# Automatic Stencil Design Aperture Openings for BGAs to Mitigate Reflow Defects Caused by Chip Dynamic Warpage Using Numerical Shadow Moiré Data

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# Outline/Agenda

- Introduction/Background
- Methodology
- Case Study and Results
- Conclusion
- Acknowledgements

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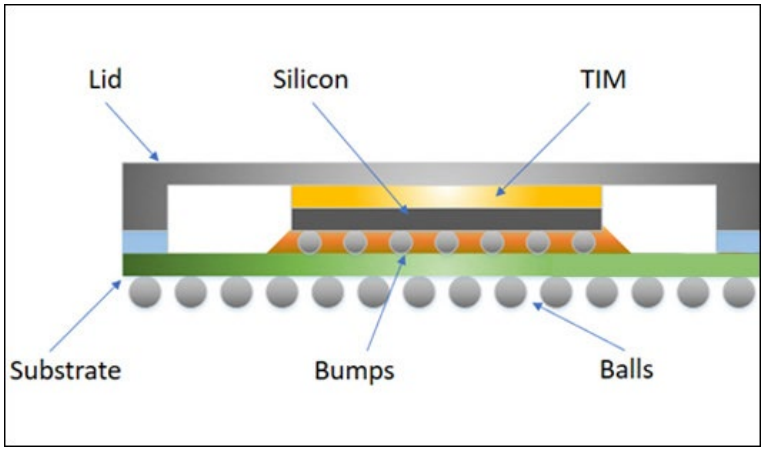
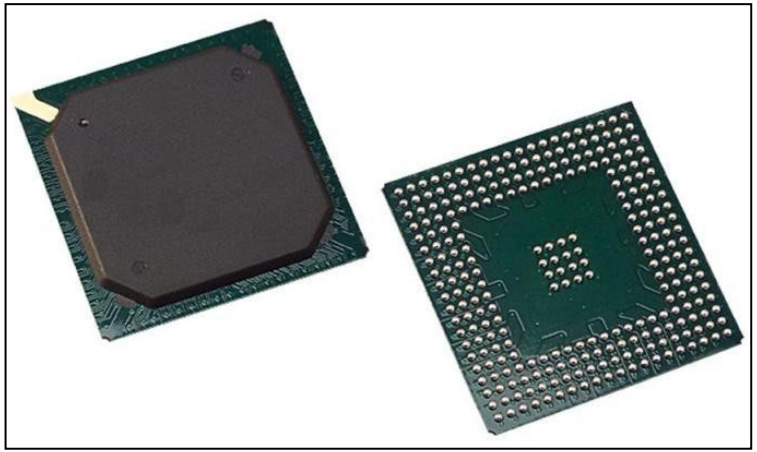
# Introduction/Background

- Ball Grid Array Packages (**BGA**): **SMD** that uses tiny **solder balls** underneath the IC package to connect to the substrate (Chip) to PCB, where solder balls **convey electrical signals**, **Mechanical support**.




https://www.pcbgogo.com/knowledge-center/BGA.html



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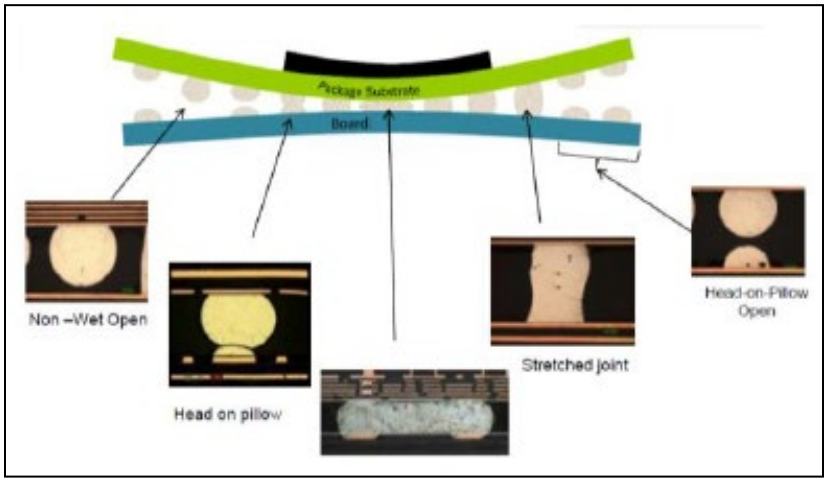
# Introduction/Background

- **Problem Description**: **Defects** During Reflow
  - Common out-of-plane deformations of BGAs are on the order of dozens of micrometers due to mismatch of Coefficients of thermal expansion (**CTEs**)
  - BGA Substrate warpage will result in **reflow defects** such as:
    - **Open** soldering
    - Solder **bridging**
    - **Head on/in pillow**

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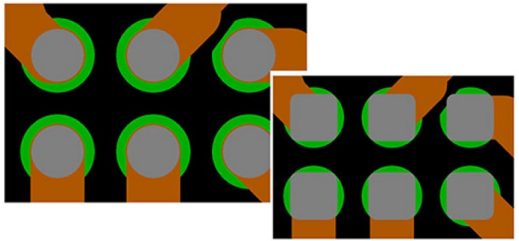
# Introduction/Background

- Industry Design **Guidelines**:
  - General Stencil design guidelines for BGAs, IPC standards (IPC-7525B)
- Several **options** for stencil opening:
  - Stencil opening **1:1** round or rounded square
  - Round with 1mil **reduction**
  - Rounded square with **overprint** 1mil



- Defects related to BGA warpage (bridging, open, etc...) will determine the optimal choice for aperture opening.
- IPC-7525B:

| Part Type | Pitch | Land Footprint Width | Land Footprint Length | Aperture Width | Aperture Length | Stencil Thickness Range | Aspect Ratio Range | Area Ratio Range | Solder Paste Type |
|---|---|---|---|---|---|---|---|---|---|
| BGA | 1.25 mm [49.2 mil] | CIR 0.55 mm [21.6 mil] | | CIR 0.52 mm [20.45 mil] | | 0.15 - 0.20 mm [5.91 - 7.87 mil] | N/A | 0.65 - 0.86 | Type 3 |
| Fine-pitch BGA | 1.00 mm [39.4 mil] | CIR 0.45 mm [15.7 mil] | | SQ 0.42 mm [13.8 mil] | | 0.115 - 0.135 mm [4.53 - 5.31 mil] | N/A | 0.65 - 0.76 | Type 3 |
| Fine-pitch BGA | 0.50 mm [19.7 mil] | CIR 0.25 mm [9.84 mil] | | SQ Overprint 0.28 mm [11.0 mil] | | 0.075 - 0.125 mm [2.95 - 4.92 mil] | N/A | 0.56 - 0.93 | Type 3 |
| Fine-pitch BGA | 0.40 mm [15.7 mil] | CIR 0.20 mm [7.87 mil] | | SQ Overprint 0.23 mm [9 mil] | | 0.075 - 0.100 mm [2.95 - 4 mil] | N/A | 0.56 - 0.75 | Type 4 |

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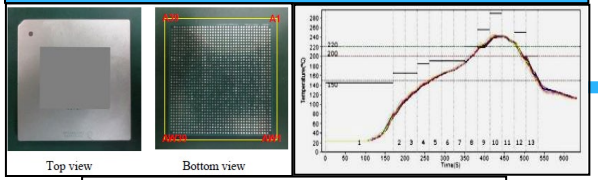
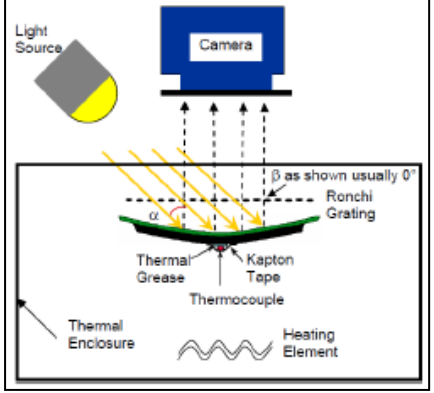
# Introduction/Background

- **Current Practice**: BGA Stencil Openings Optimization Process

## Shadow Moiré

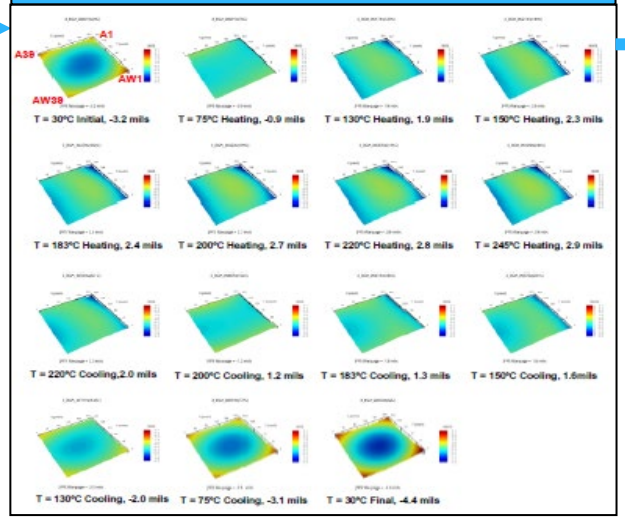
- Emulate SMT reflow process
- Measures chip **topography**




## Out of Plane Deformation

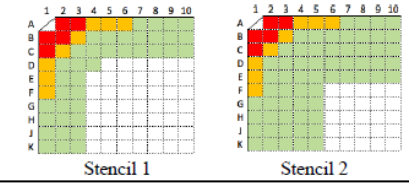
- Find potentially High-Risk locations of Open/HIP/ Bridging




## Stencil Optimization

- Control stencil opening
- Multi Zone Openings

| | Pad area | Diameter (mm) | | |
|---|---|---|---|---|
| | | PCB pad | Stencil 1 | Stencil 2 |
| BGA U1 opening | Red | 0.53 | 0.635 | 0.64 |
| | Orange | 0.51 | 0.635 | 0.62 |
| | Green | 0.48 | 0.635 | 0.60 |
| | White | 0.48 | 0.41 | 0.58 |

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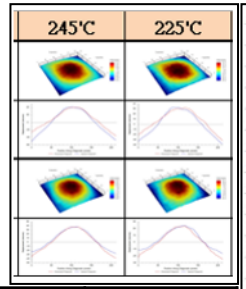
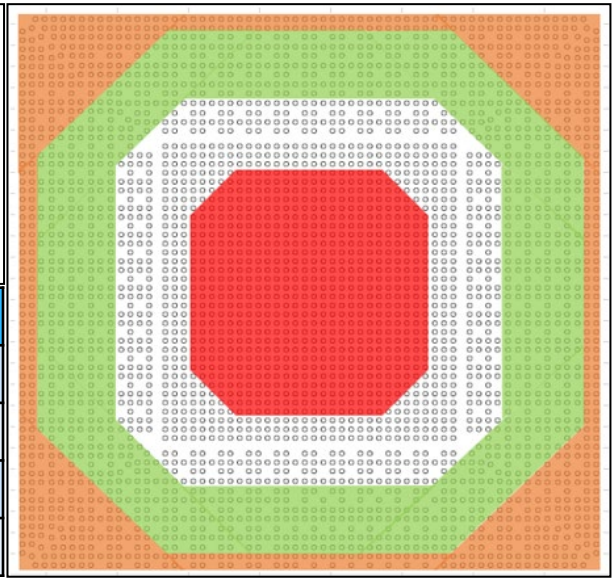
# Introduction/Background

- Disadvantages of **current practice** (Multi Zone Openings)
  - Multi-Zone Stencil Optimization of BGA has no standards
  - Totally Based on SMT Engineer Experience (Several Solutions)
  - Require Many DOEs




| Zone | Value |
|---|---|
| Orange | Zone 1 |
| Green | Zone 2 |
| White | Zone 3 |
| Red | Zone 4 |



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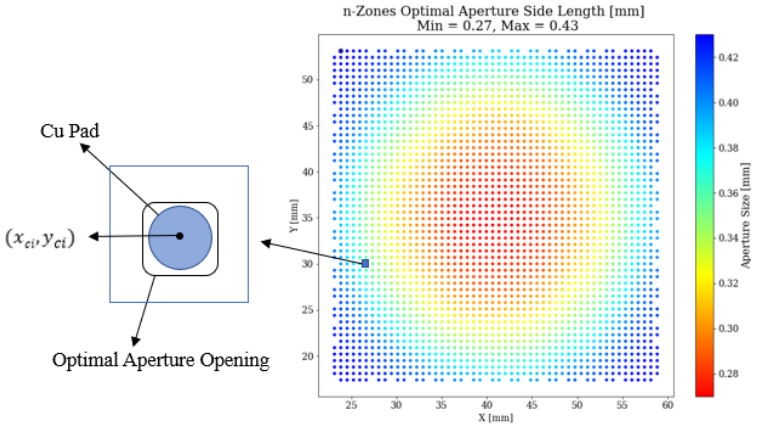
# Methodology

- Automatic Framework that use Shadow Moiré Numerical Data to Design the “Optimal” Stencil Opening
- Stencil Opening of each Cu pad will be a **Function** of the Amount of Z-Warpage at the Center of the Same Pad
- “N-zones”.... N = # of Cu Pads
- For One Cu Pad:

Shadow Moiré Data $(x_i, y_i, \Delta z_i)$ → **Optimal** Stencil Opening at $(x_i, y_i)$




$$Aperture\ Size_i = f(\emptyset, P, x_{ci}, y_{ci}, dz_i, TH)$$

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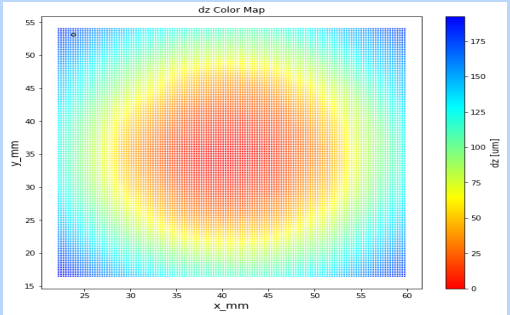
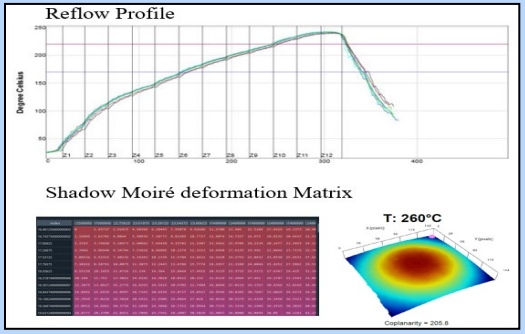
# Methodology

- **Flowchart**:

**Model Inputs:**

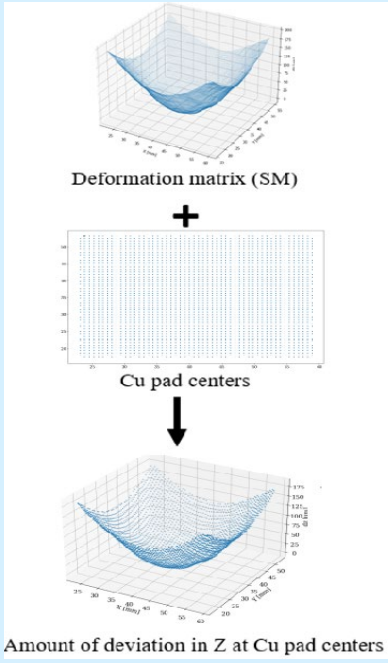
- Shadow Moiré $dz_i$ *at* $(x_i, y_i)$ *Pixels*
- Cu Pads Gerber (DXF_ASCII text)
- Cu Pads Size
- Cu Pads Pitch



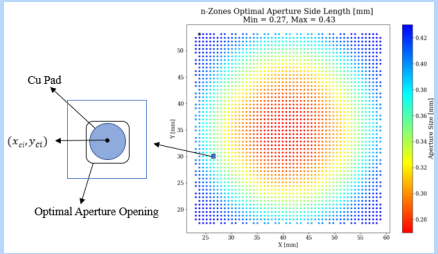

**Data Pre-Processing:**

- Random Forest Model
- Predict Z-warpage at Cu pad centers
- $\widehat{dz_{ci}}$ at each $(x_{ci}, y_{ci})$



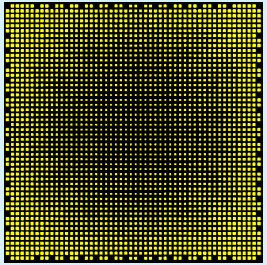

**Algorithm Execution:**

- Create intervals for Z-warpage & apertures size
- Matching optimal aperture size with the corresponding Z warpage




**Final Output: To Stencil House**

- Create a DXF drawing for all apertures
- Export and merge with original Gerber file



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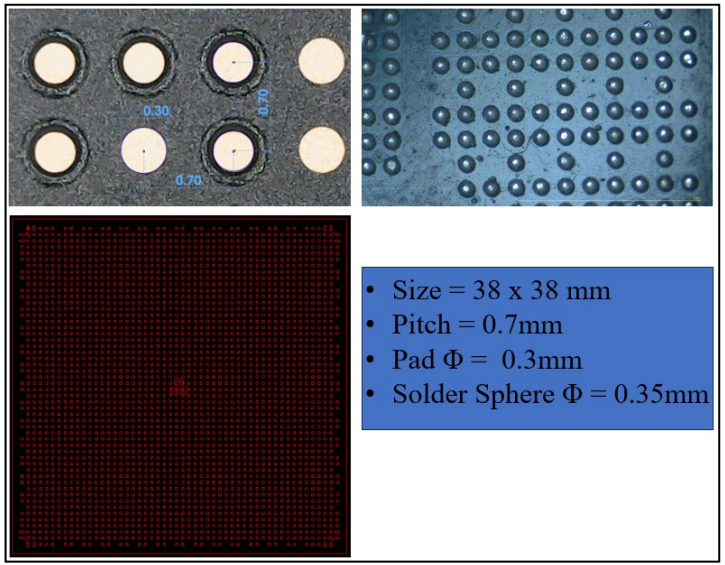
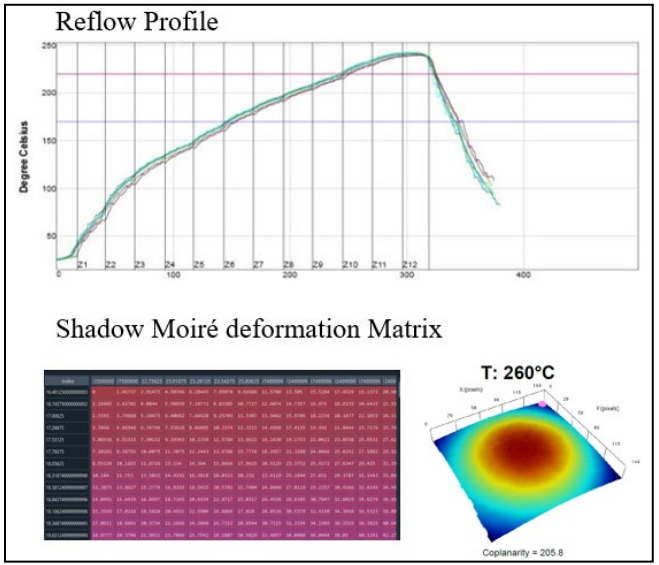
# Case Study and Results

- 38mm x 38mm Chip
- Shadow Moiré Deformation Matrix

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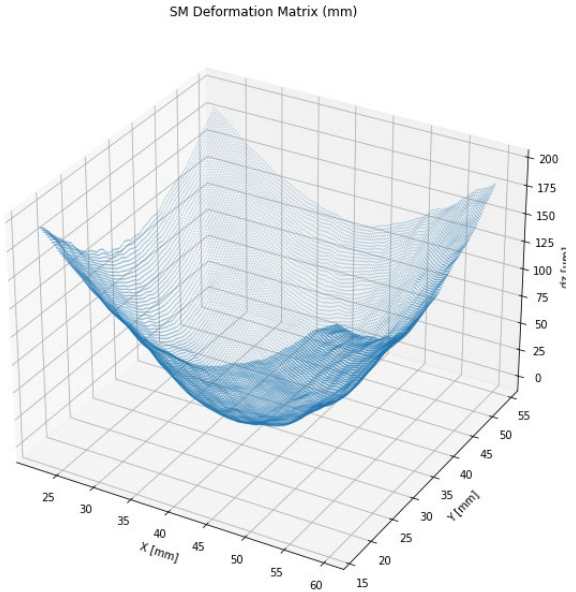
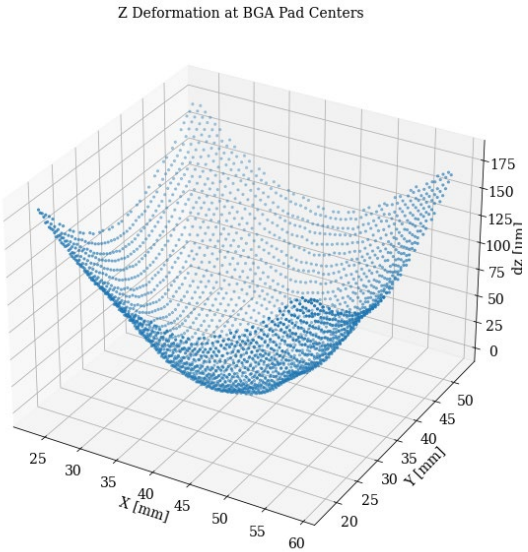
# Case Study and Results

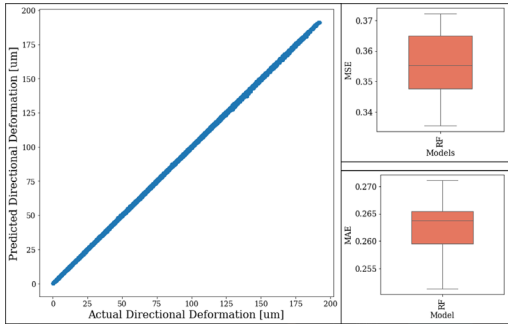
- Determine the amount of warpage at all Cu pads centers using Random Forest ML model




$(x, y, dz[\mu m])$




$(x, y, dz_C[\mu m])$




$R^2 = 99\%$

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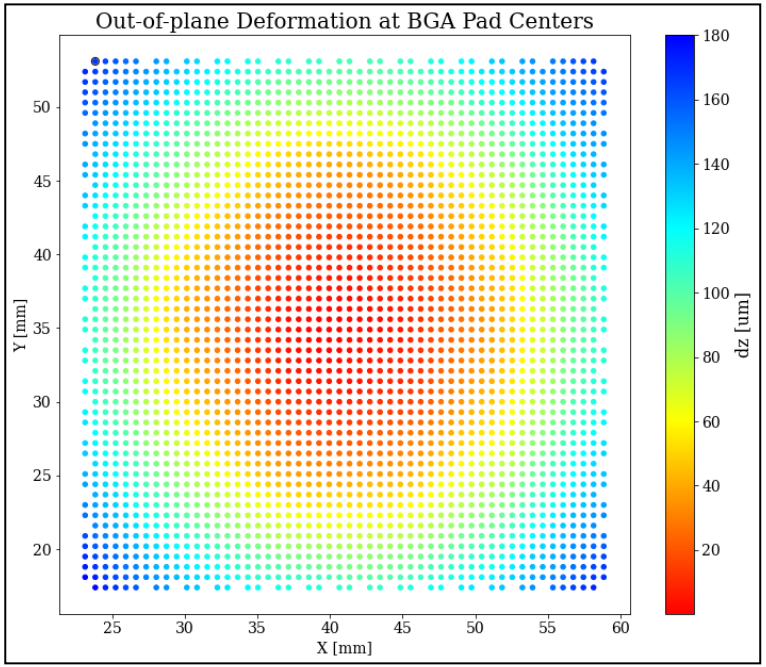
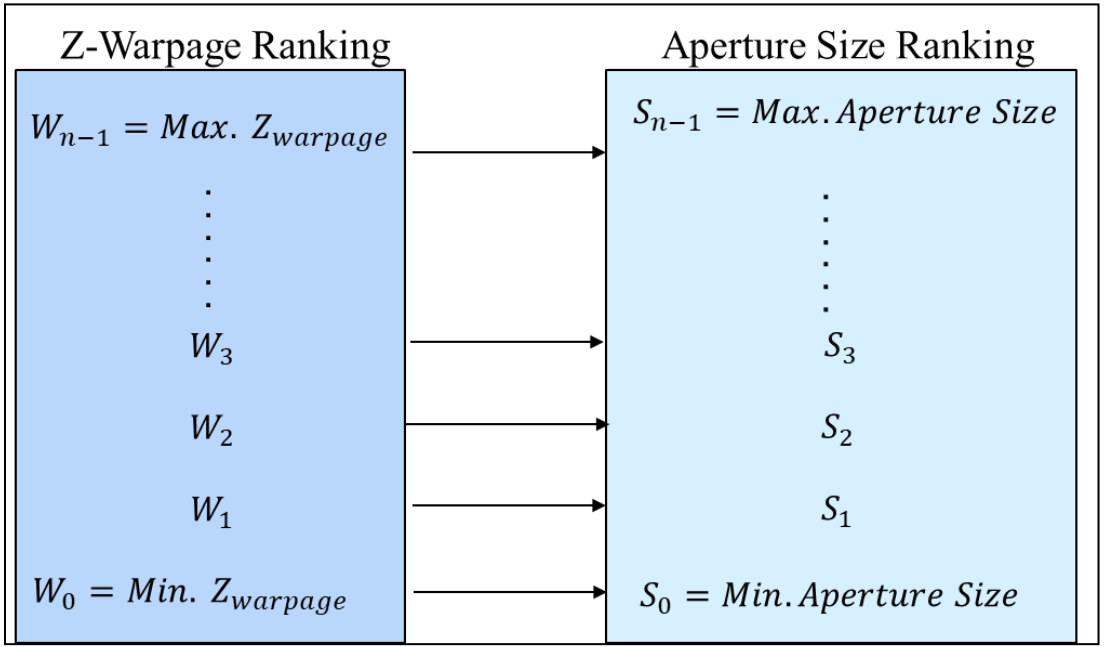
# Case Study and Results

- Matching optimal aperture Size with the corresponding amount of warpage
- Max/Min Possible Aperture Interval = [0.27, 0.43]mm

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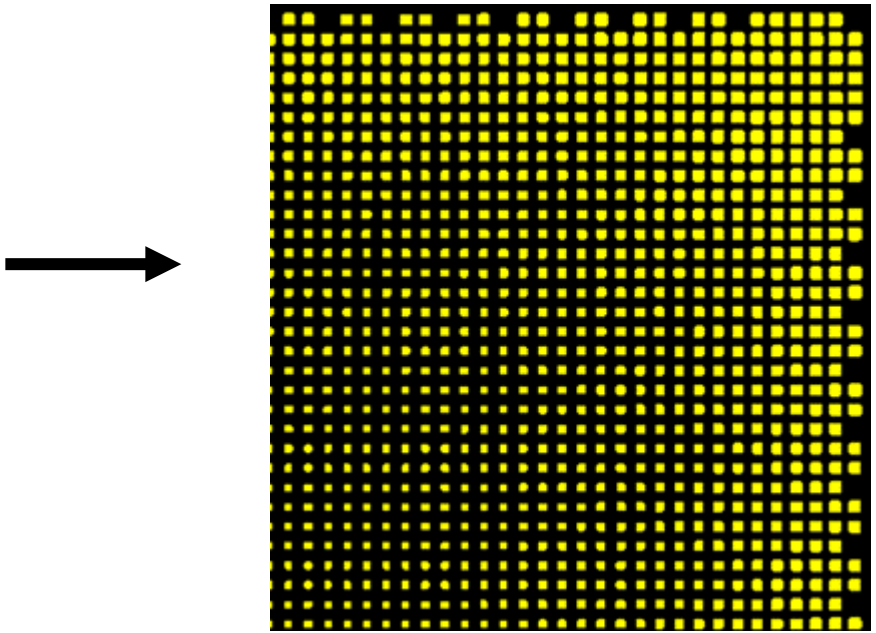
# Case Study and Results

- Utilize “ezdxf” Python library to automatically draw the apertures
- Final Results: Optimal aperture openings in Gerber format

| x | y | Z_deform_at_center | opt_ap_siz | AR |
|---|---|---|---|---|
| 40.65 | 35.6 | 0.1611 | 0.27 | 0.66437 |
| 40.65 | 34.9 | 0.5172 | 0.2701 | 0.664616 |
| 39.95 | 34.9 | 0.5399 | 0.2701 | 0.664616 |
| 39.95 | 35.6 | 0.5602 | 0.2702 | 0.664862 |
| 40.65 | 34.2 | 0.5925 | 0.2702 | 0.664862 |
| 39.25 | 34.9 | 0.6612 | 0.2703 | 0.665108 |
| 39.95 | 34.2 | 0.7124 | 0.2704 | 0.665354 |
| 40.65 | 36.3 | 0.7378 | 0.2704 | 0.665354 |
| 39.25 | 34.2 | 1.0317 | 0.2705 | 0.6656 |
| 23.85 | 53.1 | 168.565 | 0.4294 | 1.05659 |
| 25.25 | 17.4 | 168.919 | 0.4295 | 1.05684 |
| 58.85 | 18.1 | 169.38 | 0.4295 | 1.05684 |
| 23.15 | 19.5 | 170.367 | 0.4296 | 1.05709 |
| 23.15 | 52.4 | 170.848 | 0.4296 | 1.05709 |
| 58.15 | 17.4 | 171.671 | 0.4297 | 1.05733 |
| 24.55 | 17.4 | 172.709 | 0.4298 | 1.05758 |
| 23.15 | 18.8 | 173.83 | 0.4298 | 1.05758 |
| 23.85 | 18.1 | 174.26 | 0.4299 | 1.05782 |
| 23.15 | 18.1 | 179.286 | 0.4299 | 1.05782 |
| 23.85 | 17.4 | 180.089 | 0.43 | 1.05807 |



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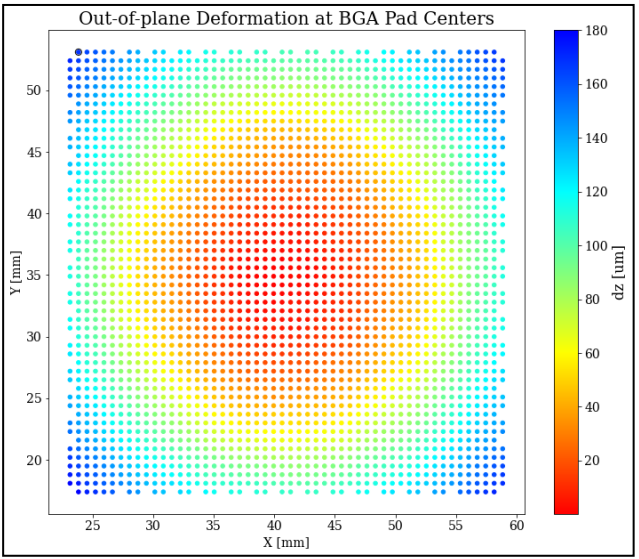
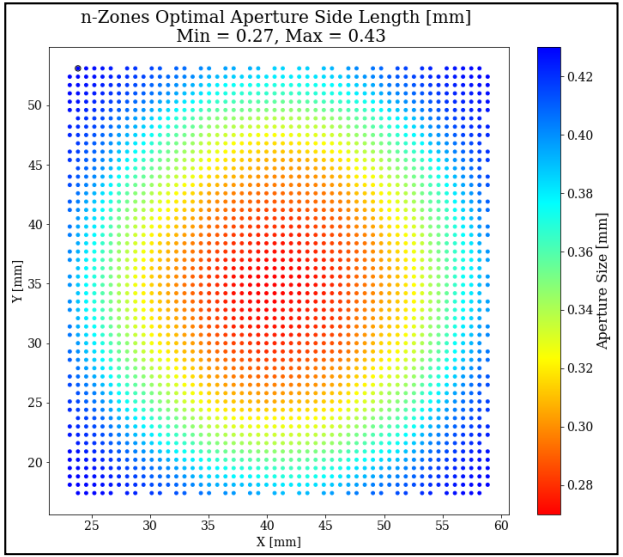
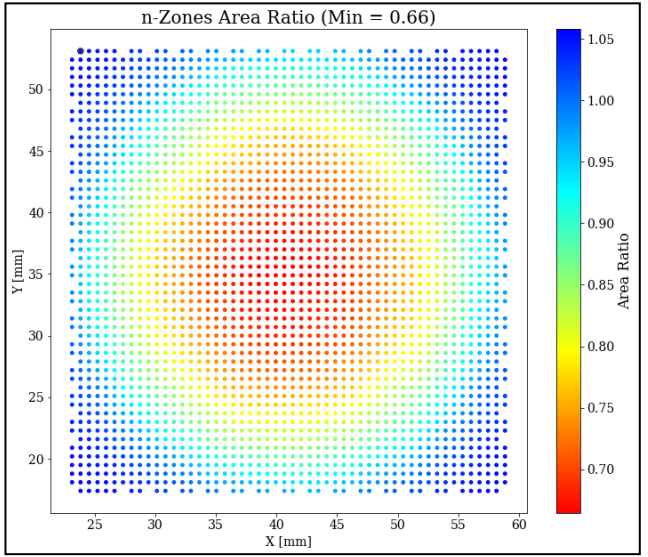
# Case Study and Results

- Out of Plane Deformation // Optimal  Aperture opening // Area Ratio Check

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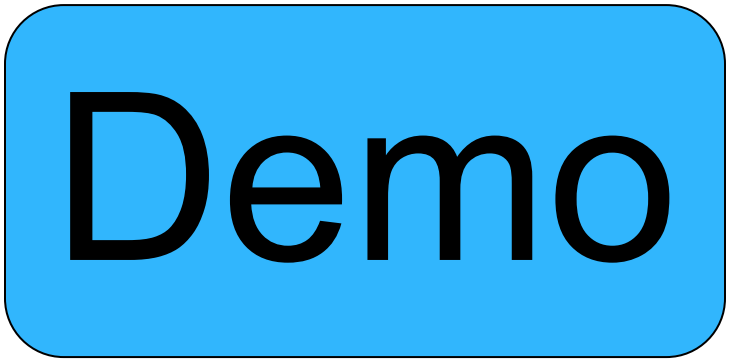
# Case Study and Results

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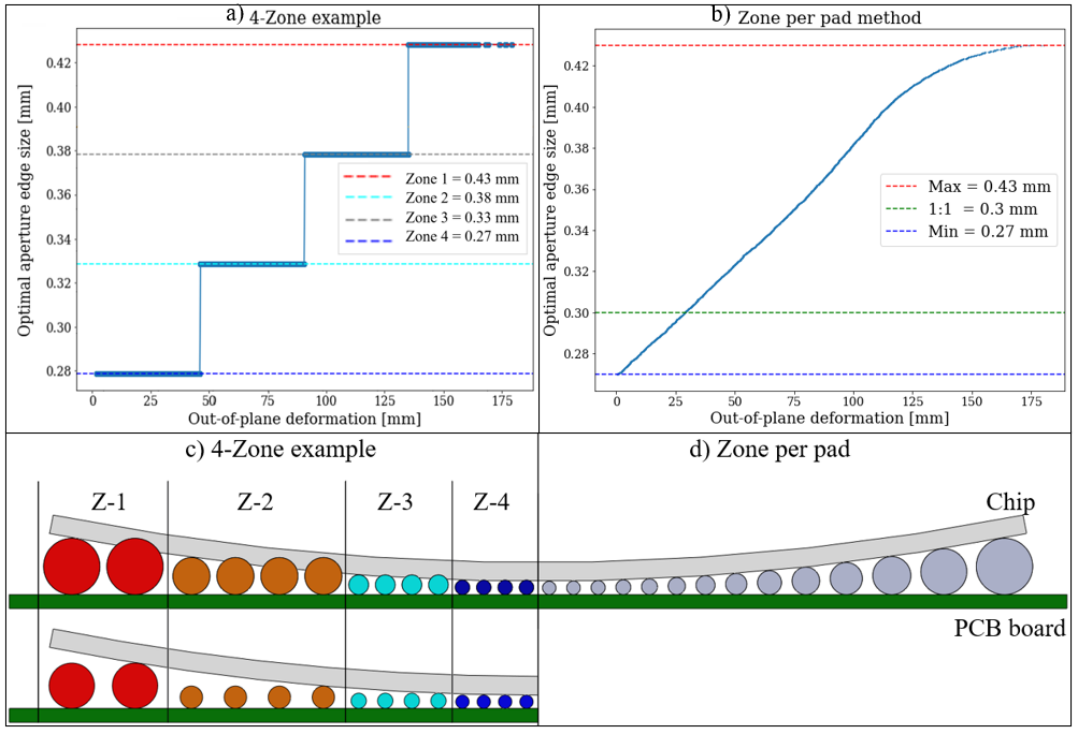
# Conclusion

- Comparison between **4-Zone** and **N-Zone** Approaches
- Smooth transition in aperture size across different warpage levels



# Conclusion

- This proposed stencil optimization method:
  - Highlights the inadequacies of current stencil aperture design guidelines in addressing chip warping
  - Provide standard, fast automatic approach
  - Reduce the number of DOE needed
  - In terms of long-term performance of solder joints created using this method, we believe this approach will have a positive impact, Although require validation through reliability testing

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# Acknowledgements


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  - Celing Liu
- AKROMETRIX:
  - Neil Hubble


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# *THANK YOU!*


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