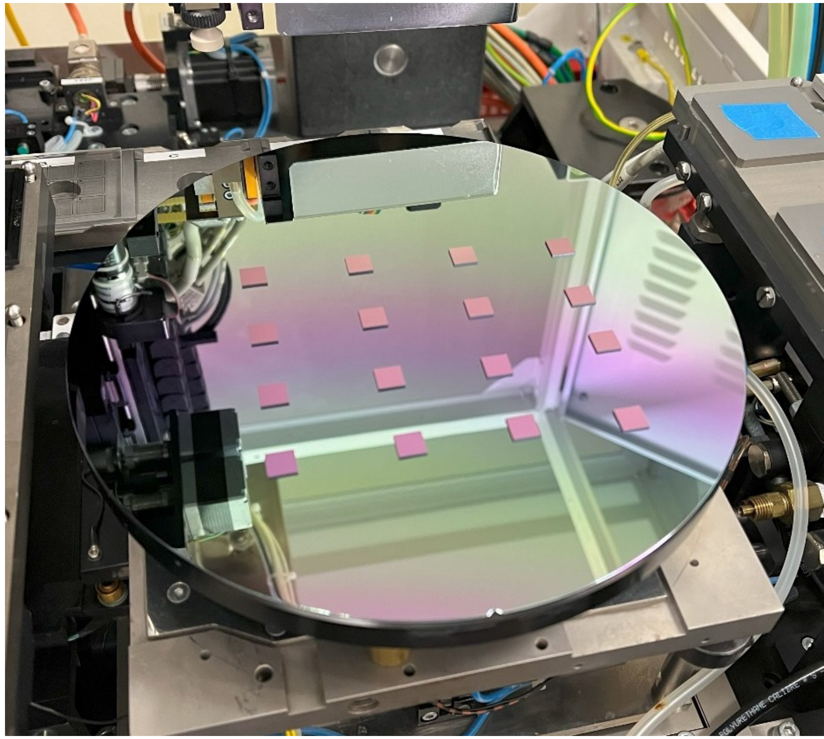
Video of Atmospheric Plasma Treatment of Die



Die to wafer bonding

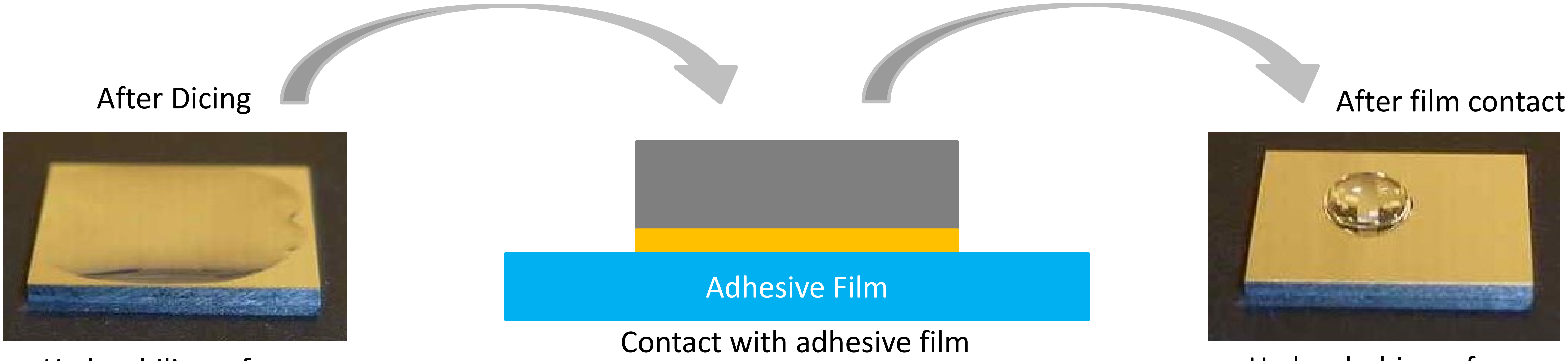


Completed Die-to-Wafer bonds

Bonding Surface Analysis

Contamination from adhesive film

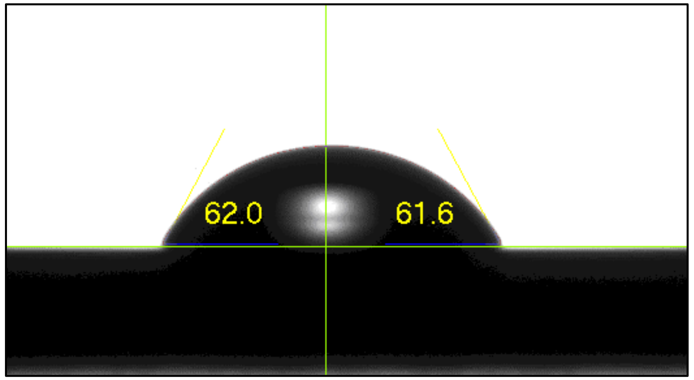


Hydrophilic surface
(Clean)

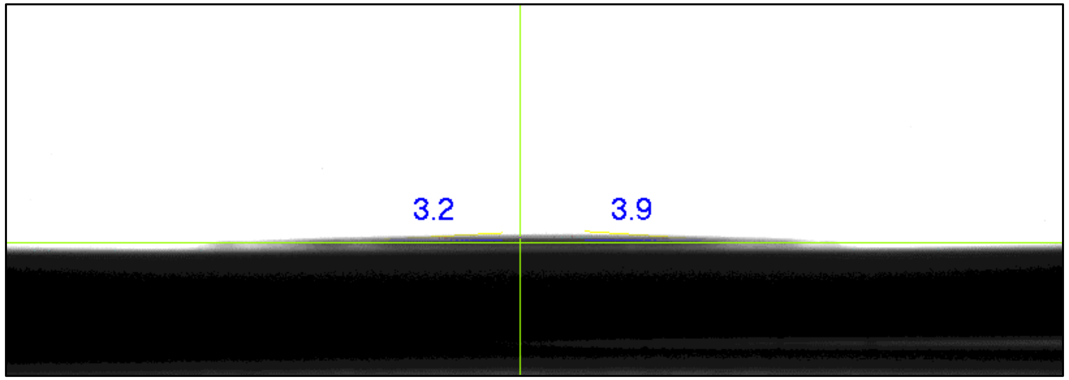
Hydrophobic surface
(Contaminated)

- Surface becomes hydrophobic after contact with adhesive film
- Although no visible residue, there is contamination at molecular level
- Water contact angle is sensitive to molecular surface changes

SiO2 Surface Cleaning and Activation

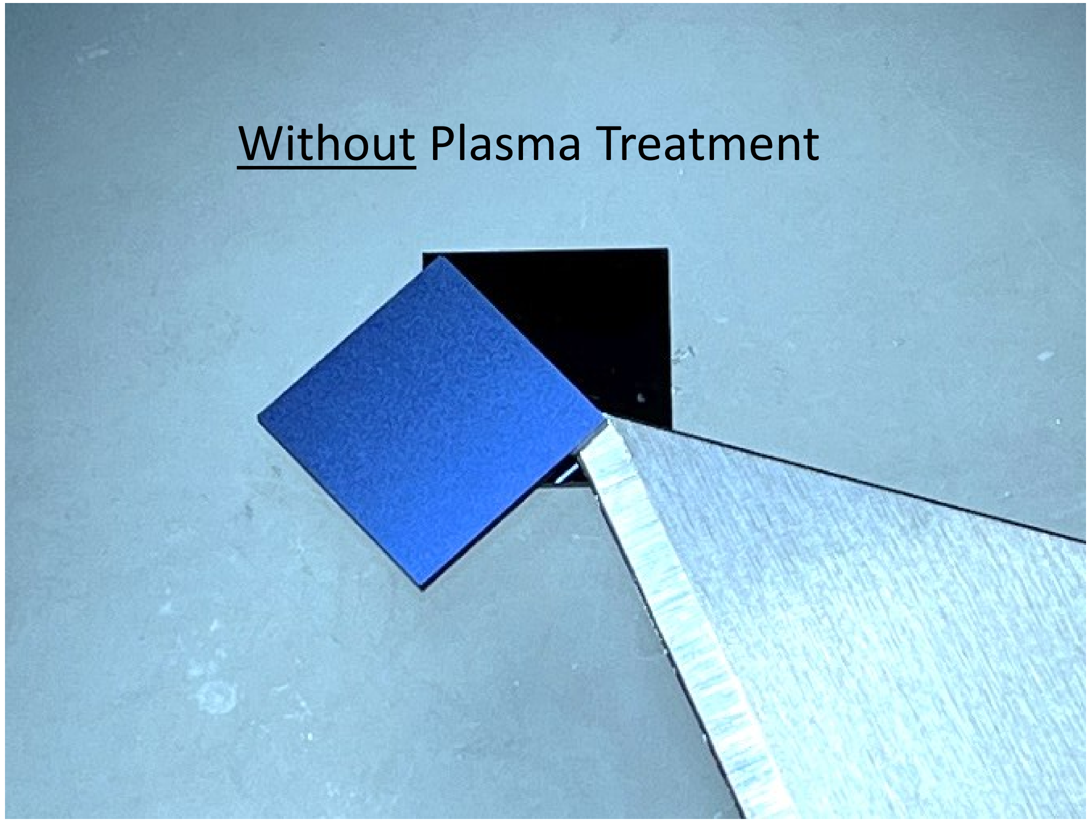


After contact with adhesive film

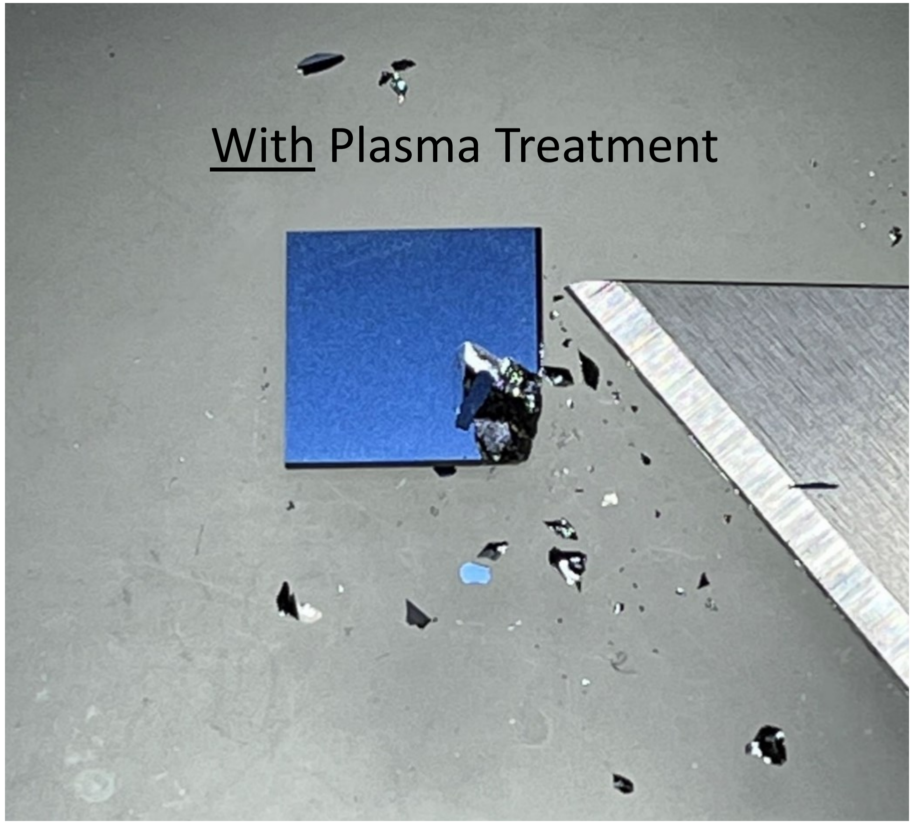


After Atmospheric Plasma treatment

SiO2 Direct Bonding Comparison



Vs.

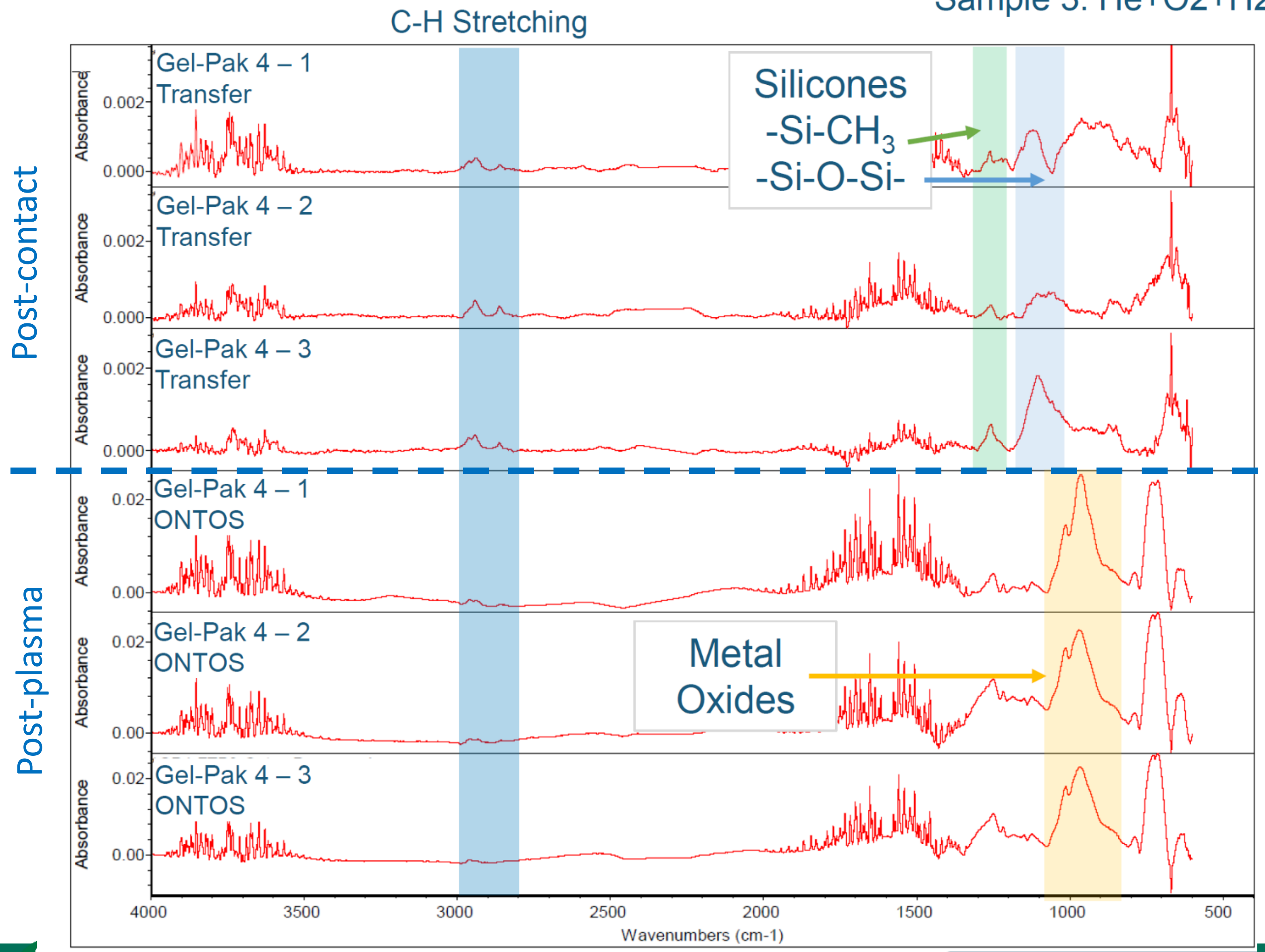


- Low bonding strength without plasma treatment
- Easily separated with razor blade

- High bonding strength with plasma treatment
- Impossible to separated with razor blade

Gel-Pak 4: FTIR

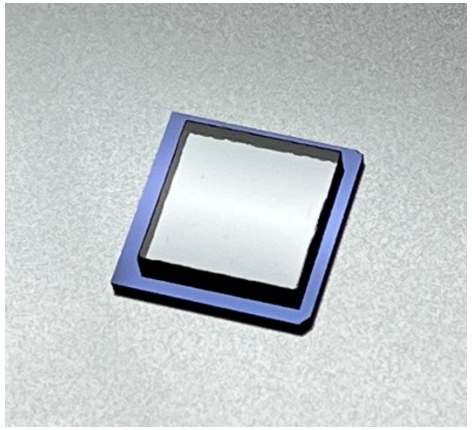
Sample 1: He+O2 Plasma
Sample 2: He+H2 Plasma
Sample 3: He+O2+H2 Plasma

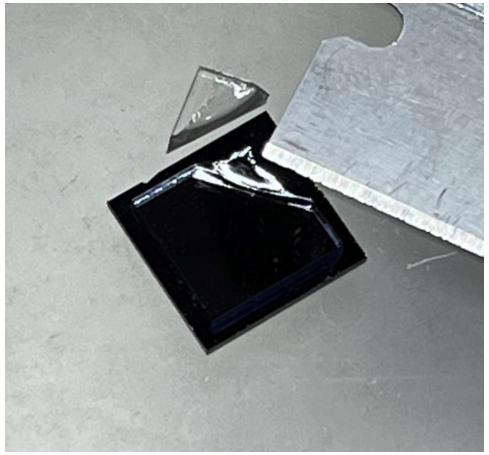


- Chrome samples used for FTIR analysis
- Hydrocarbons and silicones are present on coupons after material contact
- Hydrocarbon and silicone peaks significantly reduced or eliminated post-treatment
- Metal oxides present after aging in oxygen environment

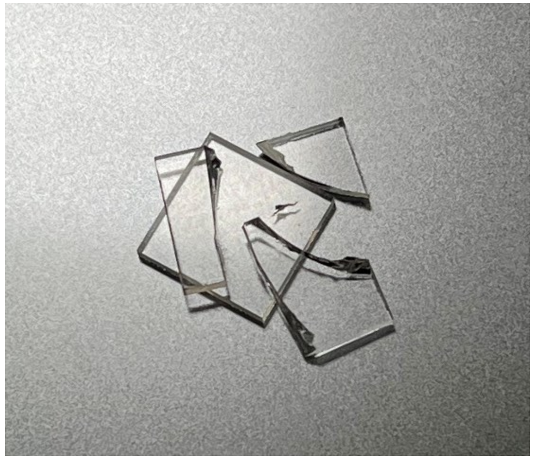
Samples treated with Atmospheric plasma show Strong, <u>Void-Free</u> Bonds

Glass to Silicon bond



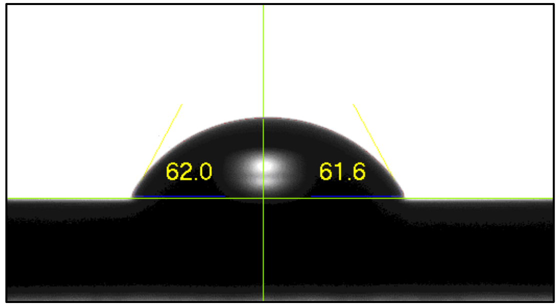


Glass to glass bond

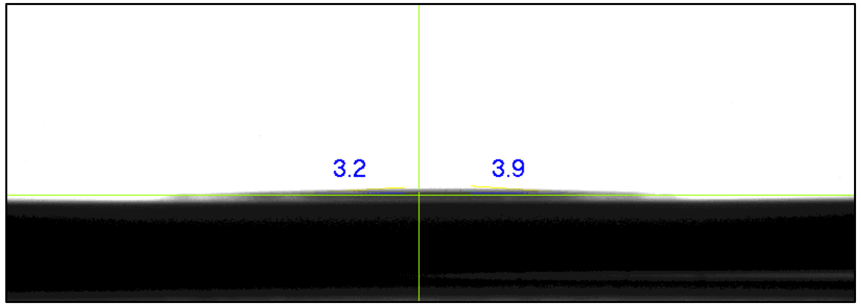


Queue Time Tests

SiO2 Surface Activation

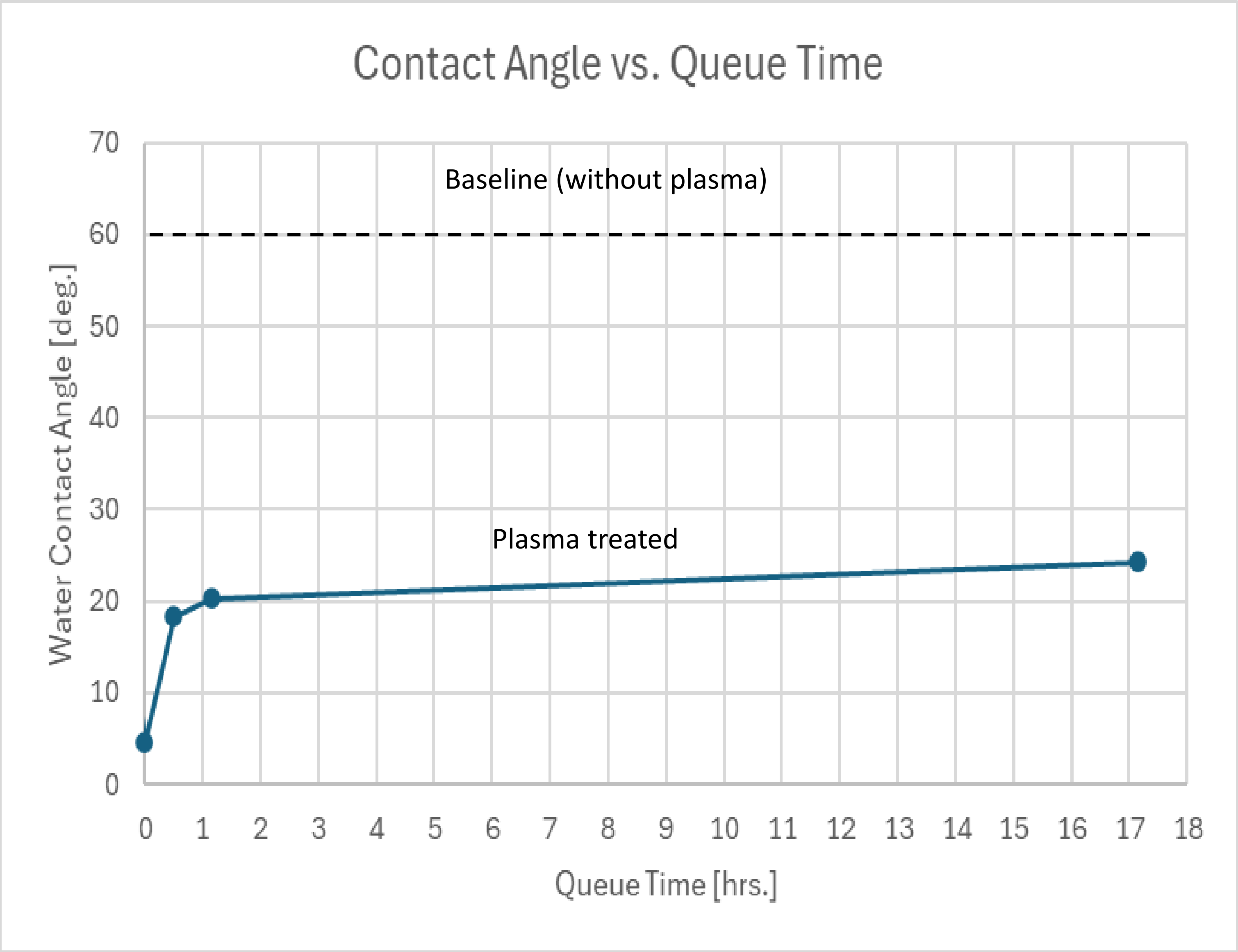


After contact with adhesive film



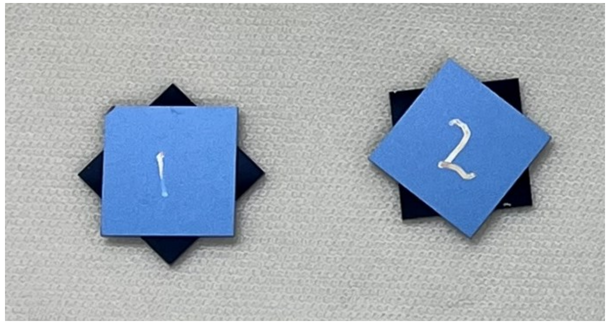
Immediately after Atmospheric Plasma treatment

But what happens after some queue time?

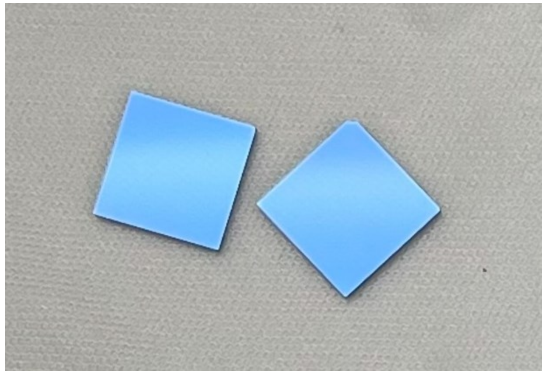


- Contact angle increases rapidly within the first hour
- Then slowly increases after 24 hrs
- This trend will be the same even for vacuum plasmas
- Still well below baseline without plasma
- This suggests that dies should be plasma treated just before bonding for optimal results
- Atmos. Plasma facilitates treatment on demand.

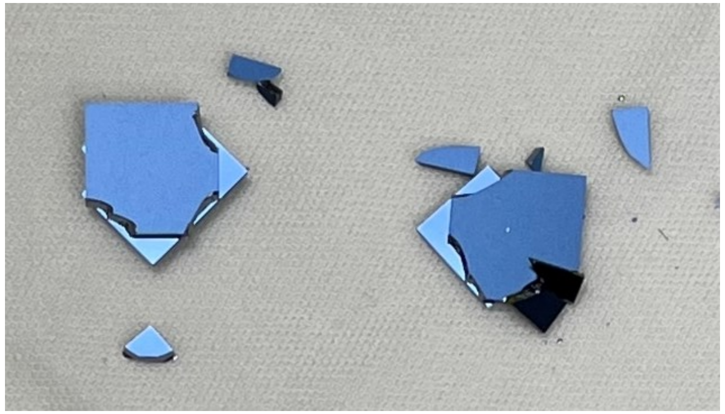
Queue time effects on bonding strength



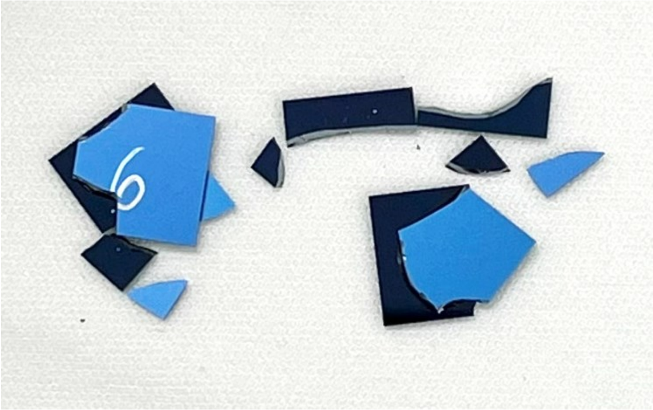
SiO2 samples bonded with rotation to facilitate bond strength testing



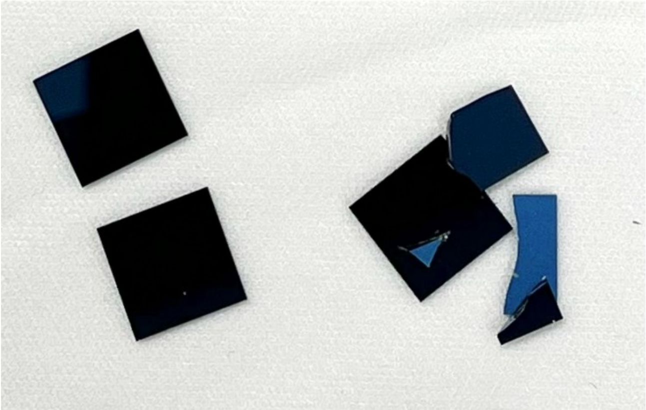
Untreated samples debonded with little force



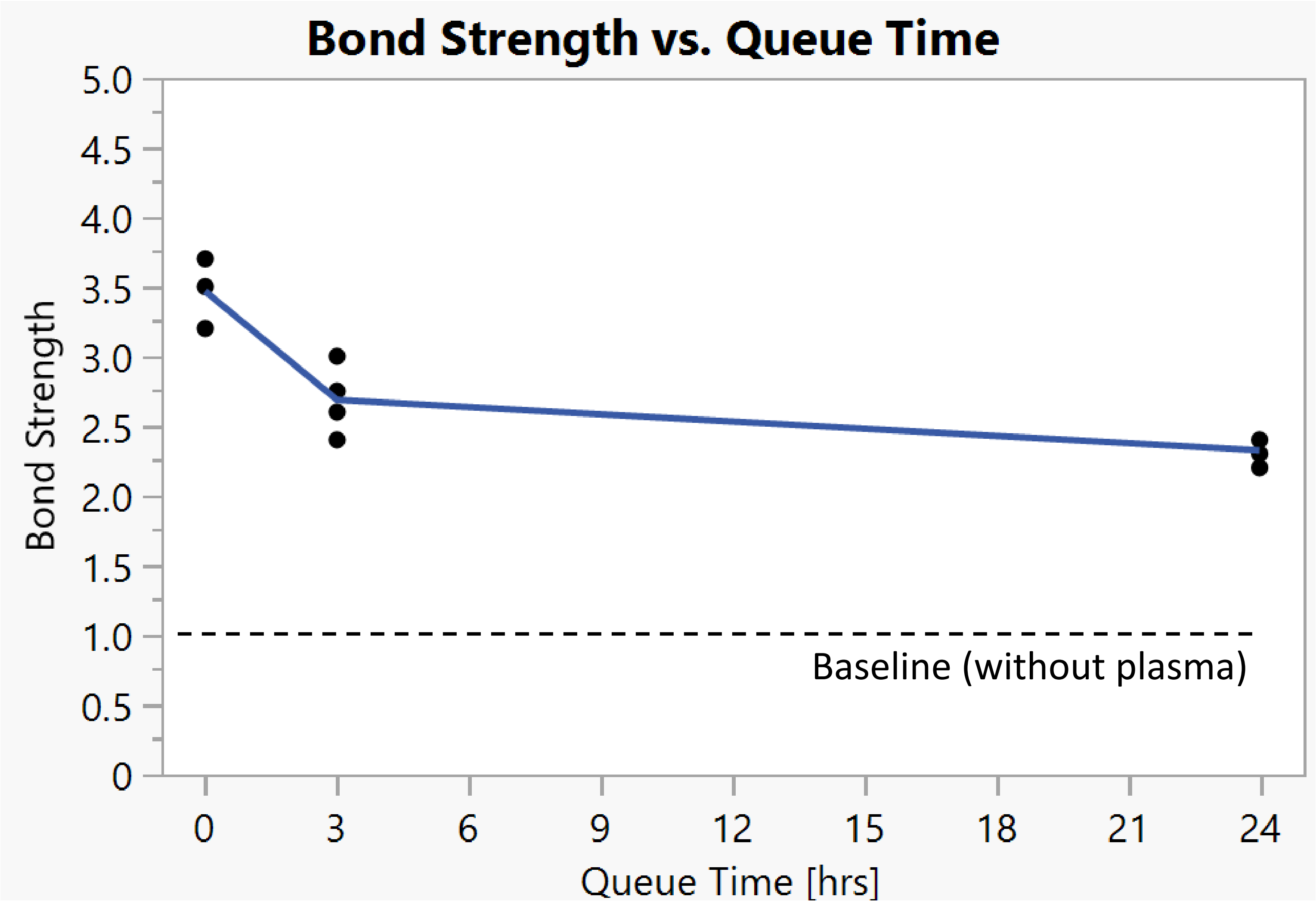
Bonded immediately after plasma



Bonded 3 hours after plasma



Bonded 24 hours after plasma

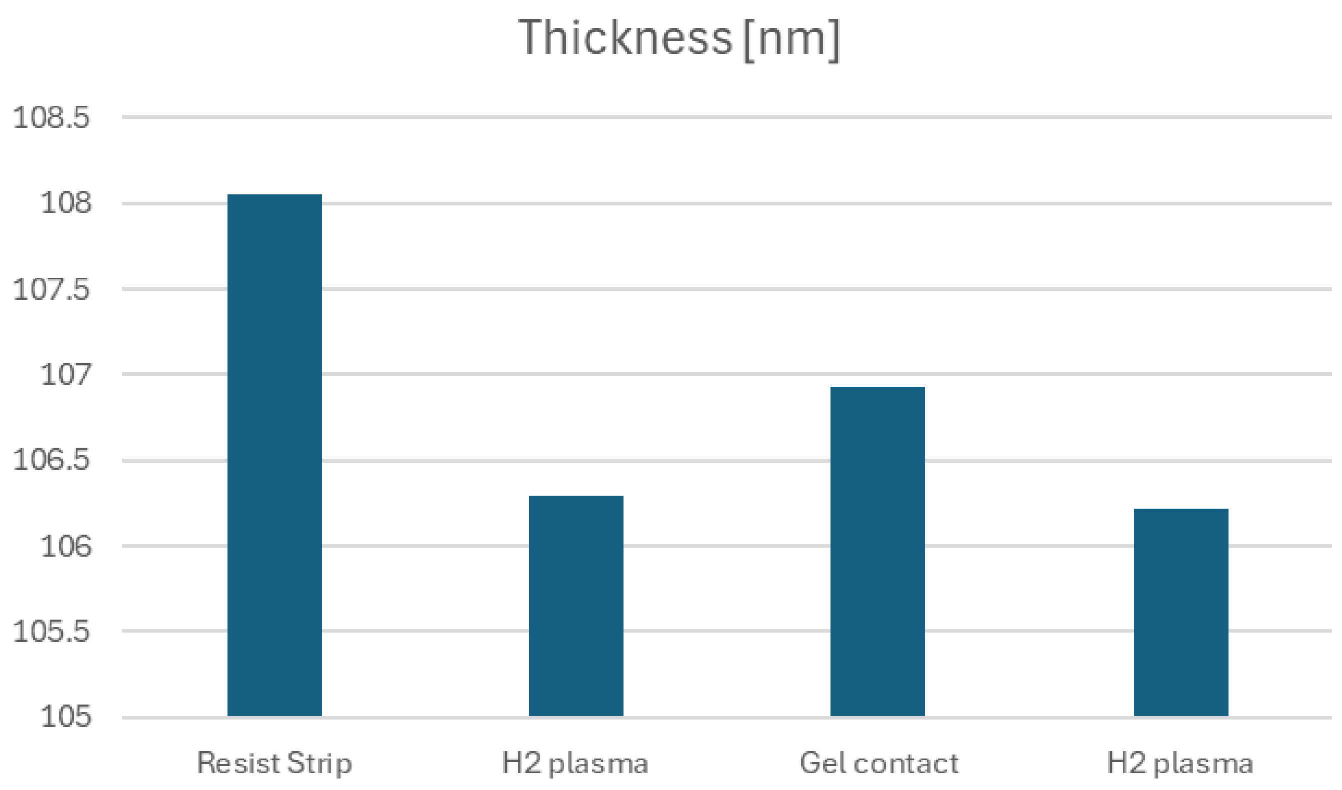


- Bond Strength dencreases rapidly within 3 hours
- Then continues to descrease slowly after 24 hrs
- This trend will be similar for vacuum plasmas
- Still above baseline without plasma
- This suggests that dies should be plasma treated just before bonding for optimal results
- Atmos. Plasma facilitates treatment on demand.

Conclusions

- An atmospheric plasma system has been developed to improve Die-to-Wafer bonding and Hybrid Bonding processes.
- Atmos. Plasma greatly simplifies process flow by eliminating the need for vacuum systems and carrier wafers.
- Process demonstrated using an existing flip chip bonder
- Strong, void-free bonds possible even after contact with adhesive film
- Queue time tests show that on-demand plasma can greatly improve bonding strength for consistent results over time.

Thank you for your attention!

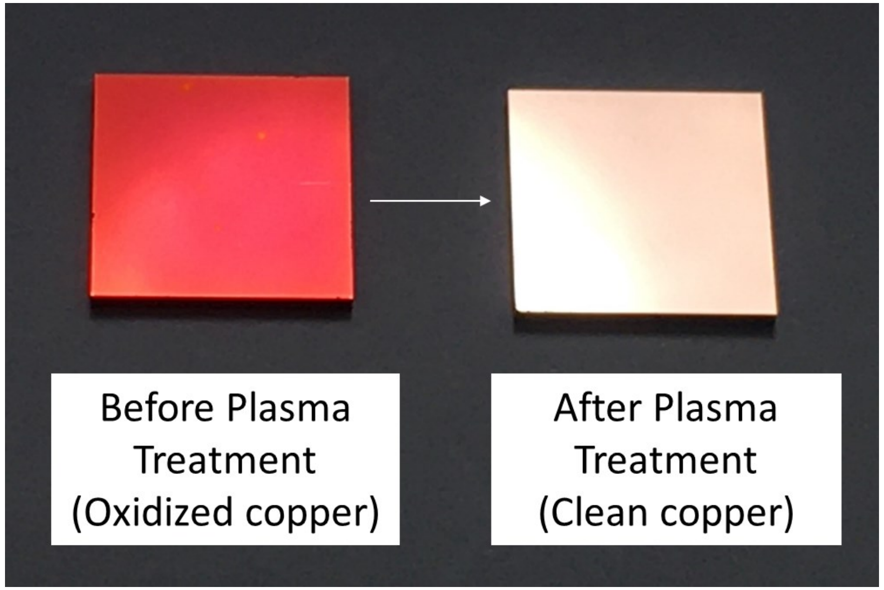


Thickness [nm]
108.5
108
107.5
107
106.5
106
105.5
105
Resist Strip
H2 plasma
Gel contact
H2 plasma

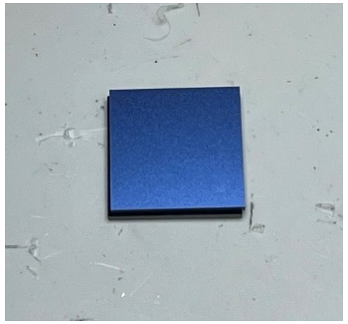
Factors for Plasma Treatment of Cu

Plasma factor settings for 28 run, central composite design DoE

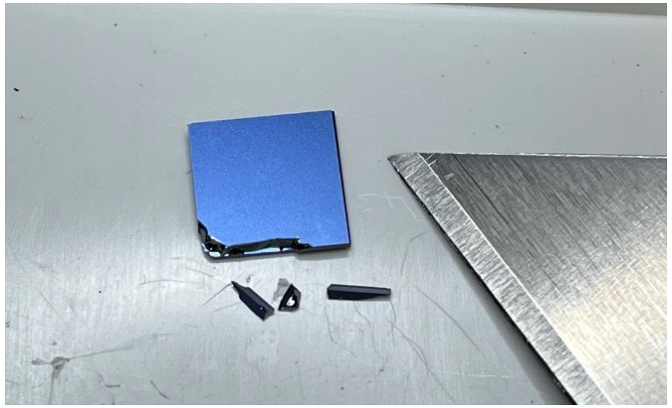
	Total Gas Flow [slpm]	H2 [%]	Power [W]	Gap [mm]	Speed [mm/s]
low	15	0.5	80	1	1
high	20	1.5	180	5	5



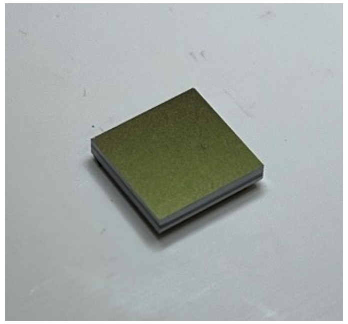
Bonding verification of DoE optimal plasma settings



SiO2-SiO2 Direct Bond
RT contact
Anneal at 240°C for 2 hrs.



Strong bonding. Chips break when attempting to pry apart.



Cu-Cu Thermocompression
Bond at 250°C, 10MPa, 10min.