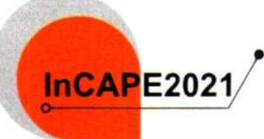

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OPTIMISING ESD COUNTERMEASURES IN 12NM GATE OXIDE SEMICONDUCTOR MANUFACTURING: A ROBUST ENGINEERING APPROACH

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INTRODUCTION

- Equipment inefficiency and ineffectiveness affect output performance/quality of production
- Case study of this work → 12 nm Gate Oxide Semiconductor Manufacturing, focusing at the back end process of IC fabrication.

SCOPE

- Overview of robust engineering approach
- Background of the problem
- Implementation and results
- Conclusion

ROBUST ENGINEERING – Brief Overview

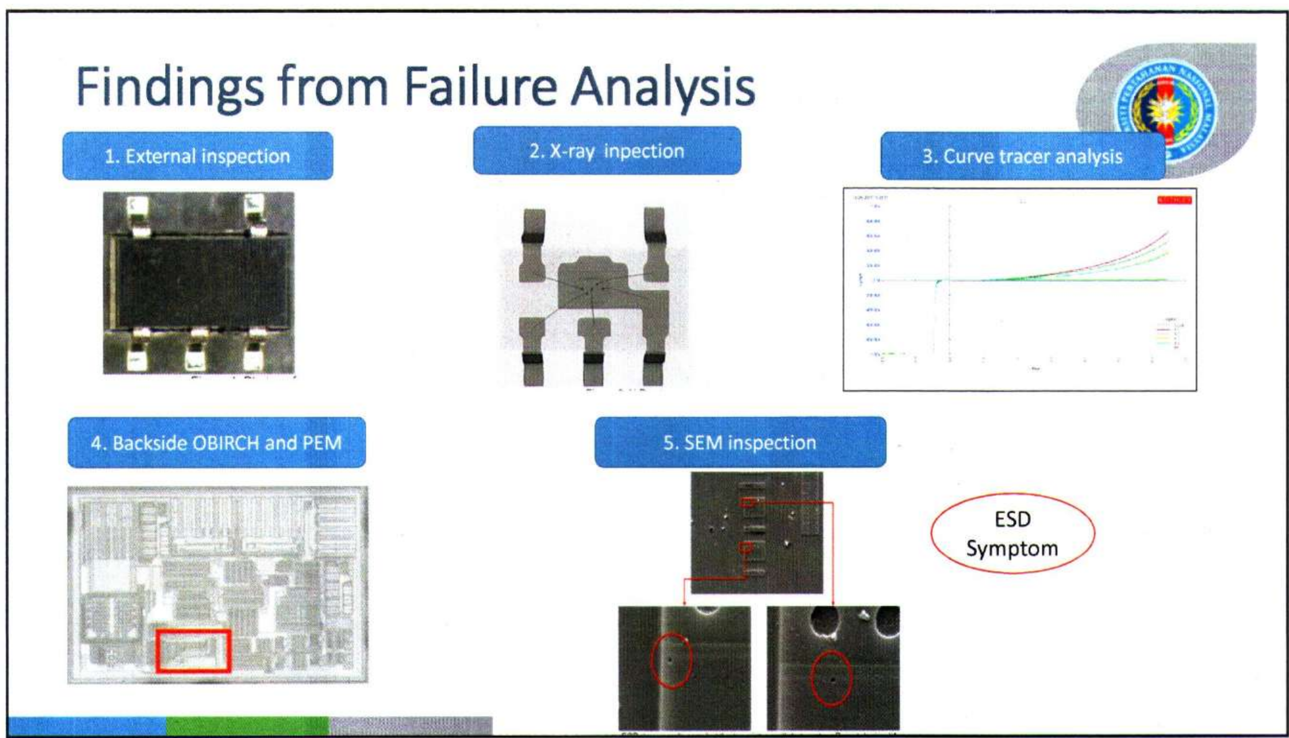
- What is it? → An engineering optimisation strategy ideally used for development of new technologies in the areas of product and process design.
  - Represent the application of Taguchi Method at start of R&D or advanced product/process development activities to optimize performance
  - Concentrates on identifying the "ideal function(s)" for a specific technology or product/process design
  - Concentrates on selectively choosing the best nominal values of design parameters that optimise performance reliability (even in the presence of factors causing variability) at lowest cost

ROBUST ENGINEERING – Brief Overview

- Taguchi Method (Robust Design method):
  - The methods had evolved over the decades after its formulation after the end of the WWII.
  - Consciously consider the noise factors; environmental variation during the product's usage, manufacturing variation, and component deterioration.
  - Focuses on improving the fundamental function of the product or process.
  - Aim to reduce product cost, improve quality and simultaneously reduce development interval.

BACKGROUND OF THE PROBLEM

- The Lot On Hold (LOH) devices were triggered due to the failing leakage current test during packaging process:
  - Supply current (ICC)
  - Power-off leakage current (IOFF)
- These abnormalities occurred at the average of 18 lots per week which is around 80% from the total weekly lot on hold (LOH).
- The failing units were sent for Failure Analysis (FA) process to determine the failure mode of the devices.



How ESD causes problems in semiconductor manufacturing

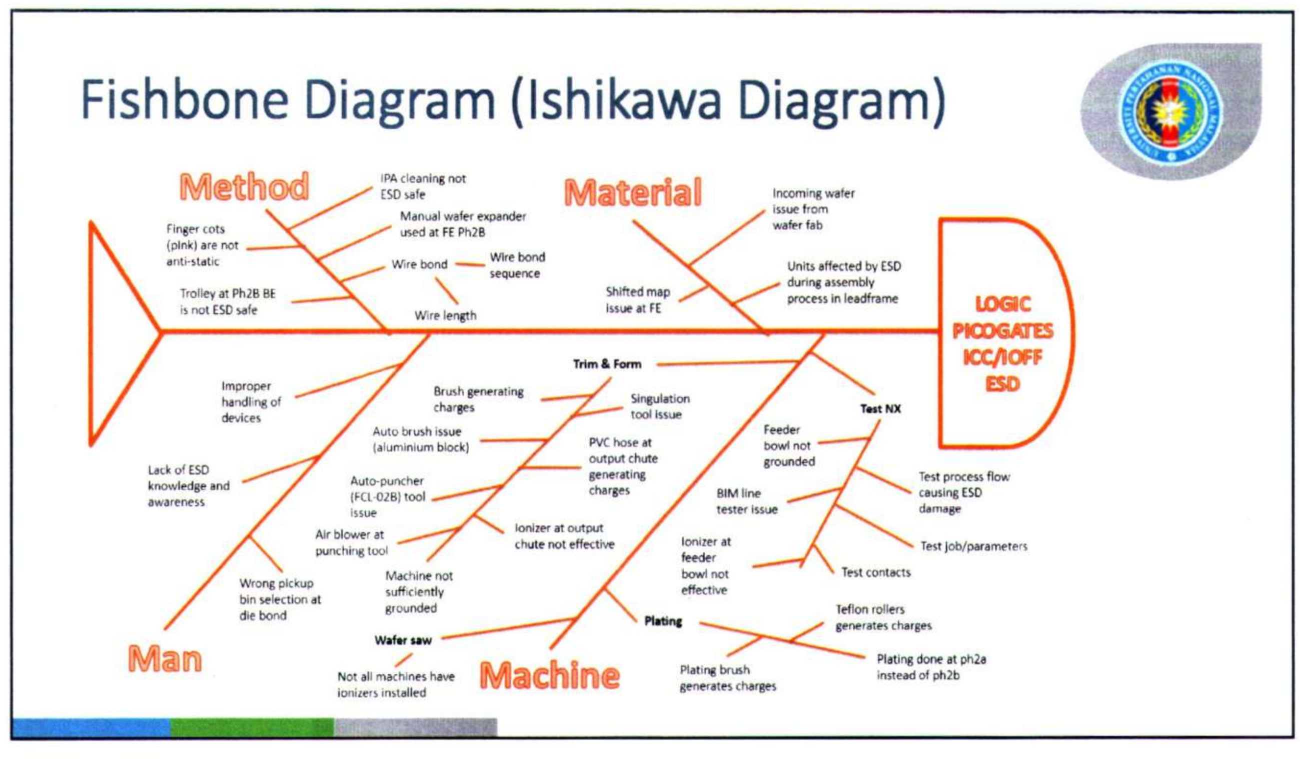
- In ESD event, the electrostatically triggered **charge moves** swiftly (typically in 1 to 10 nanoseconds) through an IC → **generating enough heat** that can breakdown the gate structure and junctions, induce spiking in contacts and burn the interconnects.
- Even at the level imperceptible to the human body, ESD events can substantially damage the nano-scale semiconductor devices and the photomasks used to create them.
- ESD may also produce **electromagnetic interference (EMI)** effects which can disrupt the smooth running of the production equipment.
- Characteristic in electromagnetic spectrum. Typically, the ESD energy occupies the **100 MHz – 2 GHz** frequency spectrum, which is also in the same operating range of the controlling microprocessors of most equipment used for ICs fabrication.

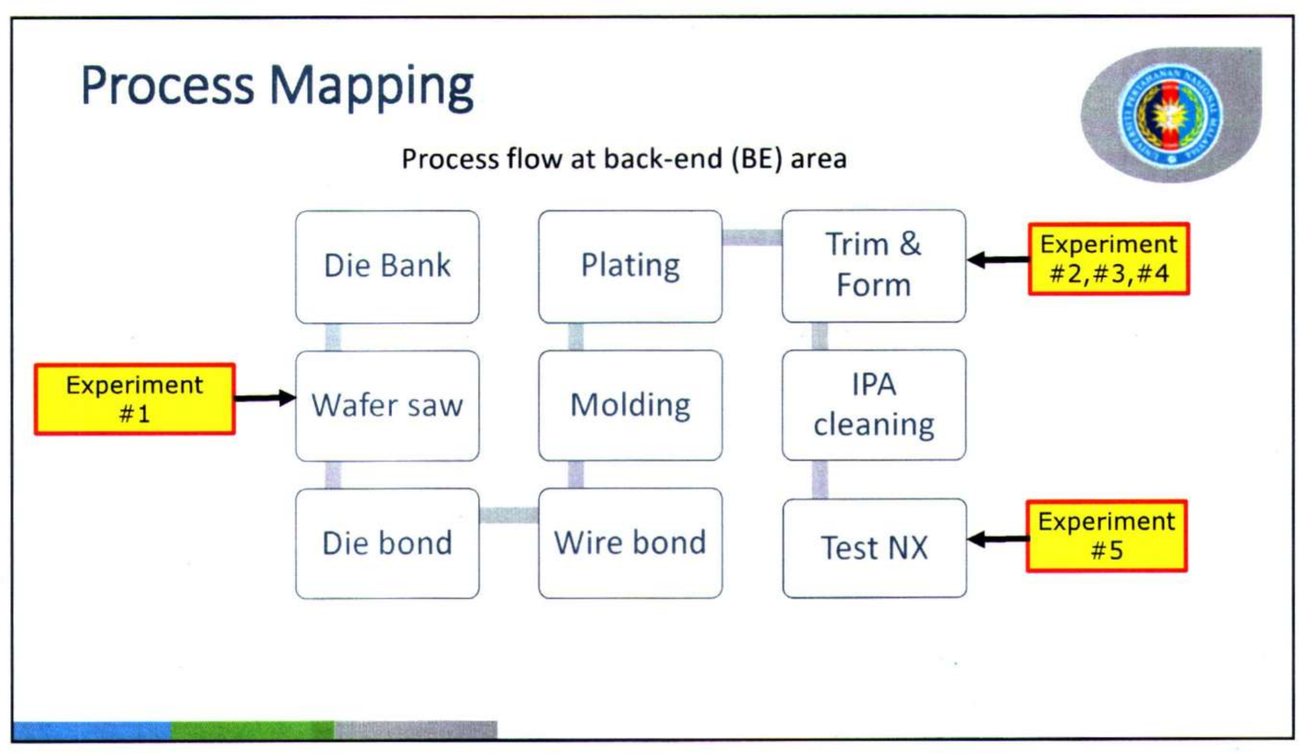
Potentially ESD Prone Areas during Fabrication

- Mechanically, ESD events occur mostly from the **contact and separation** of dissimilar materials during the manufacturing process.
  - E.g., a charged body touches a product, or a charged product touches a grounded surface, or a charged machine touches a unit product or an electrostatic field generates enough voltage across a dielectric that break it down.
- Some of the **supporting factors** causing ESD → the environment of high temperatures and low humidity, bad or no grounding of moving parts, involving metal to metal and suction cup contact.
- During the **semiconductor back-end processes**, several operations have high potential of causing ESD events such as; during wafer mount and saw operations, bonding operation, packaging with plastic molding and testing operations.

ESD Countermeasures

- Work procedures and disciplines to reduce ESD events; e.g: utilize antistatic garments, mats, wrist strap.
- Good grounding with conductive and static-dissipative materials to control unwanted charges on equipment, products and people .
- Use ionizers for neutralizing the static charges on insulators (and isolated conductors) .


Fishbone Diagram (Ishikawa Diagram)
Method
Material
Man
Machine
IPA cleaning not ESD safe
Manual wafer expander used at FE Ph2B
Finger cots (pink) are not anti-static
Wire bond
Wire bond sequence
Trolley at Ph2B BE is not ESD safe
Wire length
Incoming wafer issue from wafer fab
Units affected by ESD during assembly process in leadframe
Shifted map issue at FE
LOGIC PICOGATES ICC/IOFF ESD
Trim & Form
Test NX
Improper handling of devices
Brush generating charges
Singulation tool issue
Auto brush issue (aluminium block)
PVC hose at output chute generating charges
Feeder bowl not grounded
Lack of ESD knowledge and awareness
Auto-puncher (FCL-02B) tool issue
BIM line tester issue
Test process flow causing ESD damage
Air blower at punching tool
Ionizer at output chute not effective
Ionizer at feeder bowl not effective
Test job/parameters
Test contacts
Wrong pickup bin selection at die bond
Machine not sufficiently grounded
Plating
Teflon rollers generates charges
Wafer saw
Not all machines have ionizers installed
Plating brush generates charges
Plating done at ph2a instead of ph2b


Process Mapping
Process flow at back-end (BE) area
Die Bank
Plating
Trim & Form
Experiment #2,#3,#4
Experiment #1
Wafer saw
Molding
IPA cleaning
Die bond
Wire bond
Test NX
Experiment #5

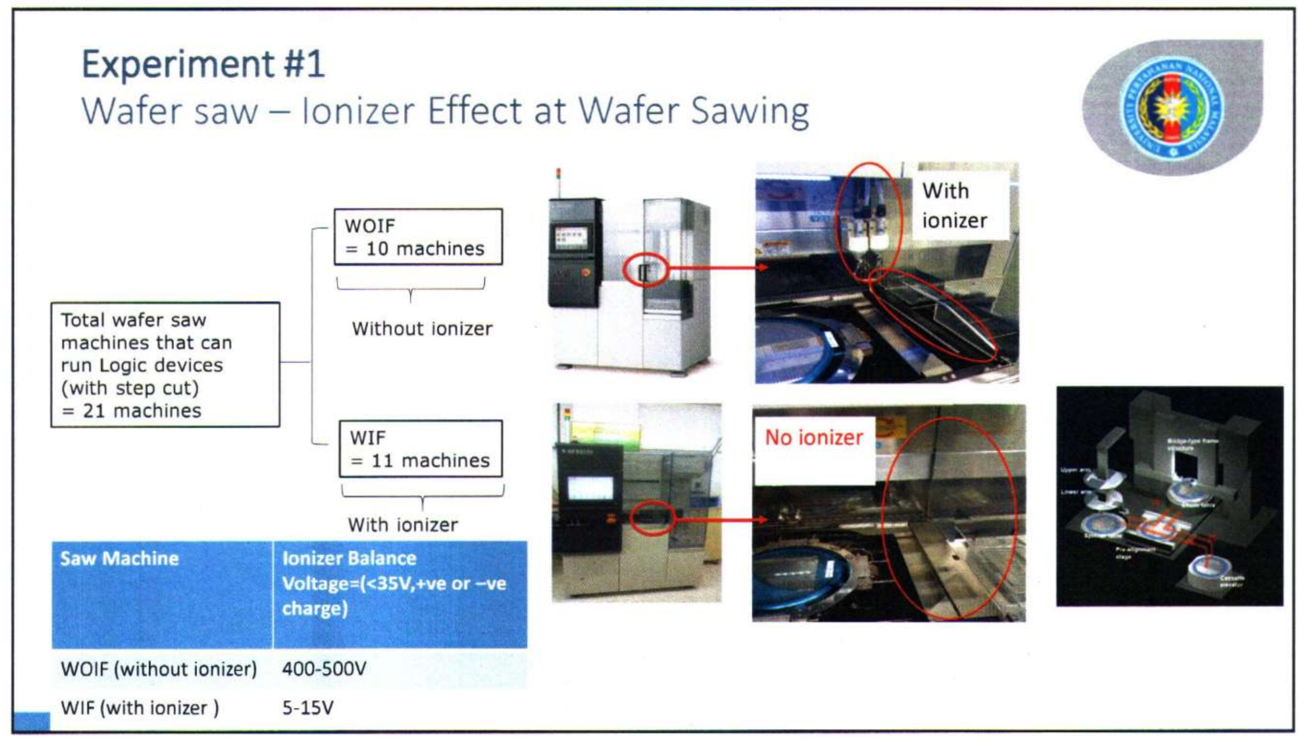
Experiment #1
Wafer saw – Ionizer Effect at Wafer Sawing

Hypothesis

- Ionizer at wafer saw helps to reduce failure of ICC/IOFF tests

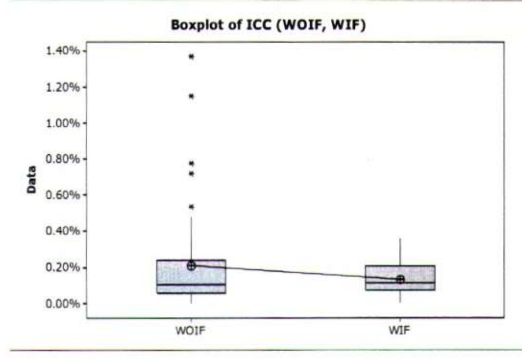
Method:

- Check the different setup on machine at wafer saw
- Compare occurrence of ESD failure



Saw Machine	Ionizer Balance Voltage=(<35V,+ve or –ve charge)
WOIF (without ionizer)	400-500V
WIF (with ionizer)	5-15V

Experiment #1
Wafer saw – Ionizer Effect at Wafer Sawing



- ❑ Perform comparison → ICC for saw machine running with and without ionizer.
- ❑ The graph shows machine running without ionizer have many outliers compared to those with ionizer machine.

Conclusion:

- ❑ Wafer saw with ionizer is able to minimize ICC fallout

Experiment #2
Trim & Form - Ionizer at output chute not effective

Steel Hose

PVC Hose

Sing. Unit Vial

Ionizer air outlet (via metal pipe)

Hypothesis:

- ❑ Custom built ionizer at Trim & Form output vial is not effective

Experiment #2
Trim & Form - Ionizer at output chute not effective

Method

i. Perform trial by creating static charge on a piece of plastic which is able to enter the small enclosure of the ionizer blower; check the discharge rate (refer to pic (i))

ii. Measure static charge of the units after singulation – with and without the ionizer turned on (refer to pic (ii))

(i) Measuring static charge of the pen

(ii) Measuring static charge of the units after pouring out from the vial

Experiment #2
Trim & Form - Ionizer at output chute not effective

Result:

- The measured charge of the units after singulation with or without the ionizer turned on was 246 V.
- Falling into vial, measurement not vary much different with or without the ionizer on.
- Measurement only reduce from 246V to 141V.

Conclusion:

- The custom built ionizer at the singulation vial is not effective and did not bring down the static charge of the units to less than 20V. Nevertheless, no evidence to suggest that this is causing the ICC/IOFF fallouts at test.

Experiment #3
Trim & Form – Machine not sufficiently grounded

Hypothesis:

- Floating conductors in the trim & form machine are causing the ESD fails

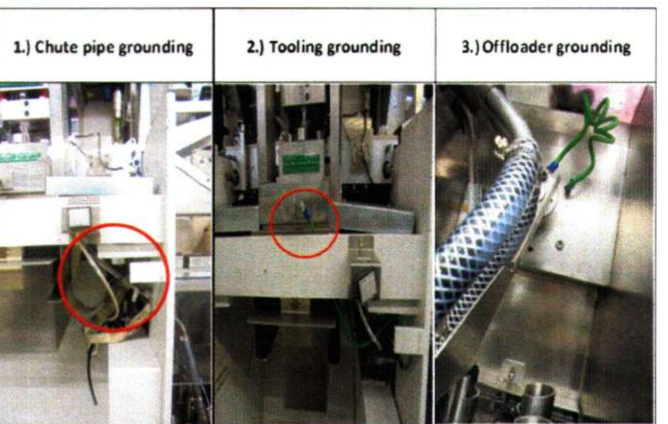
Method:

- Ground conductive parts of the machine that come into contact with the units

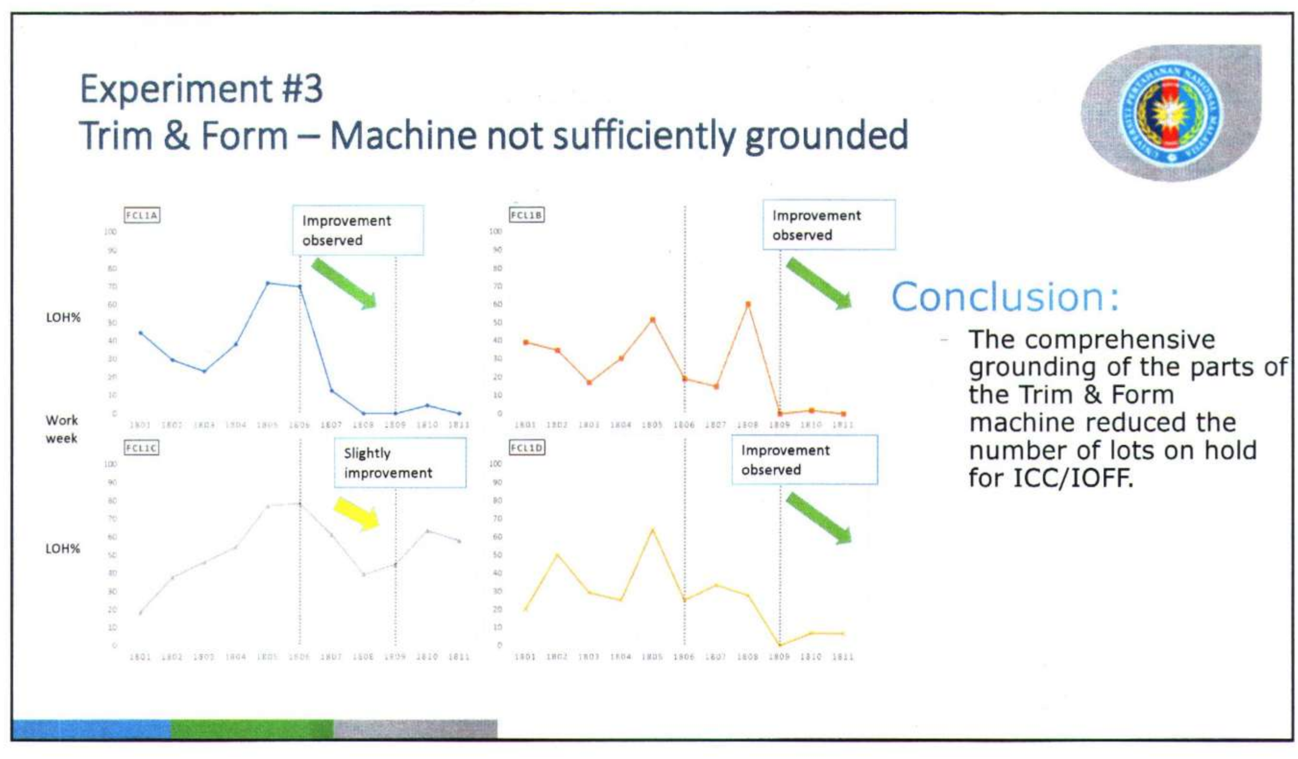
Experiment #3
Trim & Form – Machine not sufficiently grounded

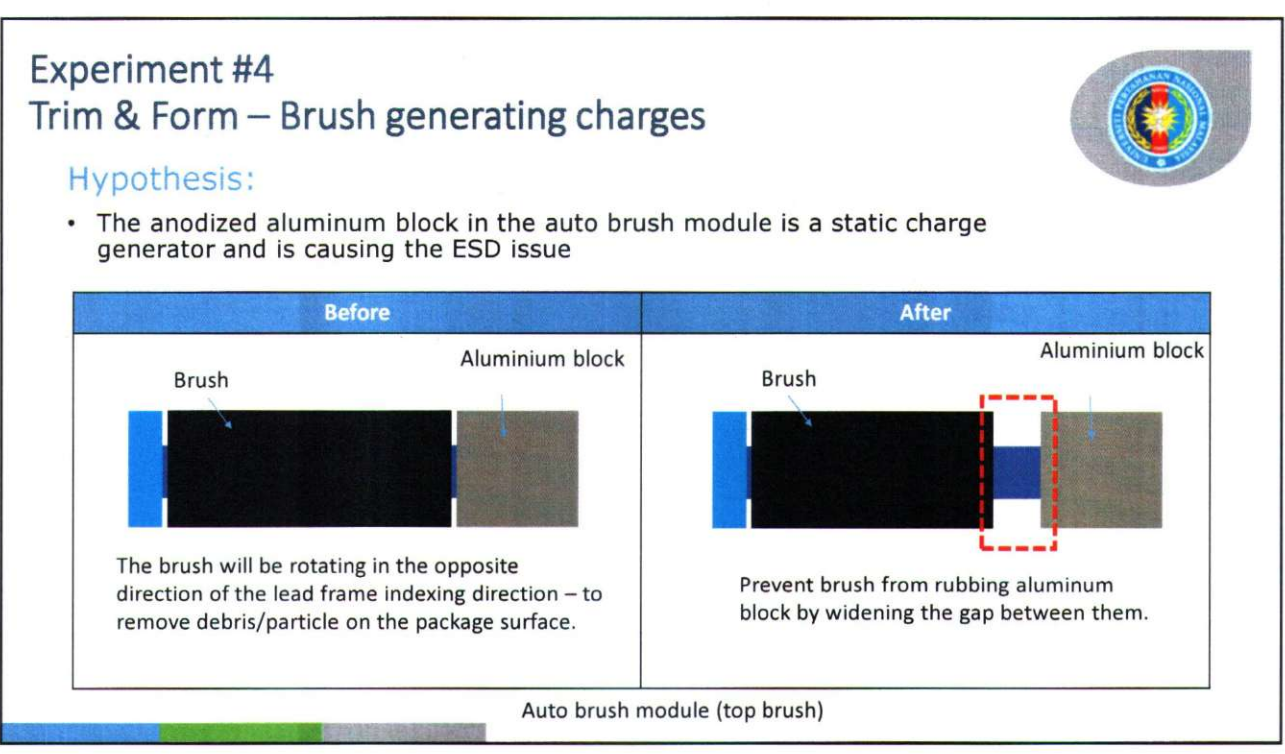
Additional grounding wire

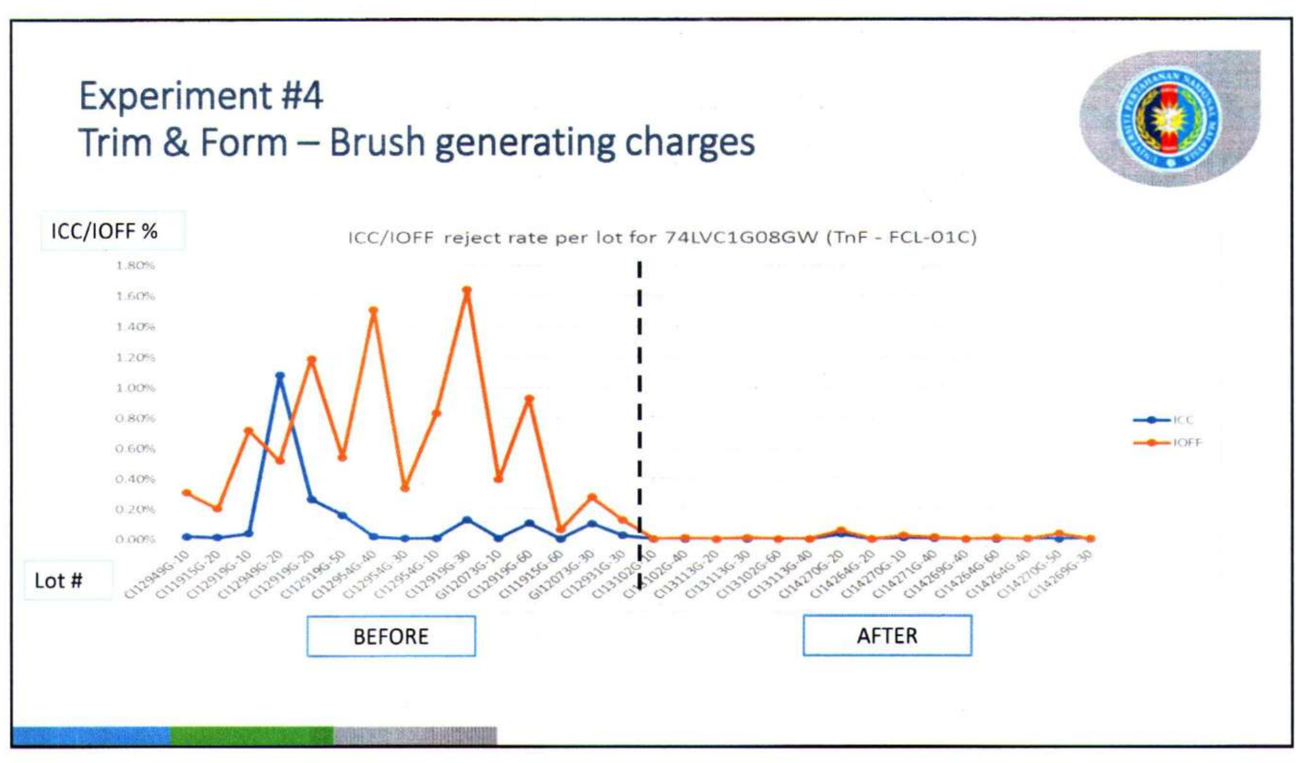
Trim & Form machine

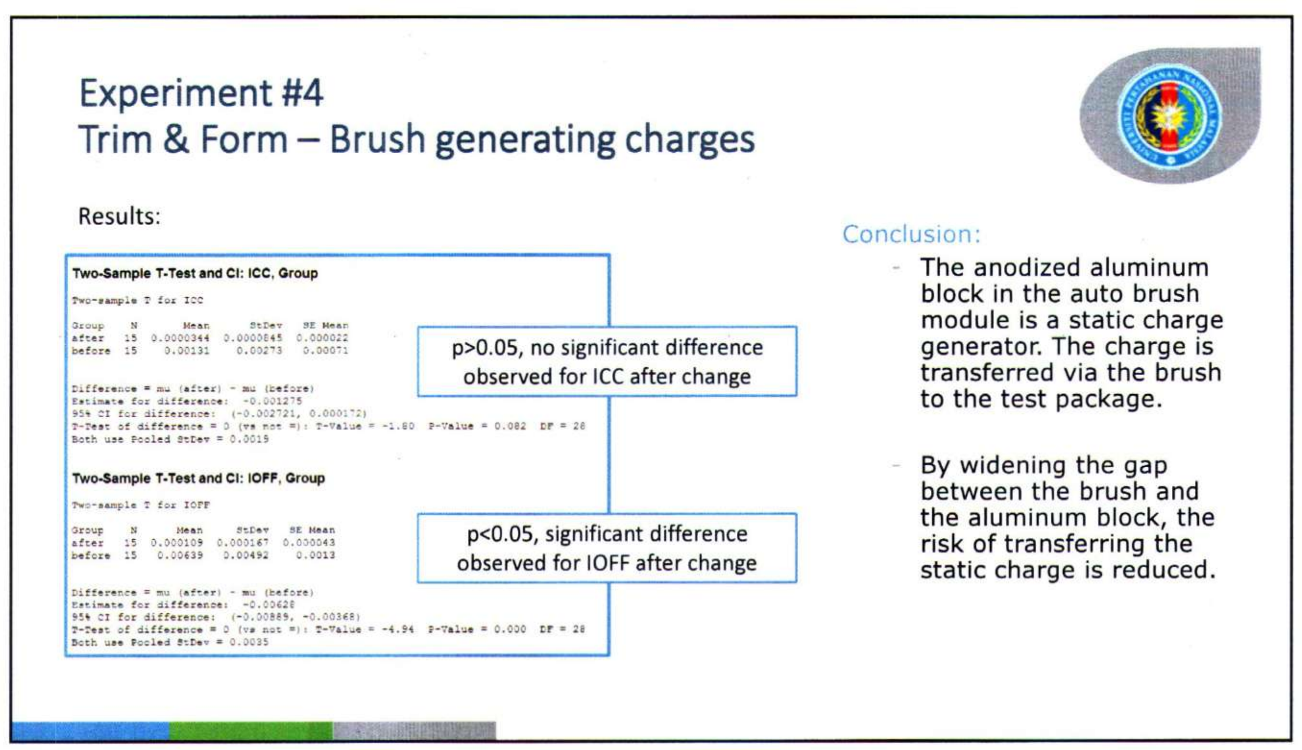


New ESD improvement action items taken


Experiment #3
Trim & Form – Machine not sufficiently grounded
FCL1A
Improvement observed
FCL1B
Improvement observed
LOH%
Work week
FCL1C
Slightly improvement
FCL1D
Improvement observed
LOH%
Conclusion:
The comprehensive grounding of the parts of the Trim & Form machine reduced the number of lots on hold for ICC/IOFF.


Experiment #4
Trim & Form – Brush generating charges
Hypothesis:
• The anodized aluminum block in the auto brush module is a static charge generator and is causing the ESD issue
Before
After
Brush
Aluminium block
Brush
Aluminium block
The brush will be rotating in the opposite direction of the lead frame indexing direction – to remove debris/particle on the package surface.
Prevent brush from rubbing aluminum block by widening the gap between them.
Auto brush module (top brush)

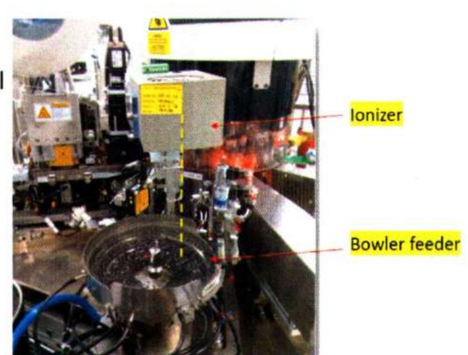

Experiment #4
Trim & Form – Brush generating charges
ICC/IOFF %
ICC/IOFF reject rate per lot for 74LVC1G08GW (TnF - FCL-01C)
ICC
IOFF
Lot #
BEFORE
AFTER


Experiment #4
Trim & Form – Brush generating charges
Results:
Two-Sample T-Test and CI: ICC, Group
Two-sample T for ICC
Group N Mean StDev SE Mean
after 15 0.0000344 0.0000845 0.000022
before 15 0.00131 0.00273 0.00071
Difference = mu (after) - mu (before)
Estimate for difference: -0.001275
95% CI for difference: (-0.002721, 0.000172)
T-Test of difference = 0 (vs not =): T-Value = -1.80 P-Value = 0.082 DF = 28
Both use Pooled StDev = 0.0019
Two-Sample T-Test and CI: IOFF, Group
Two-sample T for IOFF
Group N Mean StDev SE Mean
after 15 0.000109 0.000167 0.000043
before 15 0.00639 0.00492 0.0013
Difference = mu (after) - mu (before)
Estimate for difference: -0.00628
95% CI for difference: (-0.00889, -0.00368)
T-Test of difference = 0 (vs not =): T-Value = -4.94 P-Value = 0.000 DF = 28
Both use Pooled StDev = 0.0035
p>0.05, no significant difference observed for ICC after change
p<0.05, significant difference observed for IOFF after change
Conclusion:
- The anodized aluminum block in the auto brush module is a static charge generator. The charge is transferred via the brush to the test package.
- By widening the gap between the brush and the aluminum block, the risk of transferring the static charge is reduced.

Experiment #5
Test NX - Ionizer not effective at feeder bowl

Hypothesis:

- ❑ Ionizer position not centralized and too far from the feeder bowl
- ❑ Ionizer size too small to effectively cover feeder bowl area
- ❑ Ionizer not effective due to aging

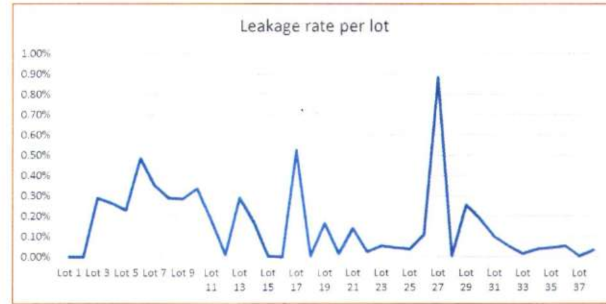


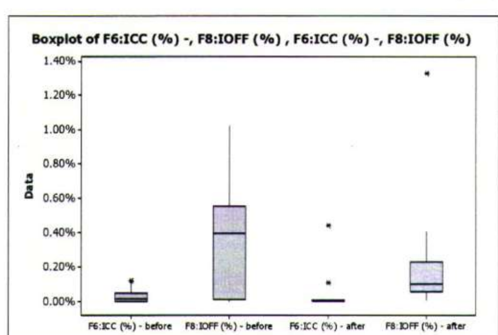
Method:

- ❑ Replace and install larger ionizer

Experiment #5
Test NX - Ionizer not effective at feeder bowl

Results:





Conclusion:

- ❑p-value > 0.05; statistically both ICC & IOFF has no significant difference after installing the larger ionizer.

Summary

1. ***Wafer saw : Ionizer effect during saw process***
   a. Conduct during sawing process where bare units need to singulate for the next process
   b. Shown significant improvement on leakage test performance
   c. Suitable to prevent the static charge
2. ***Trim & Form : ionizer at output chute***
   a. Effectiveness of ionizer was tested at the trim and form machine
   b. It was discovered that while the machine has a custom built ionizer, it was very effective as an ESD counter measure at the position it was installed
3. ***Trim & Form : Machine not sufficiently grounded***
   a. Additional groundings were implemented in several parts of the machine
   b. Reduce ESD occurrence significantly
4. ***Trim & Form : Brush generating charges***
   a. Prevent brush from rubbing aluminum block by widening the gap between them.
   b. Significantly improve IOFF reject rate
5. ***Text NX : Ionizer at feeder bowl***
   a. Conducted at the test area which are the last stage before the product shipment out of the factory
   b. The sizing of the ionizer caused no significant difference on the static charge measurement.

CONCLUSION

- ❑ Adaptation of robust engineering approach as a relatively quick and cost effective approach in output optimization was successful in the case of IC fabrication process of the 12 nm Gate Oxide semiconductor manufacturing in this case.
- ❑ Weekly LOH was significantly reduced to only the remaining 5 to 10% average of the total (due to other assembly issue) since ESD issue was mostly eliminated.

THANK YOU