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環球晶圓股份有限公司

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Study of Diamond Coated Wire (DCW) slicing technique

Learned lesson about impact of DCW on
high grade Semiconductor Wafer quality

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Introduction

My name is Carlo Zavattari, R&D senior Engineer and Fellow of GlobalWafers Company.

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My job is focused on research and development of new techniques to produce silicon wafers for semiconductors

Introduction

This study is about the learned lessons on how the slicing process parameters and wire saw set-up, using Diamond Coated Wire (DCW) instead of loose abrasive technique, can drive wafer quality, and how to take advantage of tuning those parameters to change wafer shape

The paperwork represents a 15-year-long development lead by a small group of people inside our company:

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Background (wafer parameters)

As-cut wafer major parameters

1. warp (warpage, wafer global shape)
2. TTV (total thickness variation)
- 3. Waviness: prediction of wafer behavior after polishing, where NT* (nanotopology) is measured.

*NT is a surface variation/deviation from planarity over a small square area (local warp).



Background (sawing machine)

Early days: single wafer slicing with ID (internal diameter) blade saw (FIG. 1)

Blade inner hole bonded with diamond powder.



FIG. 1: ID blade machines (manufacturer: Meyer Burger AG, now PSS: Precision Surface Solutions)

Background (sawing machine)

ID saw: good solution for slicing?

- expensive and not efficient (silicon loss – kerf – up to 50%)
- Single wafer slicing, hence: low through-put.



So, semiconductor manufacturers moved to multiwire wire sawing (FIG. 2)

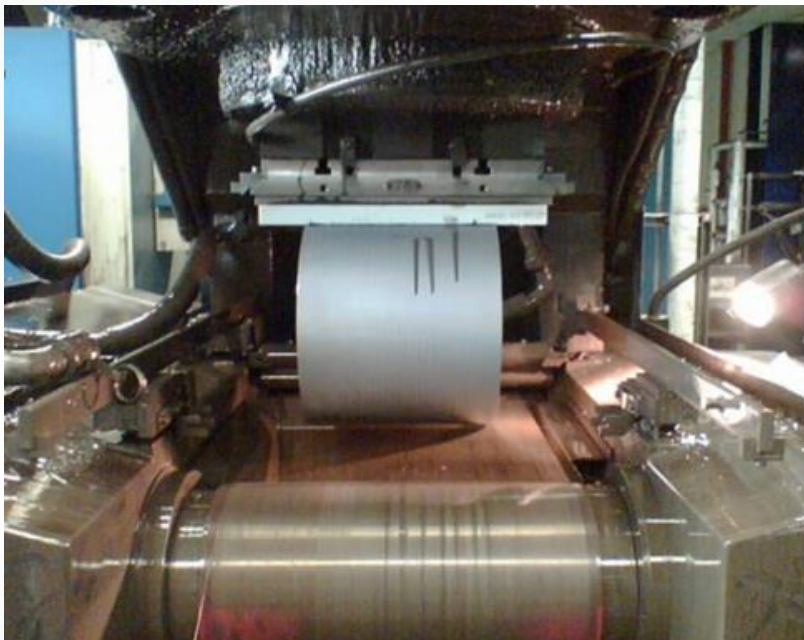
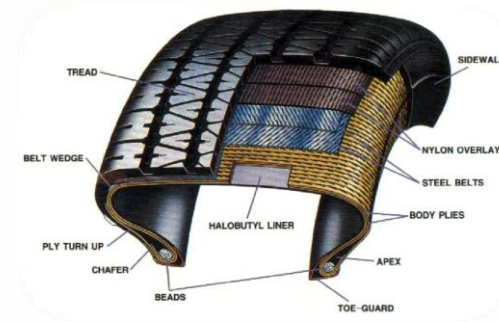


FIG. 2 Multiwire wire saw machine for simultaneous multiple wafer slicing (manufacturer: Meyer Burger AG, now PSS)

Background (sawing machine)

Old approach to multiwire saw (loose abrasive / slurry)

- Steel wire (tyre industry)
- Abrasive
 - suspending agent (fluid)
 - abrasive powder (silicon carbide [SiC] or other hard materials).



New approach to multiwire saw (fixed abrasive / DCW)

- Steel wire (tyre industry)
- Abrasive: diamond powder plated on wire surface



DCW: a combination of ID blade and loose abrasive



Background (sawing machine)

DCW advantages

1. Higher through-put (shorter cutting time): diamond harder than SiC
2. Less kerf generation
3. 1 + 2 => less manufacturing costs
=> smaller number of machines
=> less electricity and cooling water
4. No slurry preparation and disposal: bulky and expensive
5. No SiC and suspending agent manufacturing: big quantities needed, expensive and not environmentally clean. Diamond powder amount is 1000 – 10000 times smaller.

Background (slicing process)

1. DCW cutting process is different from the slurry one
2. Interactions between the equipment, consumables and process influence the wafer quality in different ways

The major slicing process parameters to look at are:

- Wire management
- Wire type
- Coolant type
- Coolant distribution system
- Feed unit
- Main roller (wire guide) lay-out
- Main roller groove shape



...too many...

Warp Vs slicing parameters / process

- Most difficult parameter to drive



- Impacted by many variables (combination of mechanical, thermal, frictional, thermodynamical, and geometrical factors)

Slicing parameters / process

1. Wire management
2. Wire type
3. Coolant type
4. Coolant distribution system

Warp Vs Wire management

- Saw suppliers developed a specific wire management for DCW
- ↓
- Much higher wire speed and acceleration Vs the old generation saws.
- ↓
- Result: warp improvement (more efficient slicing ability) [FIG. 3]

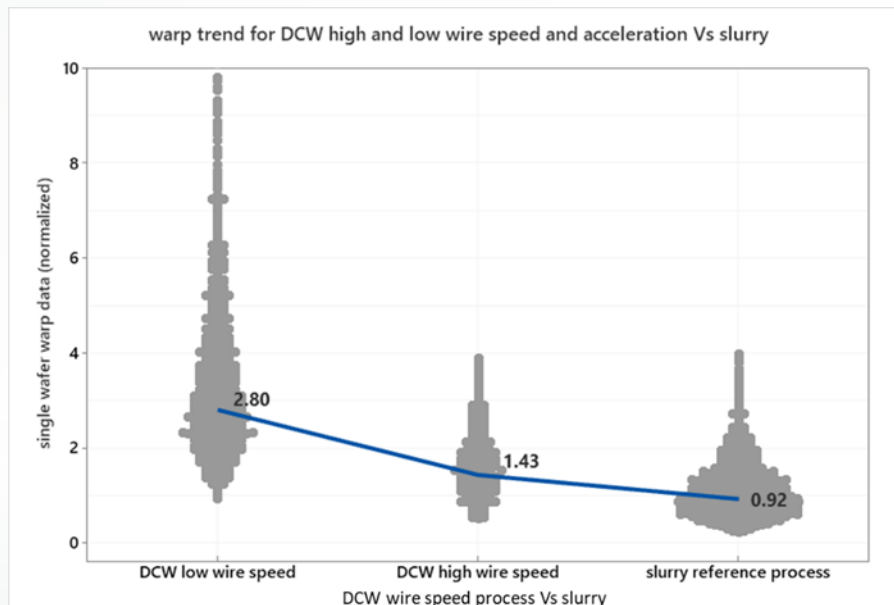


FIG. 3 warp trend performance in reference to the DCW top wire speed and acceleration (POR is slurry process)

Warp Vs Wire type

Cutting key factor: diamond grains (size, distribution and density)

Impact of grain size on warp

smaller grains



less damage



less heat



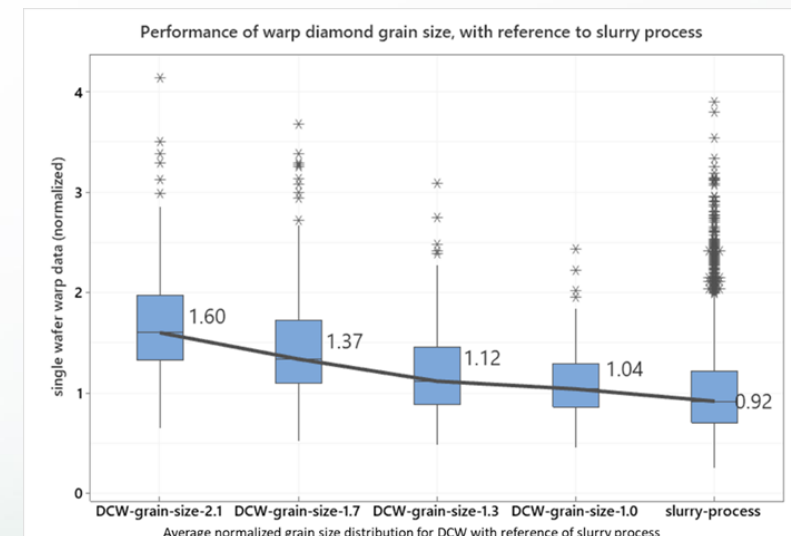
fewer thermal gradients



Warp reduction (FIG. 4)



FIG. 4 warp for DCW with different grain size Vs slurry process; grain size is normalized to the smallest size



Warp Vs Coolant type

1. Cutting liquid = water + coolant

- Water: friction heat removal
- Coolant: silicon swarf suspension removal from wire surface = no silicon load-up on wire surface = no cutting ability reduction.

.....

2. Cutting liquid = pure water = no swarf removal = bad wafer shape (FIG. 5)

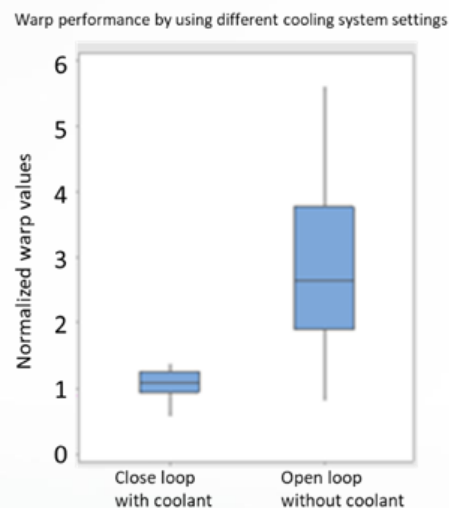


FIG. 5 warp comparison between coolant diluted in water to help swarf removal, and pure water



Warp Vs Coolant distribution system

1. Spray nozzles: low coolant flow and high pressure
2. High flow bars: high coolant flow and low pressure

Set-up 2 is better than 1 (more heat is removed) [FIG. 6]
Unfortunately, for TTV the impact is opposite

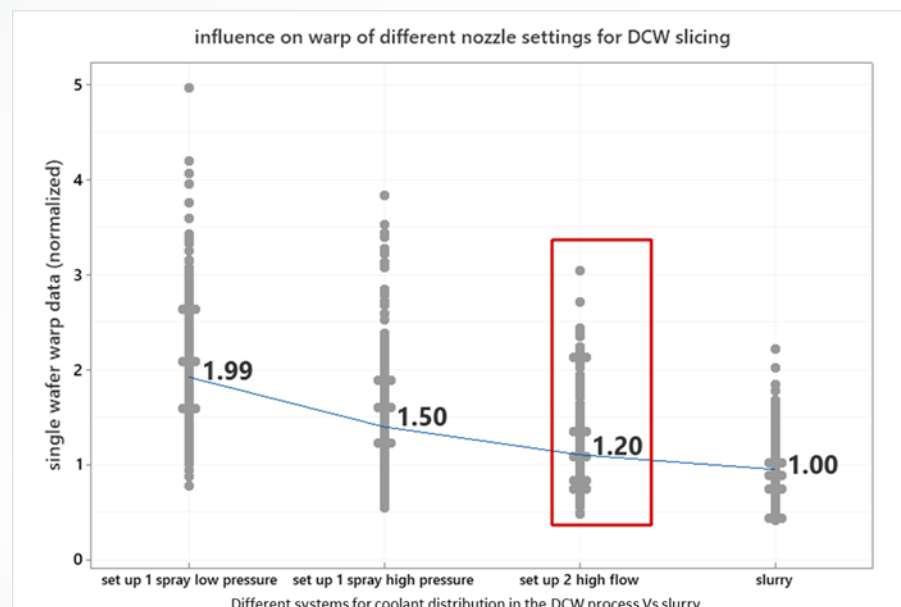


FIG. 6 warp Vs different coolant settings compared with slurry

TTV Vs slicing parameters / process

- Easy to modulate (pure mechanical parameter)
- Process and saw set-up good for TTV may not be good for warp

Slicing parameters / process

1. Coolant distribution system
2. Wire type
3. Coolant type
4. Main roller lay-out
5. Main roller groove shape



TTV Vs Coolant distribution system

1. Spray nozzles: low coolant flow and high pressure
2. High flow bars: high coolant flow and low pressure

Set-up 1 is better than 2 (less turbulence) [FIG. 7]
Unfortunately, for warp the impact is opposite

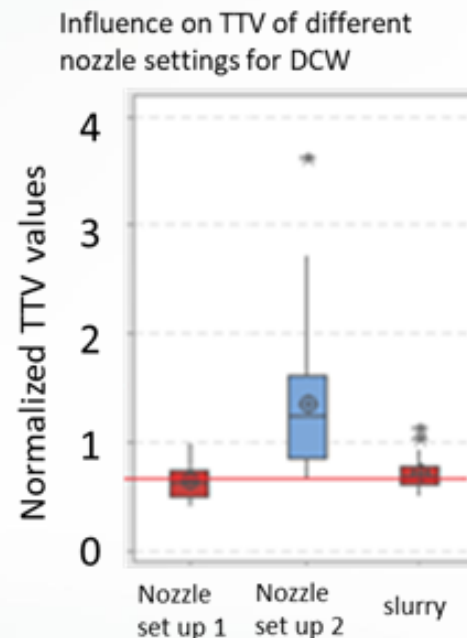


FIG. 7 TTV performances with different settings compared with slurry process

TTV Vs Wire type



Same mechanism as for warp: coarser the grit size, higher the TTV.

Wire type key parameters: grit size, distribution, and number of grains.

TTV Vs Coolant type

- Different suppliers have their own recipe and instructions for usage
- Formulation and concentration: key parameters to drive TTV
- Same saw settings could have different TTV performances when choosing different coolants (FIG. 8)

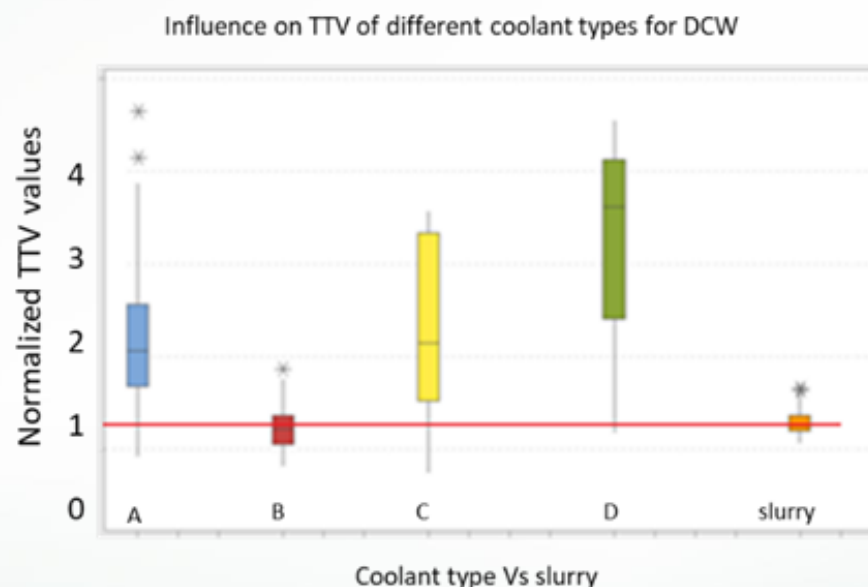
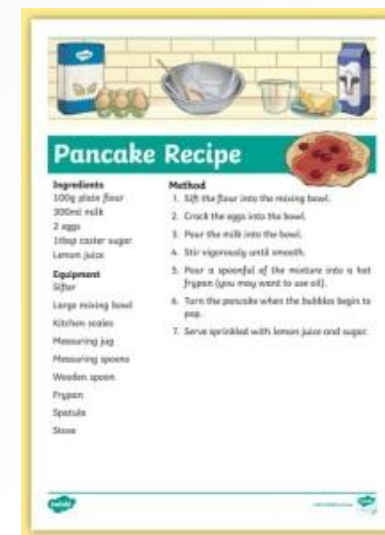


FIG. 8 Influence of different coolants on TTV, even by having the same cutting settings

TTV Vs Main roller lay-out

Span = distance between the two rollers driving the wire.

Bigger the span bigger the deflection of the web during cutting (FIG. 9)

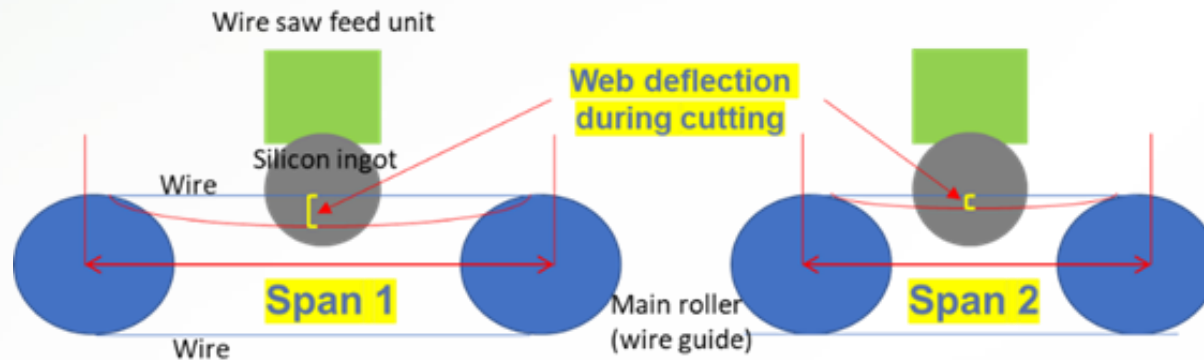


FIG. 9 long span between rollers (left picture) and short span (right picture) with evidence of a different wire web deflection during cutting

TTV Vs Main roller lay-out

Grain distribution is random around the wire diameter

Single grain is slicing in a specific direction,
Generating deflections along this direction,
Inducing Disturbance in the wire movement,
And vibrations/deviations from the straight
line along the axial direction



Longer the span more web
deflection and freedom for
the wire to deviate from
the straight line with more
vibrations (FIG. 10)

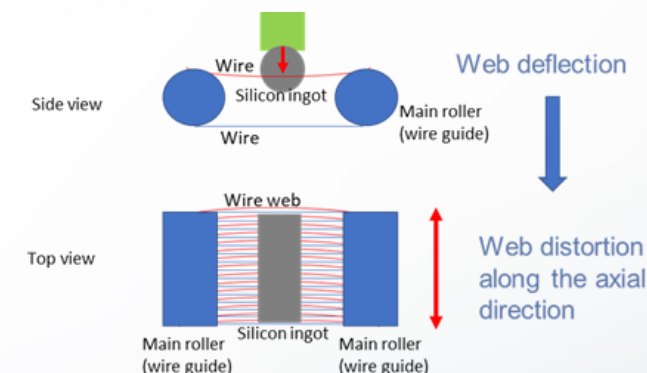
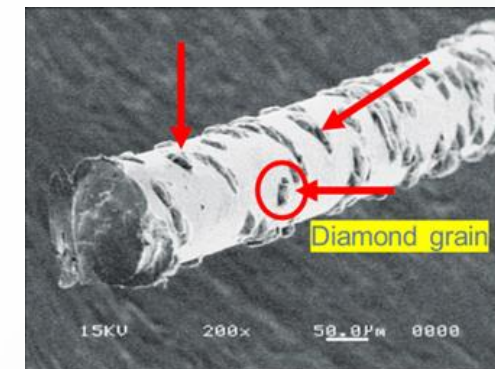
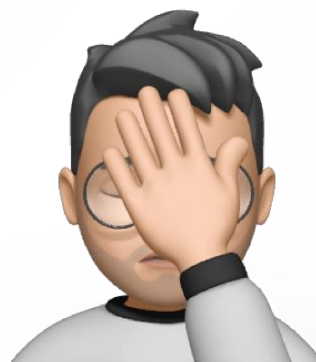


FIG. 10 uneven grain distribution
= web distortion along the axial
direction

TTV Vs Main roller groove shape

Groove shape means angle and depth (FIG. 11)

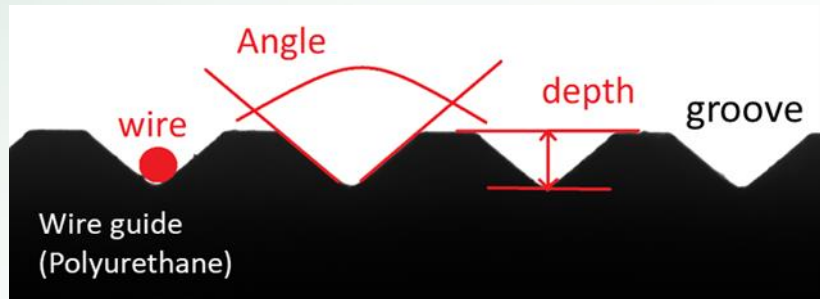


FIG. 11 wire guide section with polyurethane shape and groove

Narrower the groove angle less vibrations = better TTV (FIG. 12)

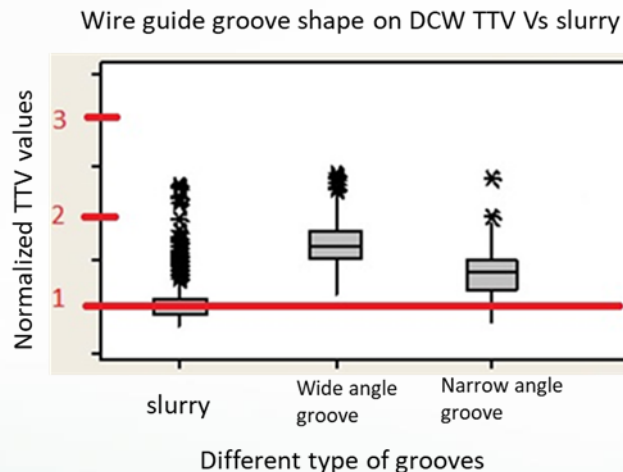


FIG. 12 groove shape (angle) impact on TTV, compared with slurry



Waviness Vs slicing parameters / process

- Waviness derives from as-cut warp
- It is used to predict end-of-line wafer quality, mainly nanotopology (NT)
- Waviness and warp are influenced by the same slicing parameters and saw set-up
- Exception: one special wire saw element is giving a very strong signal to waviness and not to warp
- It is a special saw feed unit design
- PSS is the only owner of the design and development



Bonda F.

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Waviness Vs feed unit

Variable definition for waviness calculation

- Reference: cutting direction Vs notch location (FIG. 13)
- Variable definition
 - Θ_s = angle between cutting direction and notch position
 - d_s = distance between cut entrance (start position) and the position where the waviness is calculated
 - Θ and d = generic position

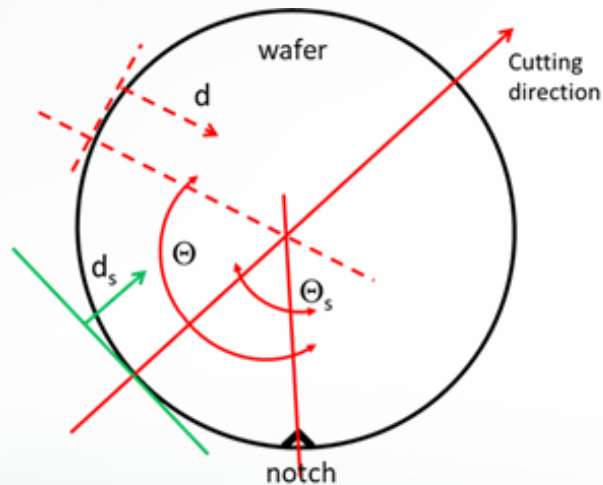


FIG. 13 as-cut wafer with notch position and cutting direction



Waviness Vs feed unit

Wafer shape measurements needed for calculation



- $W(d, \Theta)$ = warp in a defined position compared with the reference plane
- $T(d, \Theta)$ = local thickness value – minimum thickness

Wafer shape formula

$$f(d, \Theta) = \text{ma}[W(d, \Theta)] + 1/2T(d, \Theta),$$

- ma = moving average

Waviness Vs feed unit

Waviness calculation

$$w = \max |\partial_d f(d_s, \Theta_s)|$$

.....



Waviness = maximum value of the discrete derivative of $f(d, \Theta)$ with respect to d , for two consecutive points along the cutting direction

It is a non-dimensional number ($\mu\text{m}/\text{mm}$)

Waviness Vs feed unit

Lights and shadows in the NT maps = waviness (FIG. 14)

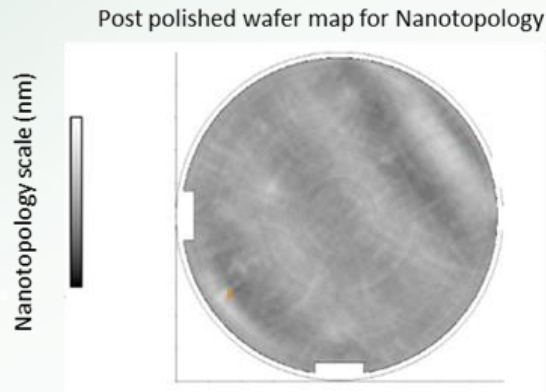


FIG. 14 post-polished wafer NT map with wavy bands generated during slicing

Waviness / NT bands are generated by small side wire movements
PSS special feed unit can break this band structure (FIG. 15)

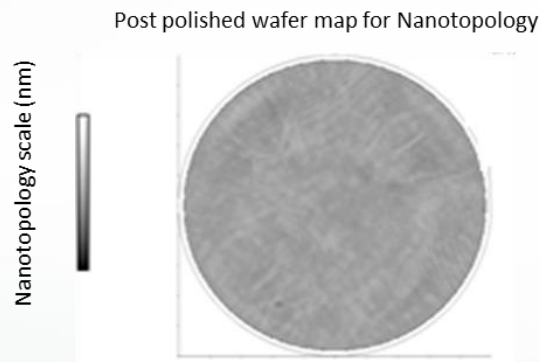


FIG. 15 post-polished wafer NT map with NO wavy bands

Waviness Vs feed unit

Special feed unit = similar improvement for Waviness (FIG. 16) and NT (FIG. 17)

Boxplot of WI (waviness index) Vs cutting feed unit set up

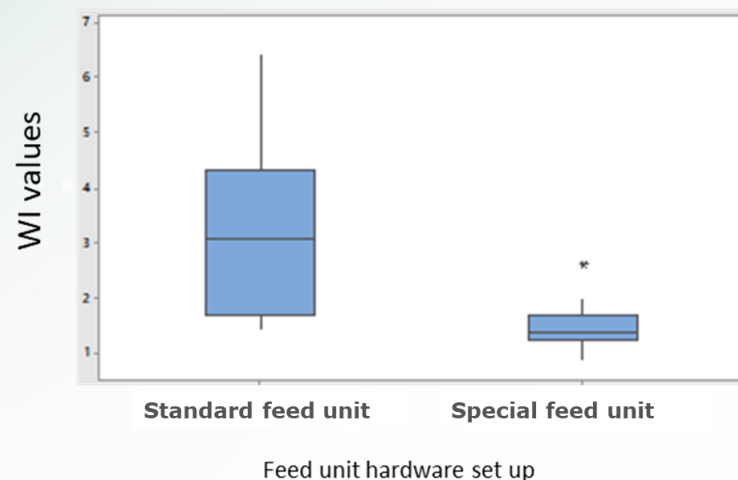
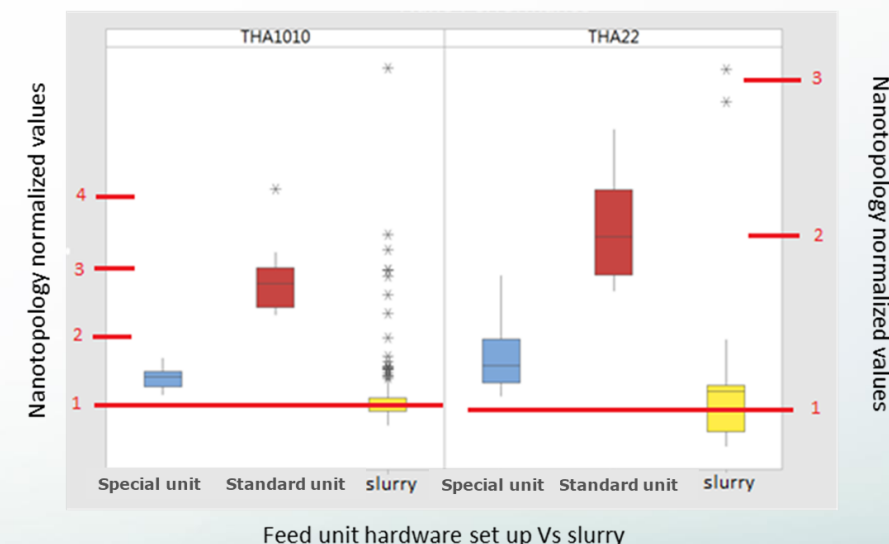


FIG. 16 special feed unit influence on waviness performances for as cut wafers

FIG. 17 special feed unit influence on NT for post polished wafers

Nanotopology performances for different feed unit set-up processes Vs slurry



Conclusions



1. DCW slicing process was introduced because of several advantages compared with slurry process (cost, through-put, environment).
2. It also carried in some disadvantages and issues: the most important was a significant degradation of wafer quality.
3. A sequence of studies allowed us to define the interaction (different than slurry) between the slicing variables and wafer quality.
4. The definition of those interactions gave the possibility to align the performances of DCW wafers with slurry wafers.



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