Chemistry and process considerations for the removal of residues for hybrid bonding

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Self Introduction

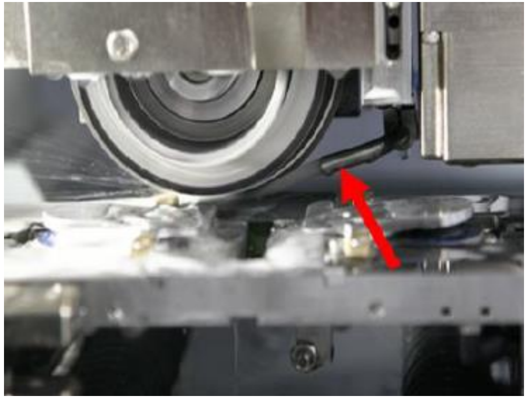
- Phillip Tyler
- Veeco Instruments
  - Manager, Process Development Engineering
- 13+ years in wafer process development
  - Georgia Tech's Institute for Electronics and Nanotechnology
  - Harris Corporation (now L3Harris Technologies)
  - Axion Biosystems
- Collaborators
  - Thomas Workman and Laura Mirkarimi at Xperi

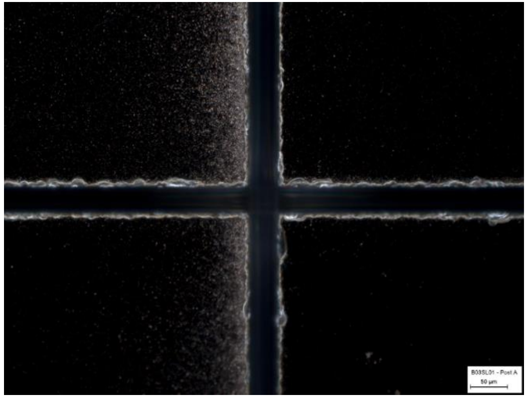
Agenda

- Introduction
- Process Flows
- Experimental Setup
- Metrology
- Cleaning Equipment
- Results
  - Initial Cleaning Investigation
    - Blanket silicon test wafers
    - Diced silicon test wafers
    - Bonding test vehicle
  - Bond Yield
  - Electrical Yield
- Conclusions

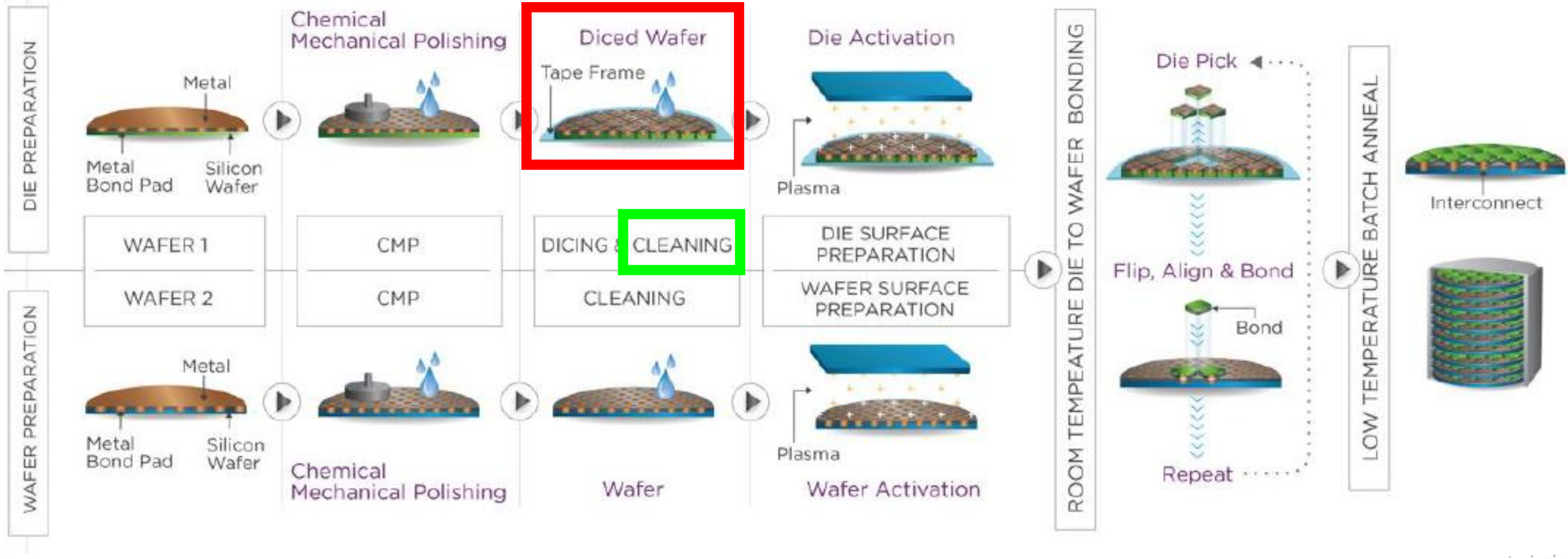
Introduction

- Wafer dicing process generates a significant amount of debris that can be challenging to remove during or after processing
- Protective dicing coatings are used to protect the surface from this debris and is subsequently removed with solvents
- Temporary bonding material (TBM) residues can also be cleaned in this same step to reduce total process flow time
- This process flow is especially important in molecular die-to-die bonding



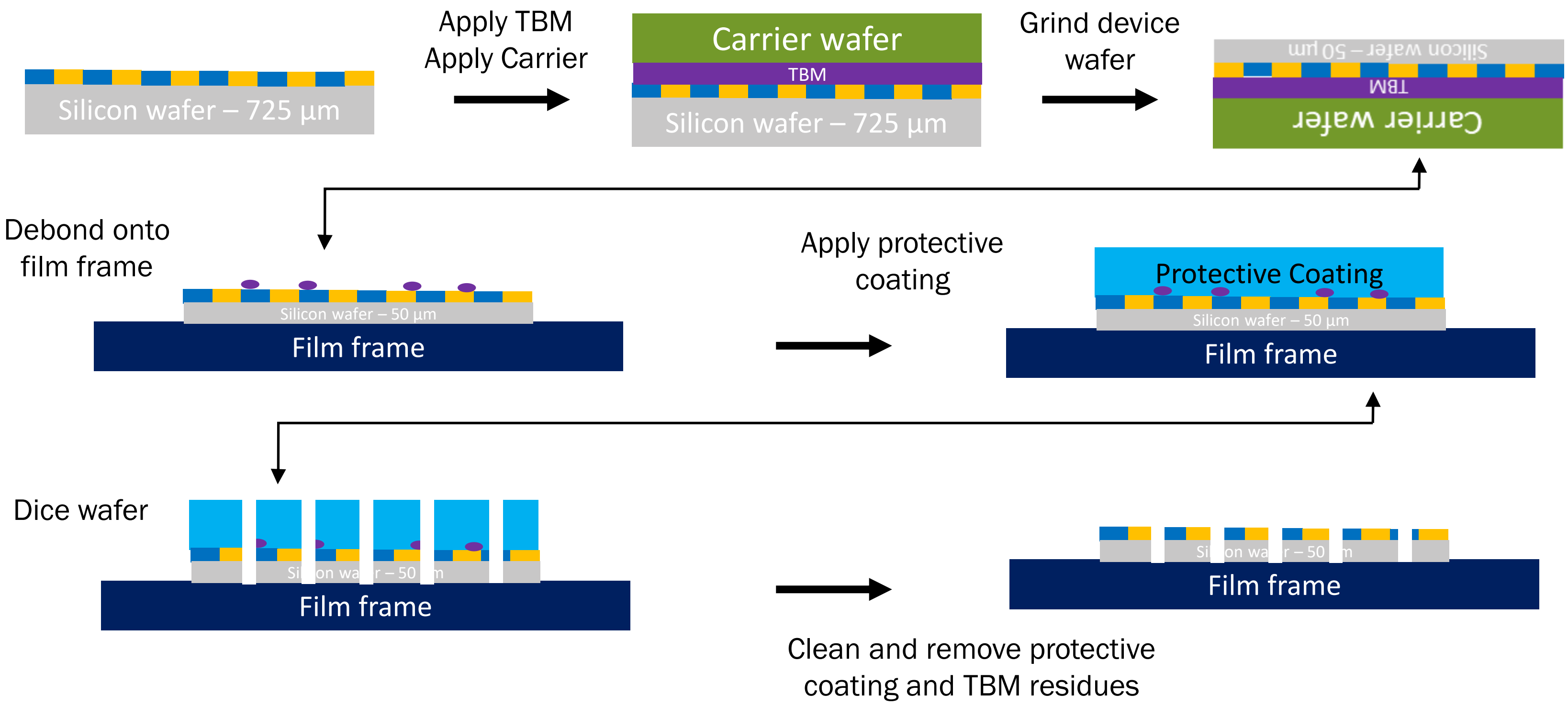


Process Flow - Overview



- This investigation will focus on the cleaning of temporary bonding material (TBM) residues and protective dicing coatings (red box).

Process Flow - Expanded



Apply TBM
Apply Carrier

Grind device wafer

Debond onto film frame

Apply protective coating

Dice wafer

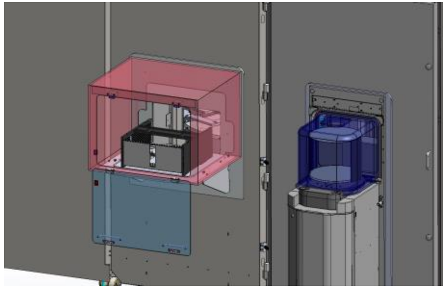
Clean and remove protective coating and TBM residues

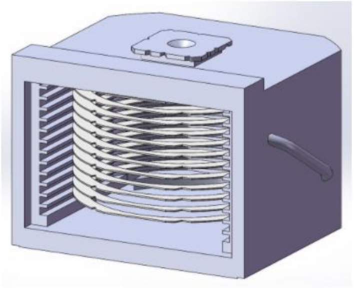
Experimental setup and metrology

- KLA Tencor Candela CS20
  - Surface defect Inspection
  - Four bins of interest
    - 0.32-1.0 µm
    - 1-5 µm
    - 5-28 µm
    - >28 µm
  - Only capable of scanning full thickness silicon wafers
- Besi Datacon 8800 CHAMEO bonder
  - Bond's daisy chain test die to substrate
  - Alignment accuracy of +/- 3 µm at 3σ
  - ISO 3 (Class 1) Clean Kit installed
- Sonoscan Gen7 C-SAM
  - C-Mode Acoustic microscope
  - Die to substrate void inspection

Cleaning Equipment

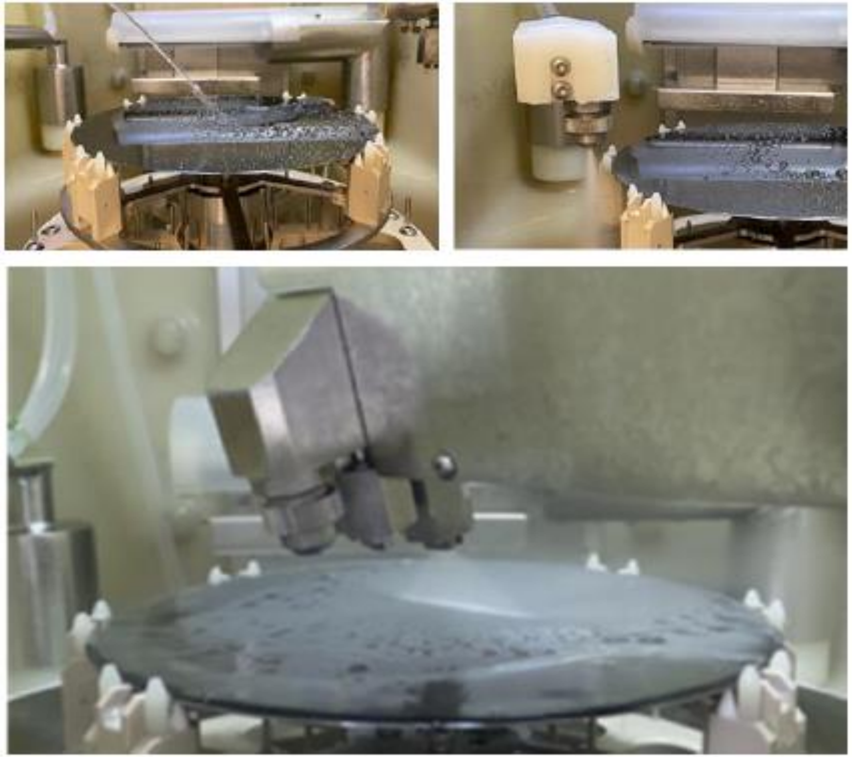
- Veeco WaferStorm® 3300 Series Platform
- Used to remove protective dicing coating and TBM residues
- Features
  - Film frame processing capable
  - Specialized hardware (chucks, end effectors, etc.) designed specifically for film frames
  - Dry in/dry out processing
  - Filtered and recirculated chemistry lower cost of ownership
  - Immersion of film frames is also available





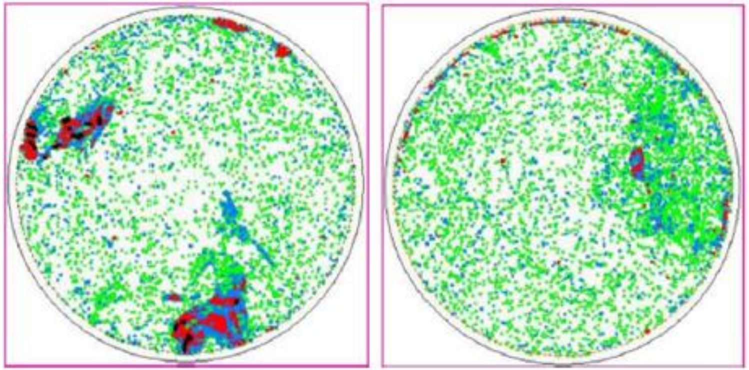
Results - Initial Cleaning Investigation

- Test silicon wafers subjected to a simulated temporary bonding/debonding process and protective photoresist was applied
- Four different cleaning techniques investigated
    - Wall mounted chemical dispense
    - High velocity spray (HVS) chemical dispense
    - High pressure chemical (HPC) fan spray
    - HPC fan spray with wall mounted chemical dispense



Results - Initial Cleaning Investigation

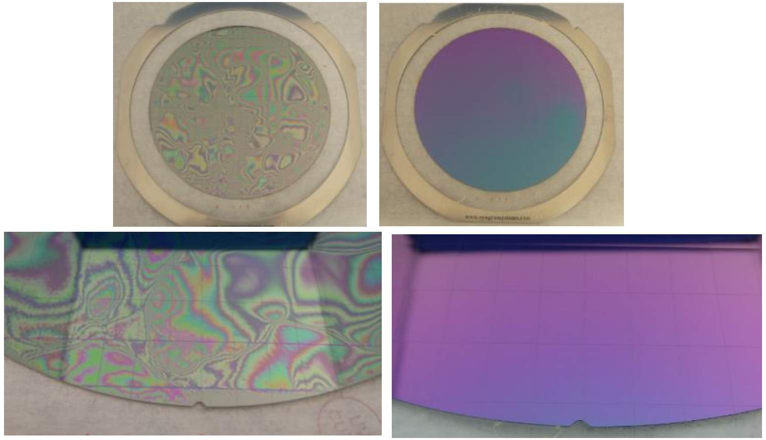
- Preliminary investigation to see which cleaning techniques had biggest impact
- Wafers scanned on KLA CS20 with below bins
    - 0.32-1.0 µm
    - 1-5 µm
    - 5-28 µm
    - >28 µm
- Cleaning efficiencies of >95% are possible with further optimization
- Highest efficiency achieved with HPC Fan Spray + Wall Dispense
- Focus shifted towards bonding and electrical yield



Sample defect maps before cleaning

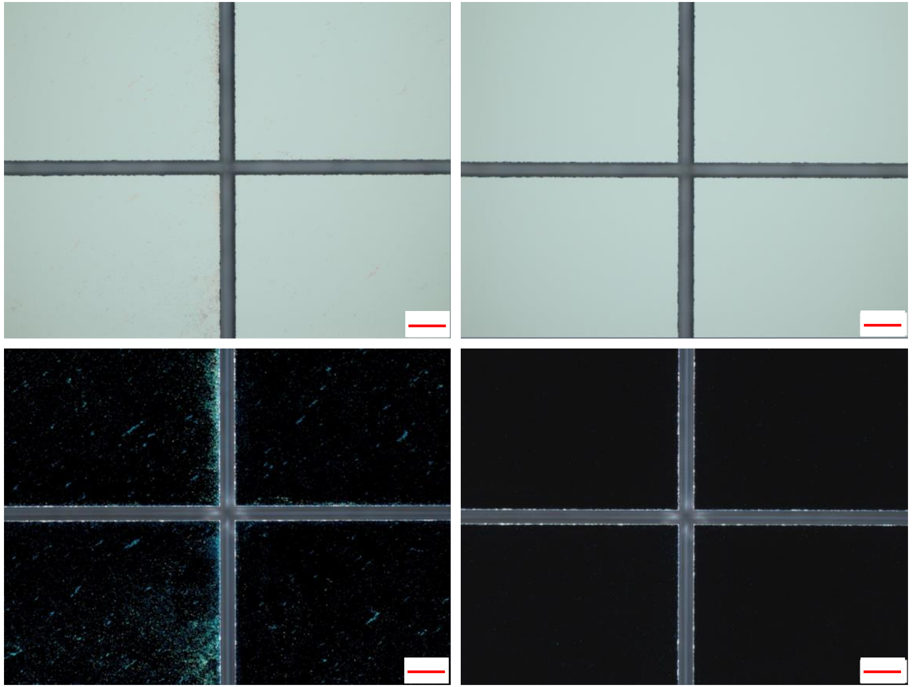
Technique	Cleaning Efficiency
Wall Dispense	-11%
HVS	27%
HPC Fan Spray	77%
HPC Fan Spray + Wall Dispense	86%

Results – Diced Silicon Test Wafer



Before Processing After Processing

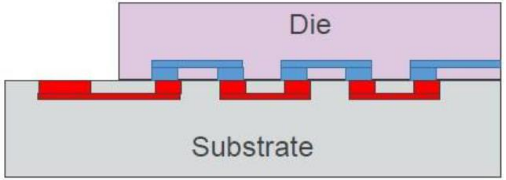
- Previous process applied to diced silicon test wafers for cleaning confirmation
- Standard brightfield (top images) did not show silicon dust and debris well
- Darkfield microscopy highlighted the surface debris

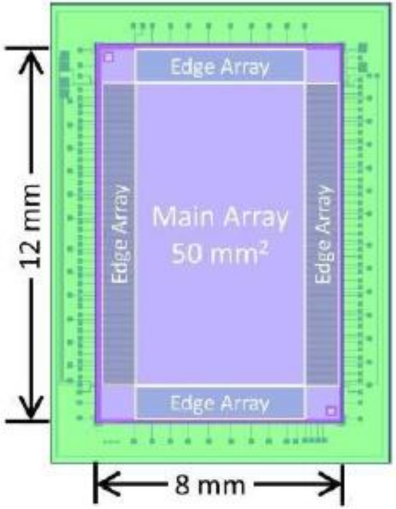


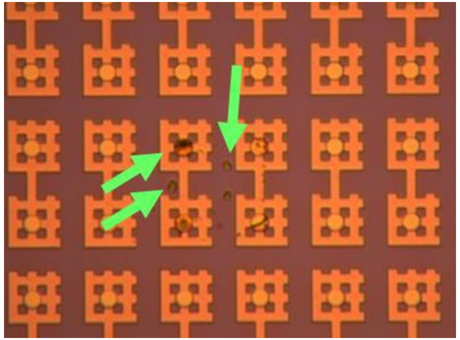
Before Processing After Processing

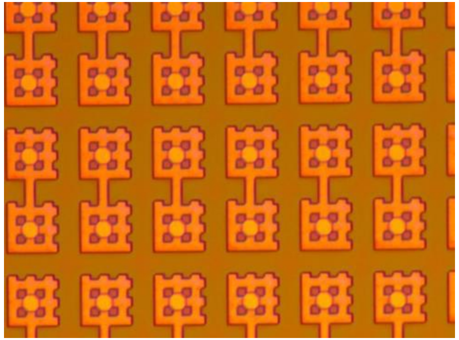
Mag: 10X, Scale bar: 100µm

Results – Bonding Test Vehicle





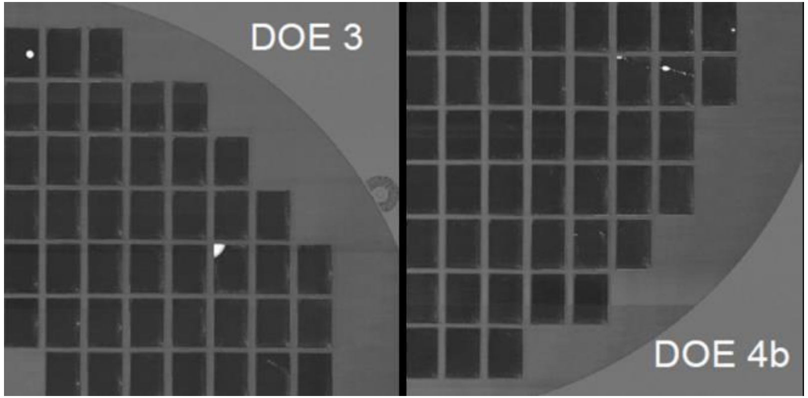

Before Processing


After Processing

- Daisy chain design used for bonding die to substrate
- Allowed electrical yield evaluation with flying probe and bonding yield evaluation with CSAM
- Design description
  - 2 layers – RDL and bonding pads
  - Pads: 10 µm
  - Pitch: 40µm
  - 31,356 electrical connections in main array
  - 3400 connections in edge arrays

Results – Bonding Yield

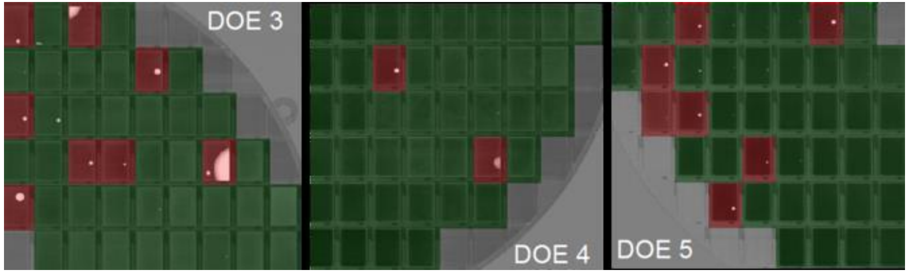
- Chemical needs to remove both photoresist and temporary bonding residues
- Chemical Composition
  - Surfactant concentration
  - Active resist remover concentration
- Considerations
  - Film frame material
  - Tape composition
  - Wafer compositions (metals, dielectrics, etc.)
- 42 daisy chain die were bonded to the substrate for each clean condition
- C-SAM images show minimal voids
- Void free yield indicates the two chemicals investigated are comparable



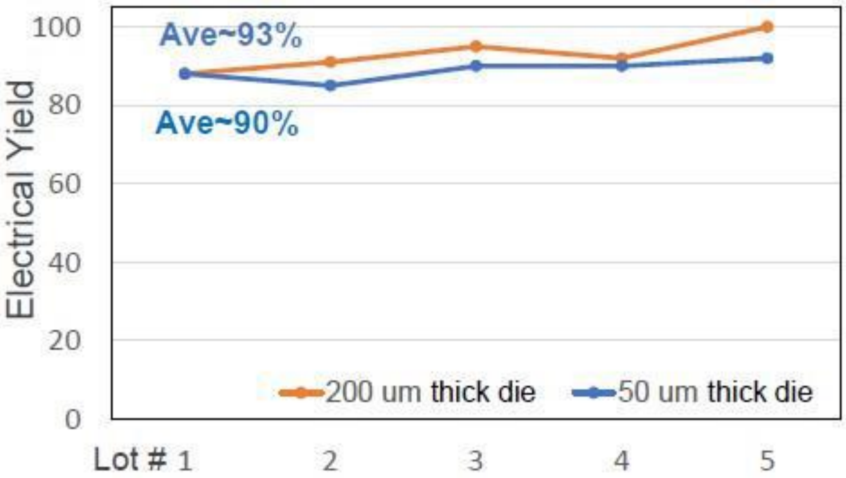
DOE	Chemical	Void Free Yield
3	A	93%
4b	B	91%

Results – Electrical Yield

DOE	HPC Fan Spray Pressure	Rotational speed	Electrical Yield
3	High	High	81%
4	Low	Low	95%
5	Low	High	83%

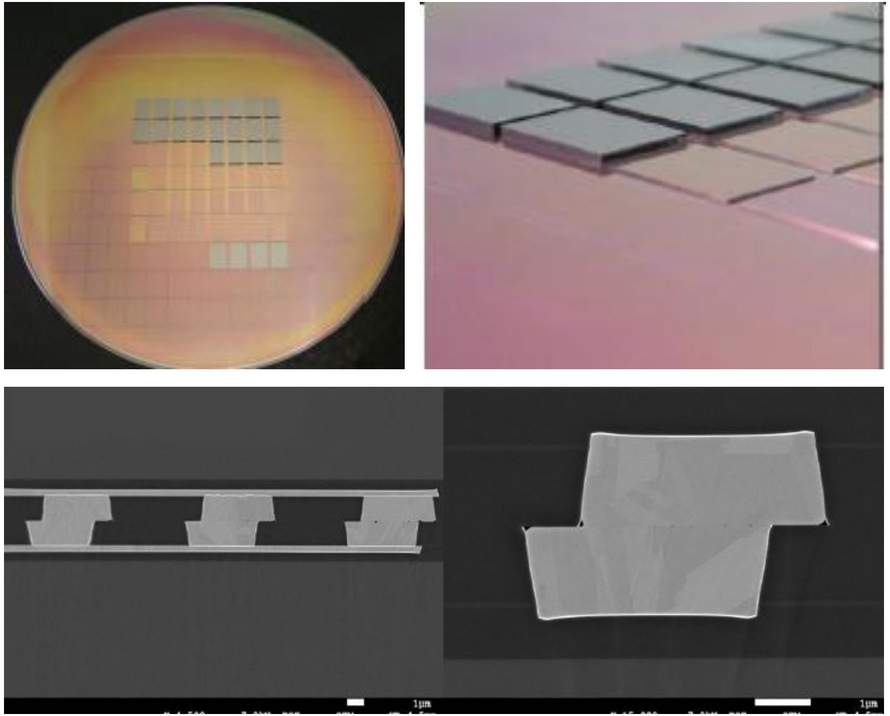


- DOE with HPC Fan Spray pressure and rotational speed
  - Fan Spray range (300-3000 psi)
  - Rotational speed range (50-1500 rpm)
- 42 daisy chain die were bonded to the substrate for each clean condition
- Bonding yield data overlayed with electrical yield data
- Clear correlation between bond yield and electrical yield



Conclusions and Next Steps

- Complete protective dicing coating and temporary bonding material residue removal demonstrated on 200 µm and 50 µm thick die
- HPC Fan Spray + Wall cleaning techniques demonstrated highest cleaning efficiency in preliminary studies
- Early process results applied to bonding test vehicles produced high yields
    - ○ Bond free yield – 93%
    - ○ Electrical yield – 95%
- These initial cleaning results on a Veeco WaferStorm® are promising for use in manufacturing optimization.



Workman, et. al, “Cu interconnect scaling with hybrid bonding for 2.5 and 3D integration”, IMAPS Device Packaging Conference, Scottsdale, AZ, March 2020

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MAKING A **MATERIAL** DIFFERENCE