IMAPS 11th International Conference on Device Packaging | March 16-19, 2015 | Fountain Hills, AZ USA

A Cost and Yield Analysis of Wafer-to-Wafer Bonding

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Agenda

- **Introduction**
- **Model & Cost Drivers**
- **Sensitivity Analysis**
- **Trade-off Scenarios**
- **Summary**

Introduction

- **Why Wafer-to-Wafer Bonding?**
  - Results already studied in direct comparison to wafer-to-wafer
  - High throughput, low cost potential with right yields
- **Generic Process Flow**
  - Model for this analysis does not focus on one solution
  - Variables allow enough diversity to account for many scenarios

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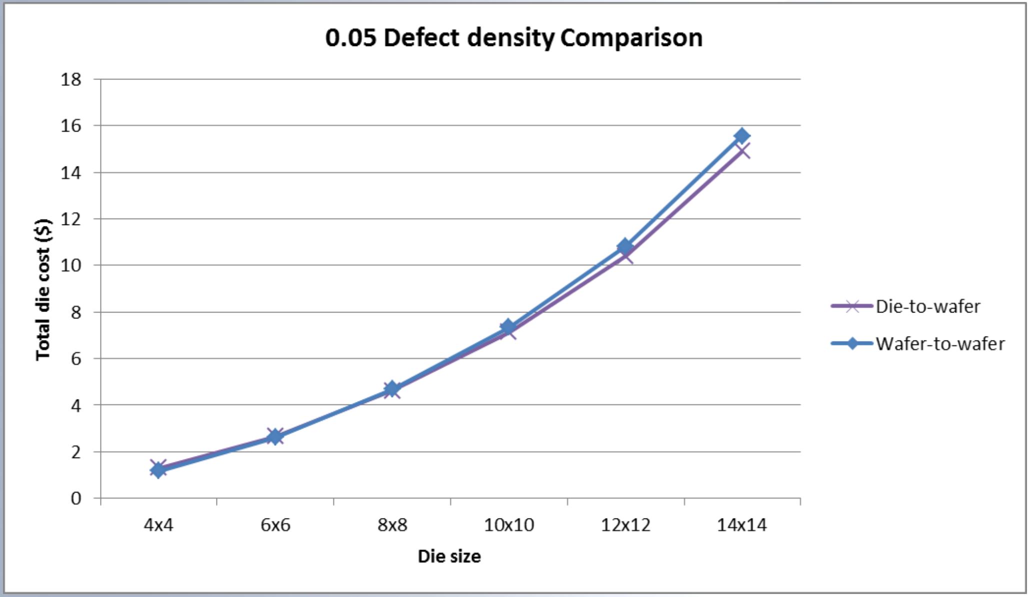
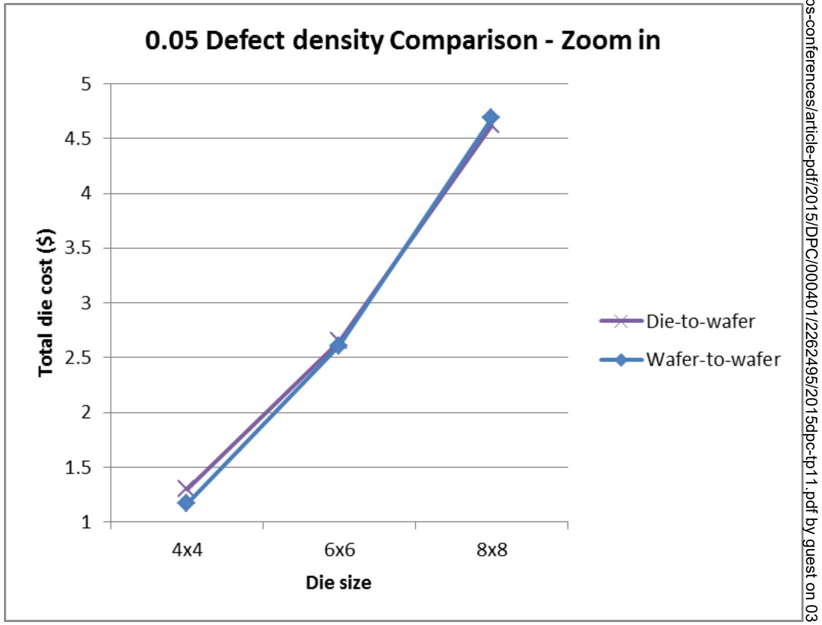
D2W and W2W – Direct Comparison

- **Crossover point between W2W and D2W**
  - At what point does W2W become more cost effect than D2W?
    - *Small die (4x4mm, 6x6mm) at 0.5 defects per square cm*





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Background

➢ Wafer-to-wafer vs. Alternatives

- W2W
  - *Advantages: Highest throughput, best alignment accuracy*
  - *Disadvantages: Yield, same-sized die*
- D2W (and D2D)
  - *Advantages: Yield (KGD), different sized die*
  - *Disadvantages: Throughput, alignment accuracy*

➢ Bonding Methods

- Cu-Cu Thermocompression
  - *Well-understood and relatively mature, but requires a fair amount of time, pressure, and heat for bonding*
- Direct bonding (fusion bonding)
  - *Plasma activated direct bonding has a high throughput and doesn't require high pressure/temperature, but surface prep is very important*
- Adhesive bonding
  - *Not the most popular choice in the industry today, but good for some applications*

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Activity Based Cost Modeling

Cost Components of each Activity

- The time required to complete the activity
- The amount of labor dedicated to the activity
- The cost of material required to perform that activity – both consumable and permanent material
- Any tooling cost
- The depreciation cost of the equipment required to perform the activity
- The yield loss associated with the activity

Sample Output

Substrate	Labor	Material	Capital	Tooling	Yield	Macro	Running Total
2-[IL-Core]	$0.0007	$0.2000	$0.0007	$0.0000	$0.0000	$0.0000	$0.2014
3-[IL-Photoresist]	$0.0007	$0.0120	$0.0011	$0.0000	$0.0000	$0.0000	$0.2152
4-[IL - Image]	$0.0007	$0.0144	$0.0045	$0.0000	$0.0000	$0.0000	$0.2349
5-[IL-DES]	$0.0009	$0.0072	$0.0088	$0.0000	$0.0000	$0.0000	$0.2517
6-[IL - Oxide]	$0.0010	$0.0001	$0.0026	$0.0000	$0.0000	$0.0000	$0.2554
7-[IL-AOI]-[Setup]	$0.0001	$0.0000	$0.0006	$0.0000	$0.0000	$0.0000	$0.2561
7-[IL-AOI]-[Test]	$0.0025	$0.0000	$0.0099	$0.0000	$0.0000	$0.0000	$0.2686

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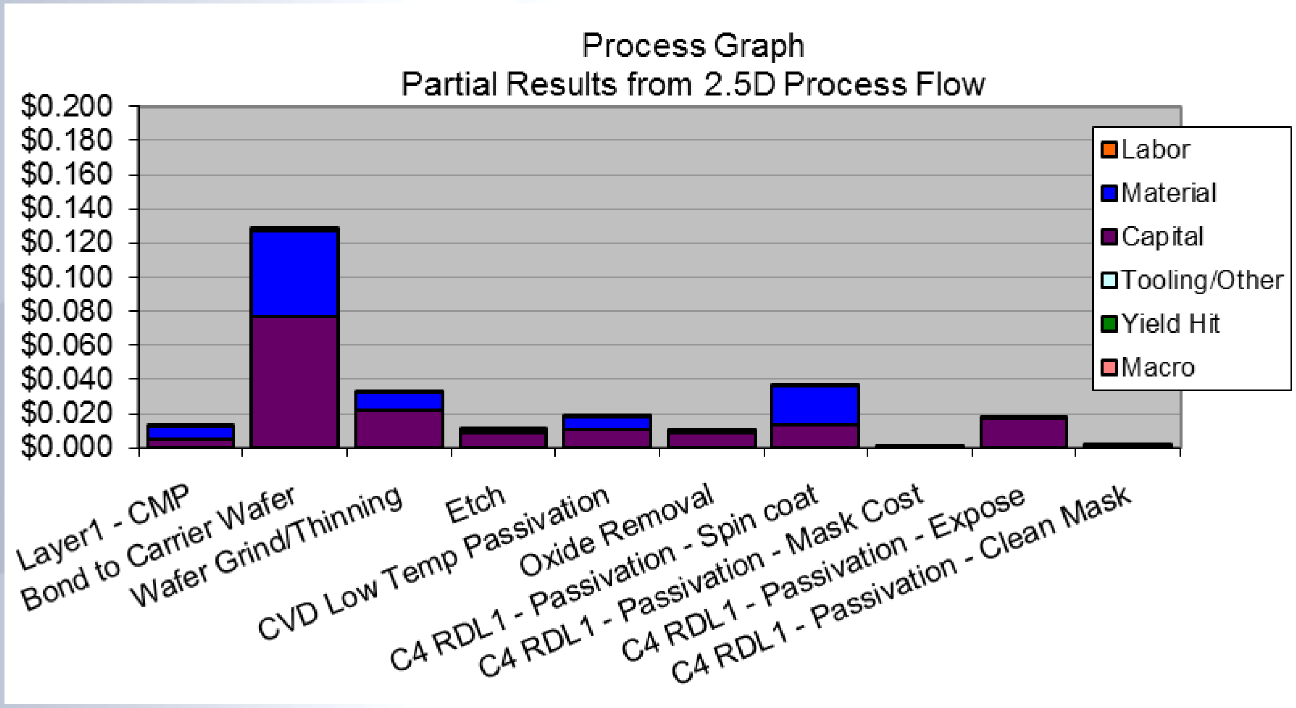
Sample Cost Detail Graph

- **Sample graph: Activity-based Cost Results for 2.5D Process flow**
  - Steps shown in the graph below are the steps immediately before and after bonding the device wafer to a carrier wafer
  - In this series of steps, the primary cost drivers are material and capital, as seen by the blue and purple bars



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Components of Total Cost / Price

- Labor Cost
- Capital/Depreciation Cost
- Material Cost (Consumables and Permanent)
- Tooling/NRE Cost
- Scrap / Rework Cost

Direct Cost

- Indirect Labor Cost
- Factory Overhead Cost
- Corporate Overhead Cost

Indirect Cost

- Profit Margin
- Risk Factor

Margin

Usually Applied As a Percentage On Direct Cost

Process Flow

Generic Process Flow – Model Assumptions

- 300mm wafers
- Results are direct costs, not price (no overhead for profit margin and indirect costs)
- Scenarios assume well balanced lines
  - *In a real factory, there may be load balancing issues that affect depreciation*

Step(s)	Comments	Variable(s)
Incoming wafer data	Cost and defect density are set for the top and bottom wafers	Cost and defect density
Preparation steps	Both wafers go through a variety of preparation steps (oxide removal, DI rinse, CMP, etch, and align); there are no variables in these steps	None
Bonding	The wafers are bonded (including an anneal step); the throughput and equipment cost of the bond step are variables	Throughput and equipment cost
Dice	There is an edge trim, then bonded wafers are diced	None
Yield	This step accounts for the yield of the bond process only	Bonding yield

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Cost Drivers and Assumptions

➢ Variables Introduced as Cost Drivers

- Incoming wafer cost
- Incoming wafer defect density
- Bonding step time
- Bonding equipment cost
- Bonding process yield

➢ Assumptions for sensitivity analysis

- Values below used, except where stated otherwise

Die size	10mm x 10mm
Wafer cost	$2000
Defect Density	0.3 defects per square cm
Bond equipment cost	$2M
Bond equipment throughput	15 minutes per wafer
Bond yield	98%

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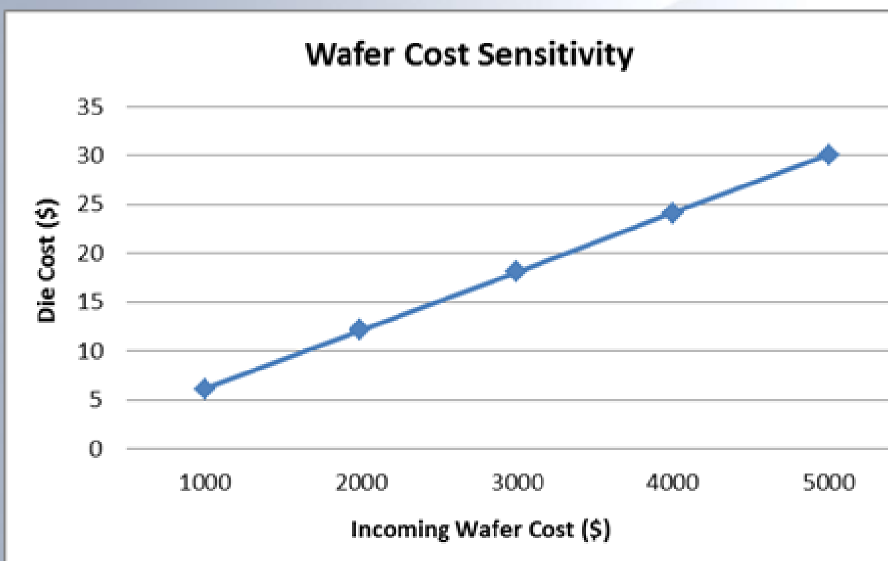
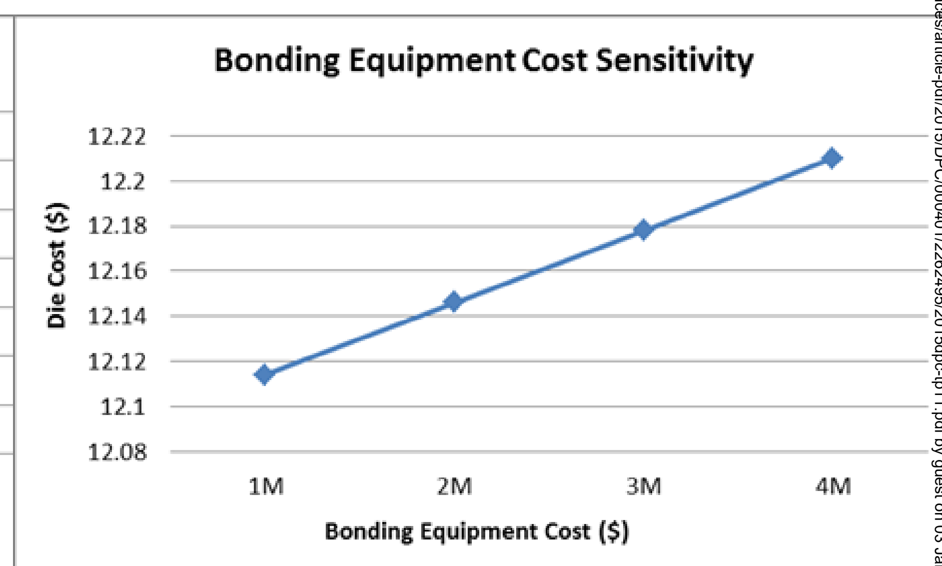
Sensitivity Analysis

- **Incoming wafer cost**
  - Linear impact
    - *Cost of an incoming wafer is a large portion of the resulting die cost—basically a giant material cost*

- **Equipment cost impact is also linear**
  - Low impact





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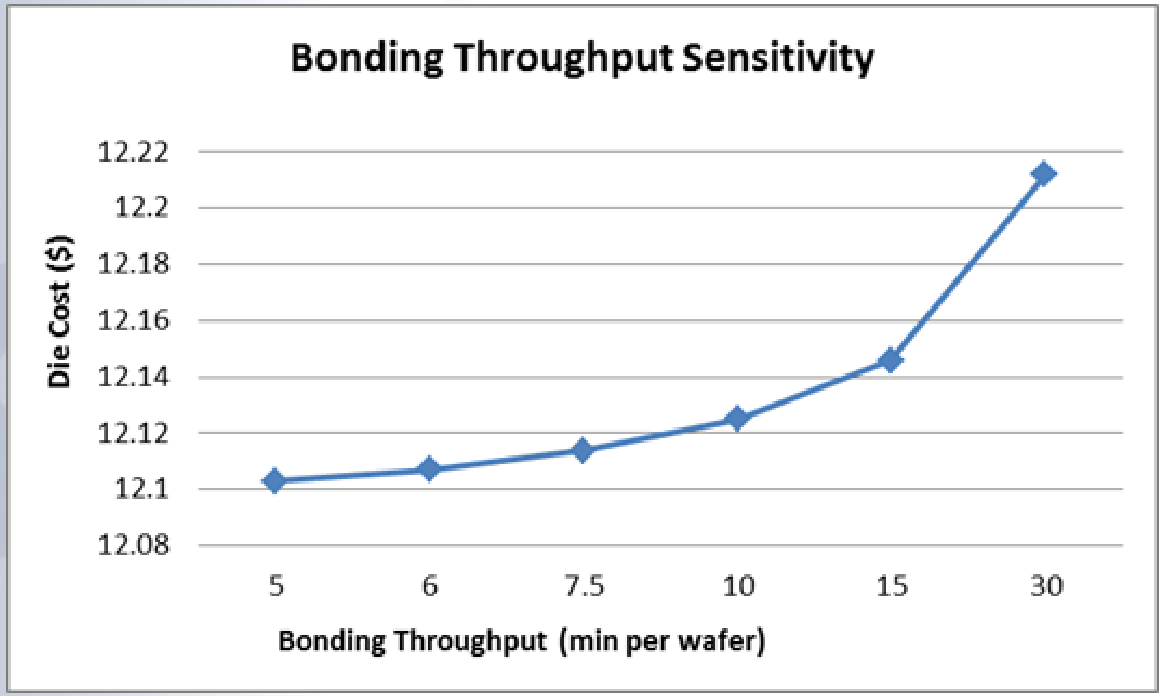
Sensitivity Analysis

- **Throughput sensitivity**
  - Low impact, similar to equipment cost
  - Changing between spending 5 minutes per wafer (12 wafers per hour) and 30 minutes per wafer (2 wph) is only about ten cents



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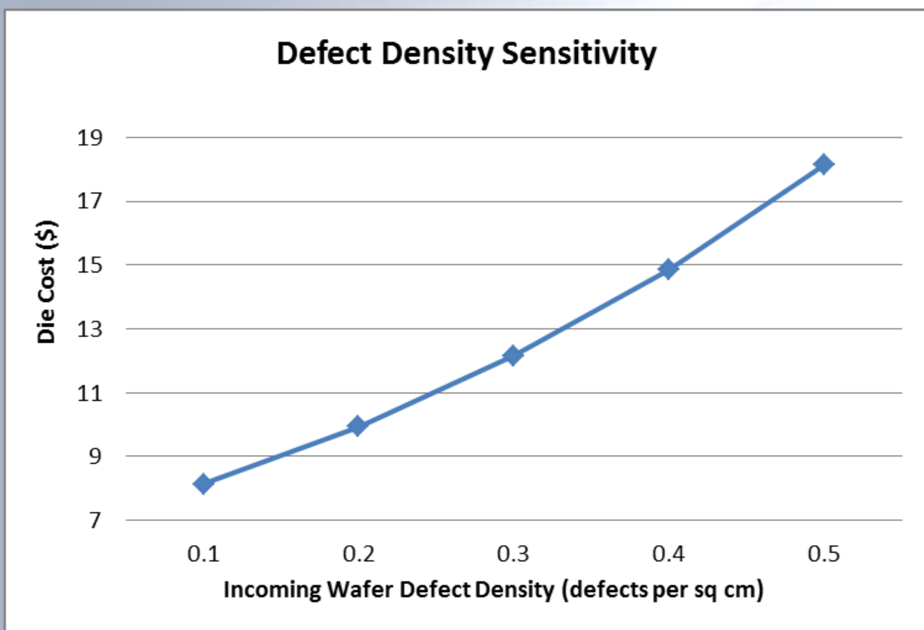
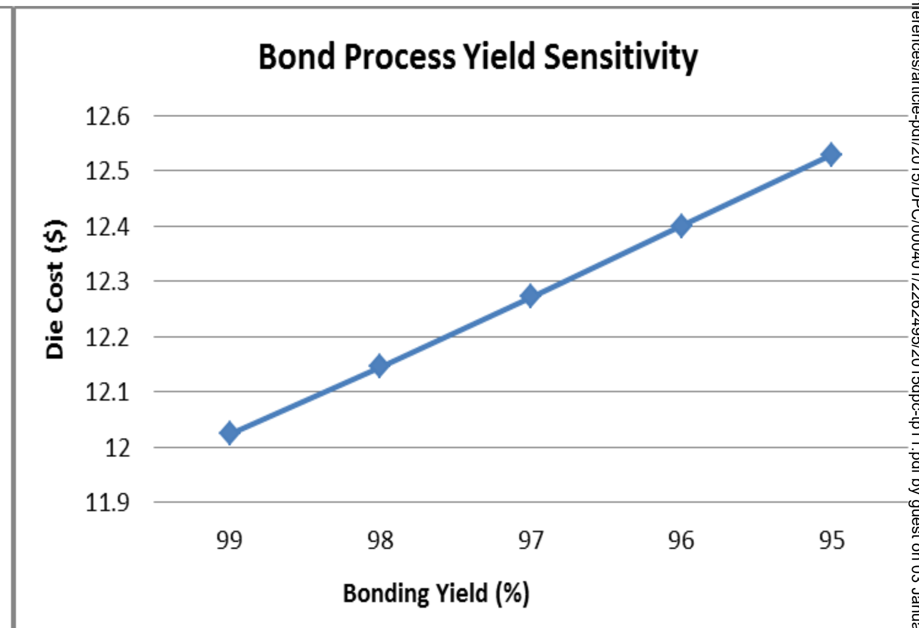
Sensitivity Analysis

- **Yield**
  - Defect density of the incoming wafer
    - *Important in W2W because of defects on top and bottom*
    - *Most important cost driver*
  - Yield of the bonding process
    - *Simple, clean bonding processes will have higher yields*
    - *Introducing other elements—heat, high pressure, or materials like adhesives—may reduce yield*





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Cost and Yield Trade-offs

➢ Scenario 1: Equipment cost and equipment throughput

- When does it make sense to pay more for increased throughput?
- Situation: More expensive equipment provides improved bonding speed

Equipment Cost	Throughput (min per wafer)	Die Cost
$1M	30	$7.7569
$3M	10	$7.7558
$3M	5	$7.7315

Equipment cost up by 3x, throughput improved by 3x, die cost almost identical

Die cost is improved with further throughput loss, but only by 2.5 cents

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Cost and Yield Trade-offs

➢ Scenario 2: Bonding process yield and throughput

- How much does bonding process yield matter?
- Situation: More expensive equipment sacrifices throughput for better yield
  - *Throughput affected by factors such as temp ramp for a Cu-Cu thermocompression bond or the necessity of applying pressure*

Bond Yield (%)	Throughput (min per wafer)	Equipment Cost	Die Cost
94	5	$1M	$18.587
95	10	$2M	$18.440
96	15	$3M	$18.329
97	20	$4M	$18.252

Each row shifts from lower yield with cheaper equipment/quick throughput to improved yield with more expensive equipment/slower throughput

Each shift gains anywhere from 7 to 14 cents of improvements—despite increasing both equipment cost and processing time per wafer

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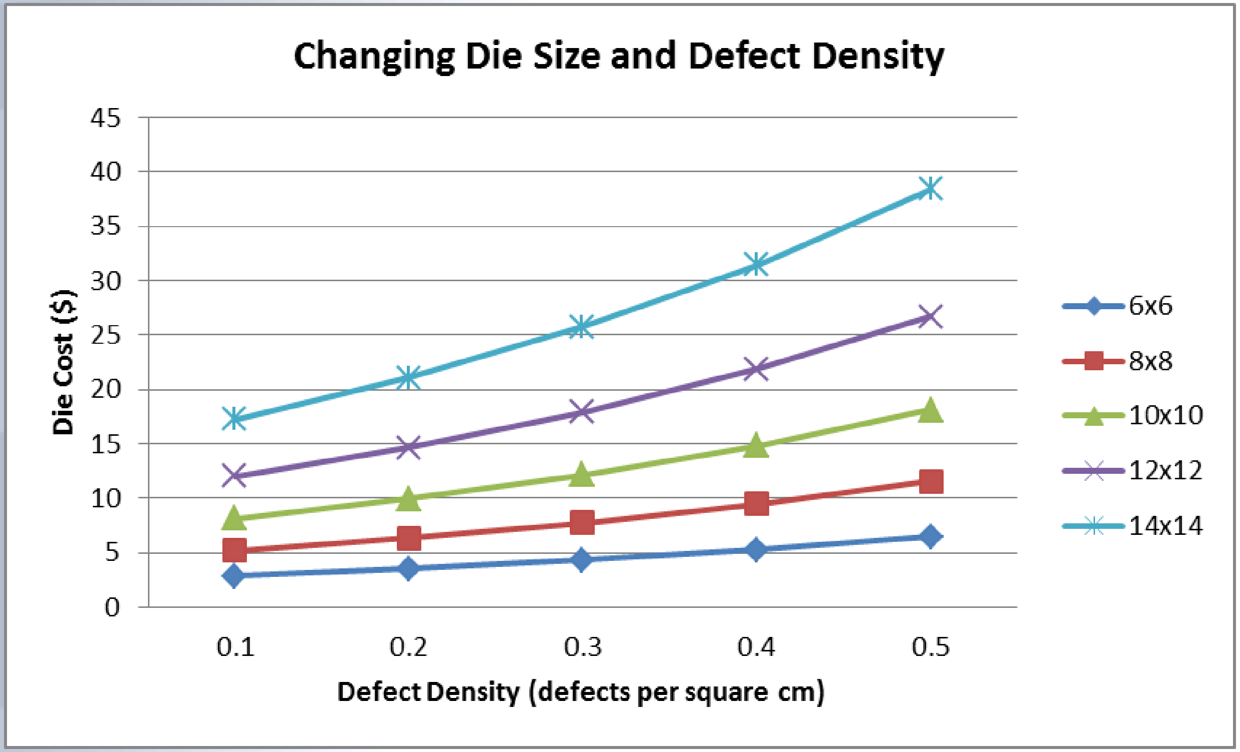
Cost and Yield Trade-offs

➢ Scenario 3: Defect density and die size

- In-depth look at relationship between defect density and die size



Larger die sizes are more sensitive to changing defect density

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Summary

- **Defect density matters**
  - W2W bonding is heavily dependent on defect density of the incoming wafers
  - For W2W to compete with other processes that allow for KGD, high quality wafers must be used
- **W2W most suitable for smaller die sizes**
  - Sensitivity to defect density increases as die size increases
- **Cost driver analysis**
  - Equipment cost and throughput → Limited impact
    - *On the order of about 10 cents from one end of range to the other*
  - Incoming wafer cost → One big material factor
  - Yield factors → Most impact
    - *Process yield impacts on the level of 7 to 14 cents per die per percent change*
    - *Defect density changes die costs by multiple dollars*

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Thank you for your attention!

Questions?