Applications of AI, Machine Learning and Big Data in Chemical Mechanical Polishing

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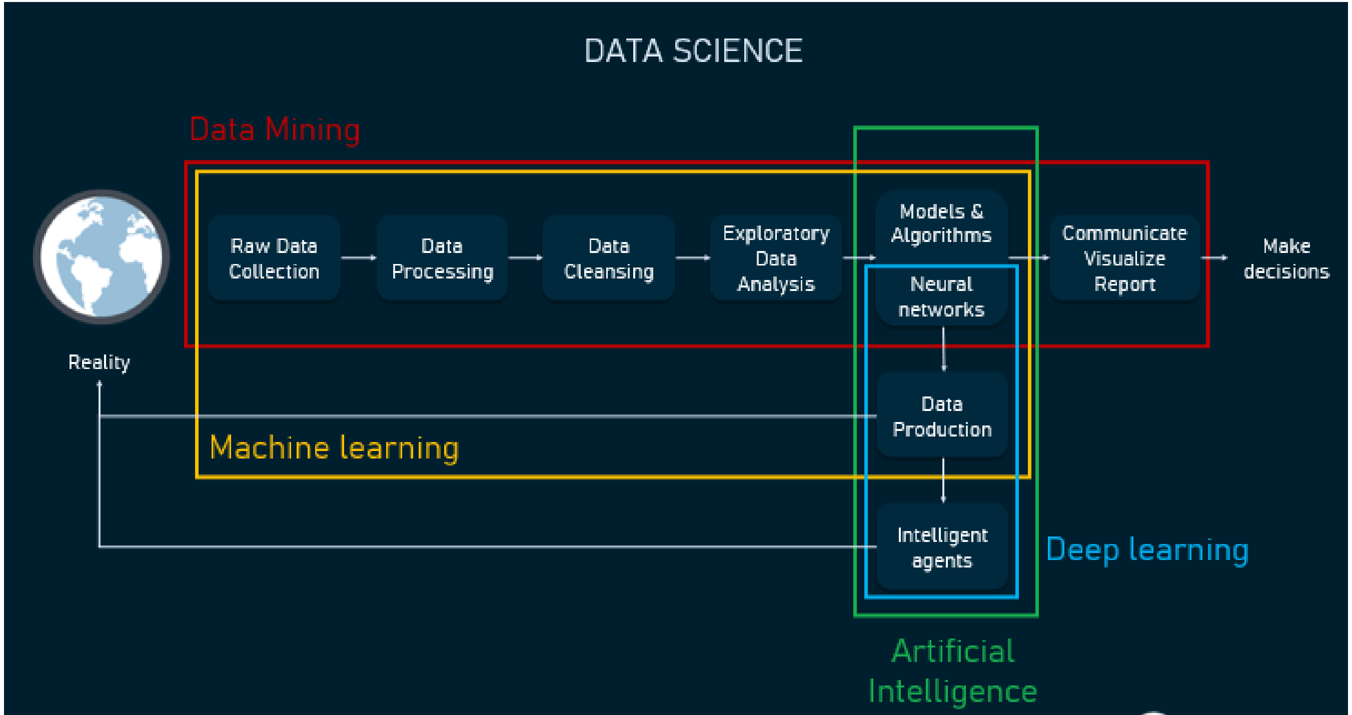
Introduction

- Background
  - What are we really talking about here, anyway?
  - History of AI
  - Requirements for a good application of AI/Big Data
- A specific example: Diamond Sorting
- Other applications of AI/Big Data in CMP
  - Infrastructure
- Market implications of AI/Big Data in CMP
- Summary

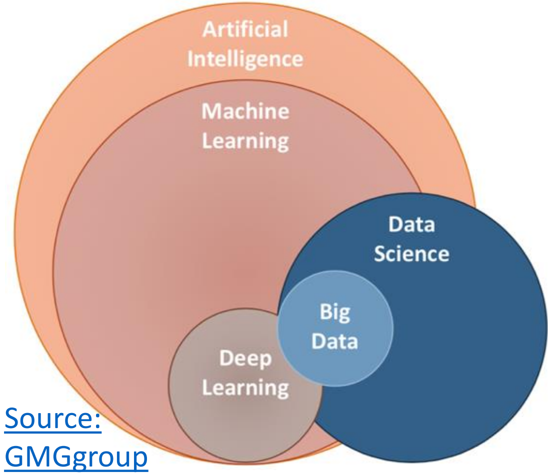
Definition of Terms

- "Data Science"
  - An interdisciplinary field encompassing the analysis of data to extract knowledge and insights, using algorithms, processes and systems
  - "Big Data" is a subset of Data Science dealing with datasets so large so as to be difficult or impossible to analyze by conventional means
  - "Data Mining" is another subset of Data Science, more specifically focused on finding useful patterns in data
- "Artificial Intelligence" ("AI")
  - Definition: the theory and development of computer systems able to perform tasks that normally require human intelligence, such as visual perception, speech recognition, decision-making, and translation between languages. (Oxford Dictionary)
  - "Machine Learning" is a subset of AI, where machines can be "trained" to improve through the incorporation of data into models, and algorithms
  - "Deep Learning" is a subset of Machine Learning utilizing multiple levels of non-linear processing where the output for one layer becomes the input for the next successive layer, i.e. complex neural networks

Battle of the Venn Diagrams!



Source: Altexsoft



Source: GMGgroup

- **A visual map can provide insight into how all of these tasks/disciplines interact/overlap**

Emphasis on “Big” and “Deep”

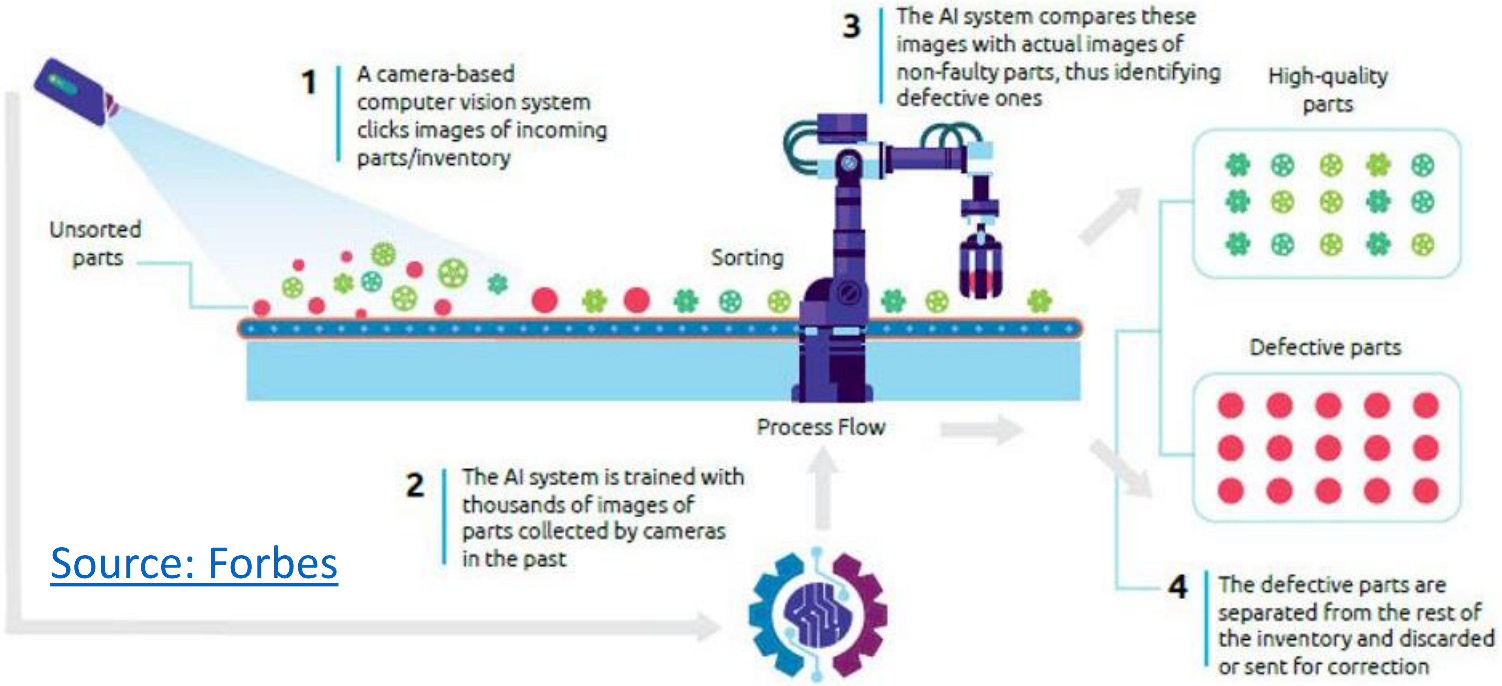
[Source: SAS]

- **None of this is new, the concepts of AI and Machine Learning are (at least) decades old**
- **The big thing that has happened to enable AI is computing power, along with the mass digitization of information**

History of AI

- Even in ancient times, philosophers hypothesized about the possibility of reducing thought to a series of calculations
- The modern history of AI parallels the development of mechanical and electronic computing in the 20th century
  - Turing, et al
- AI has already experienced multiple "boom and bust" cycles
  - Following an initial period of excitement, the first "AI winter" hit in ~1974
  - Another period of excitement (and FUNDING) ended in the bubble bursting in about 1987
  - Both of these cycles can be attributed to the inability to deliver against high (and in retrospect, unreasonable) expectations
- Additional "micro bursts" have happened in more recent memory
  - For example the exuberance of IBMs Watson project was sufficiently damped when it's medical application was canceled due to misdiagnoses ("this product is crap")

Killer Apps

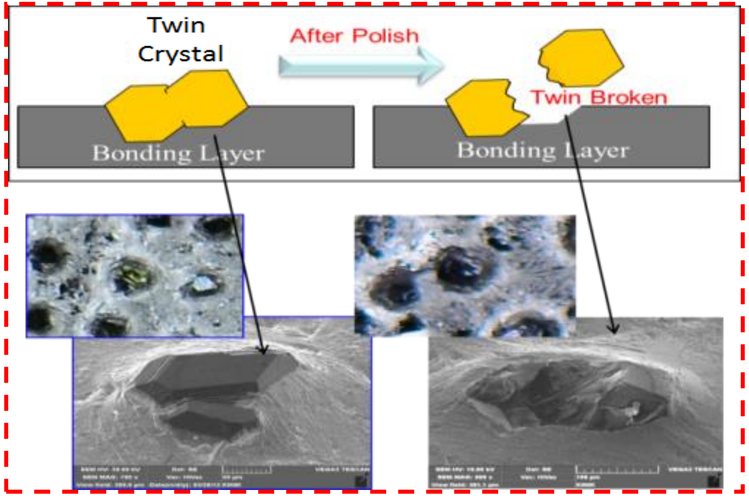


[Source: Forbes]

- **In this example, defective parts are identified visually and automatically**

- **To be amenable to a "Big Data" based AI implementation, a process/system has to have a large amount of high quality, actionable data**

Twin Diamonds



- Weakness of Twin Crystal
  - Poor Diamond Strength
  - Risk of Diamond Crack

DiaInspect -P

↓

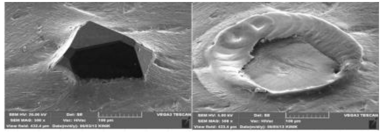
Diamond Image Comparison System

↓

Laser processing

Normal Crystal | Twin Crystal

Detect the Twin Crystal on the disk

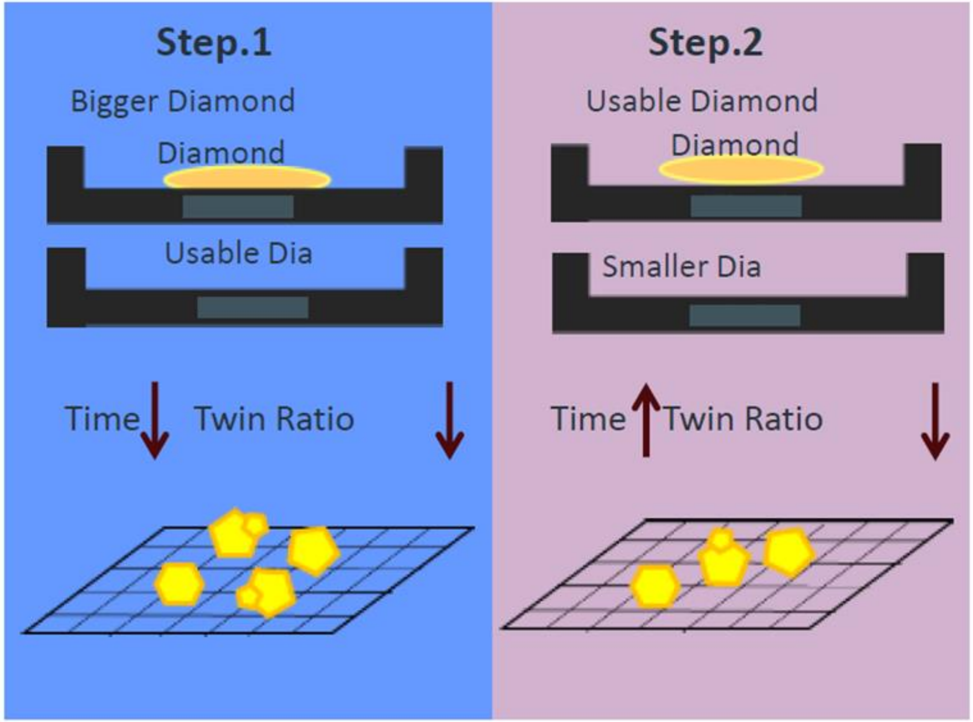


Remove the Twin Crystal on the disk

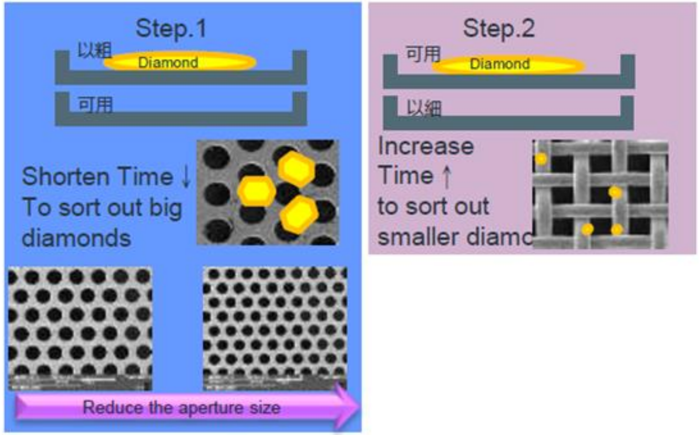
- DiaInspect -P is an old system to detect twin crystals and avoid using diamonds with higher twin ratio to make Disks.
- DiaInspect -P can't completely remove the twin crystal during the IQC.
- DiaInspect –P can only inspect small amount of diamond sample.

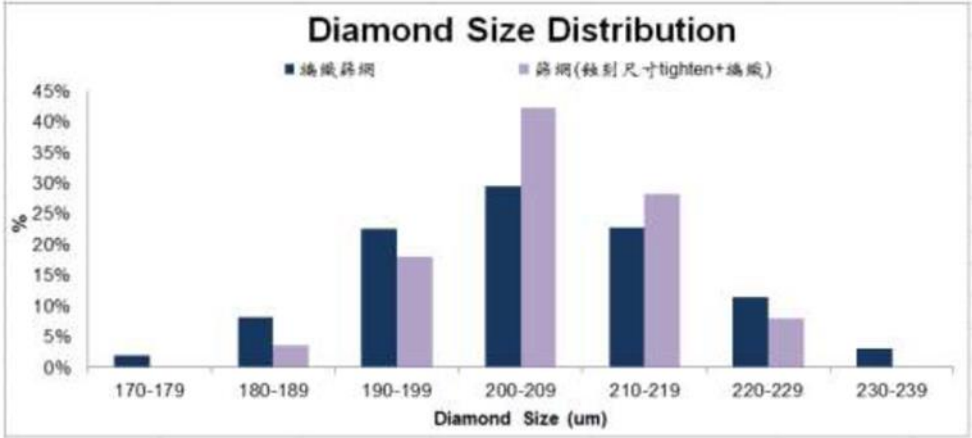
Conventional Twin Sorting

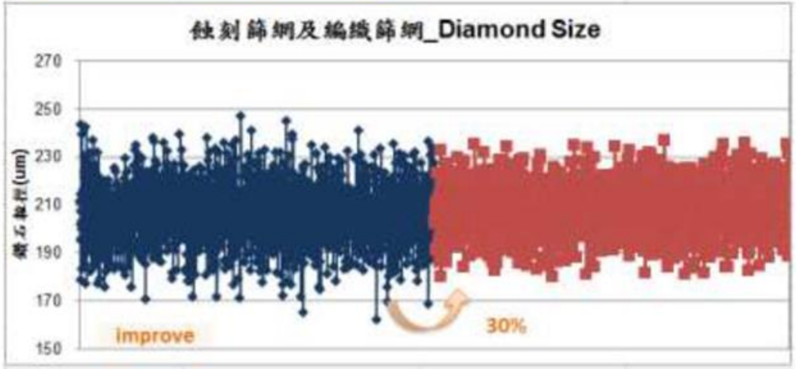
- Controlling Sifting time to decrease twin diamond ratio
- Sifting CIP can remove parts of twin diamonds



Conventional Twin Sorting







- Step 1: Shorten sieving time and use perforated sieve to sort out big diamonds.
- Step 2: Increase sieving time and use woven wire sieve to sort out small diamonds.
- Diamond Size range improve 30%.

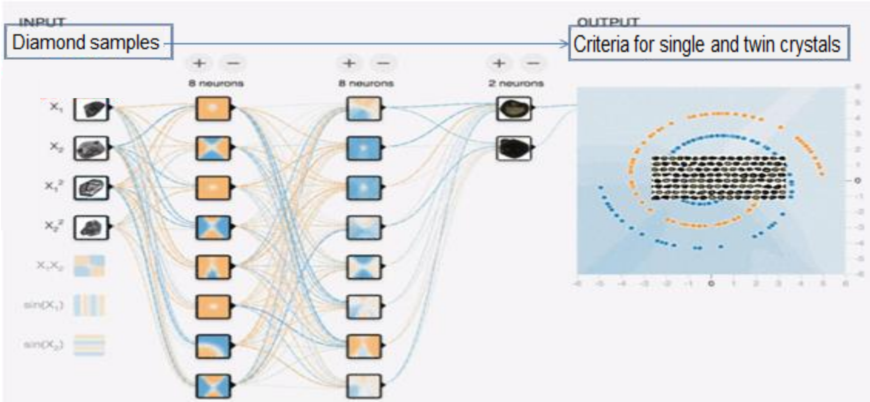
AI-Based Twin Sorting

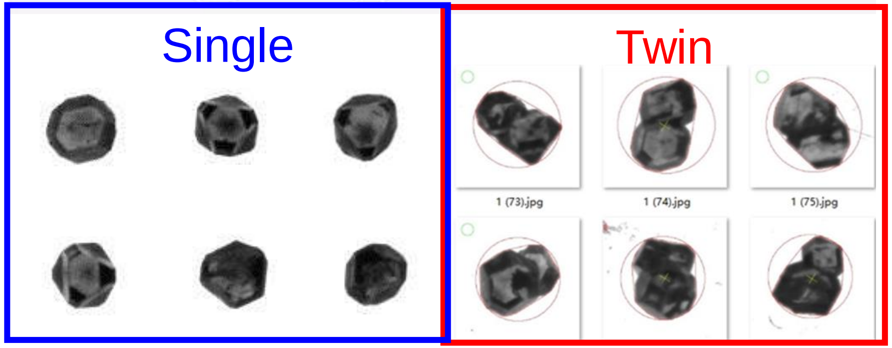
Twin Sorting (AI & Image Recognition) Gen1

Twin ratio 5.95%→0.51%

KINIK Do In-house Twin Sorting

- **Big Data Learning**
- **AI Image Sensor**





- ➢ The identification software can input a large number of learning samples and analyze data.
- ➢ Produce the diamond inspection criteria through AI learning.
- ➢ Inspect (all diamonds) and remove twin crystals during IQC.

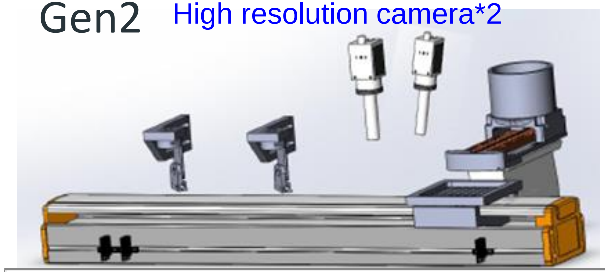
AI-Based Twin Sorting

Twin Sorting Gen2

Twin ratio 6.12%→0.49%

Size Analysis (New Function)

Gen2 High resolution camera*2



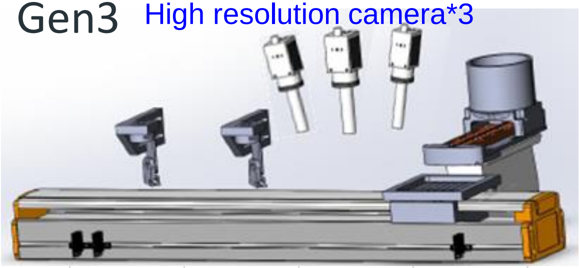
Increase camera

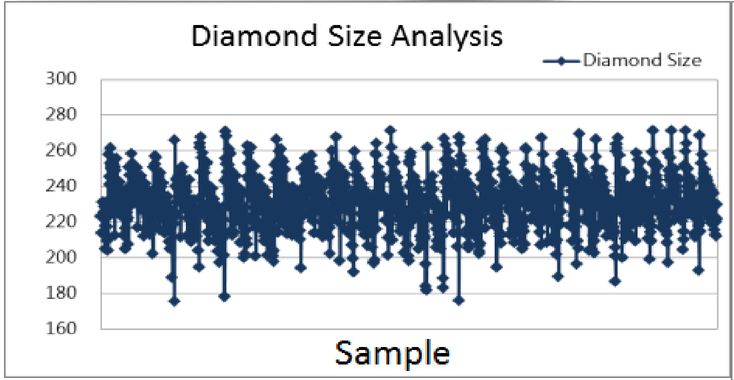
Twin Sorting Gen3

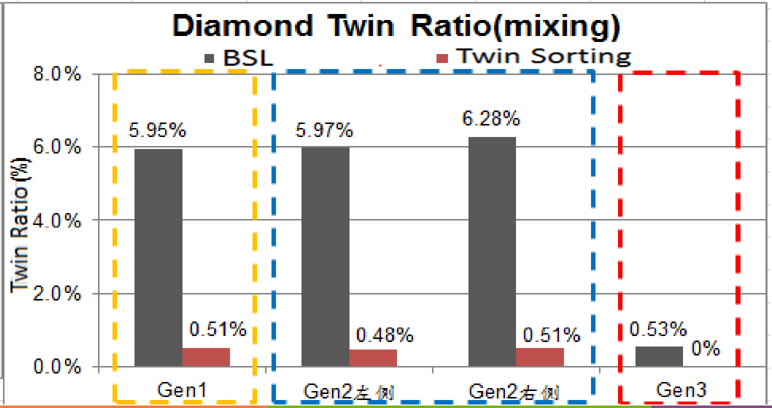
Twin ratio 0.53%→0%

Size Analysis (New Function)

Gen3 High resolution camera*3



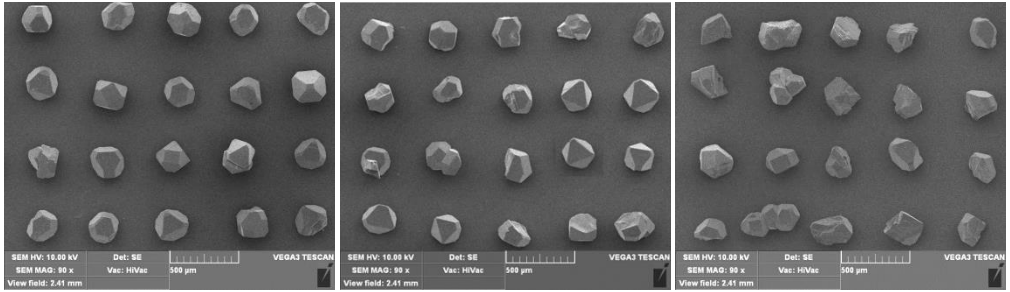




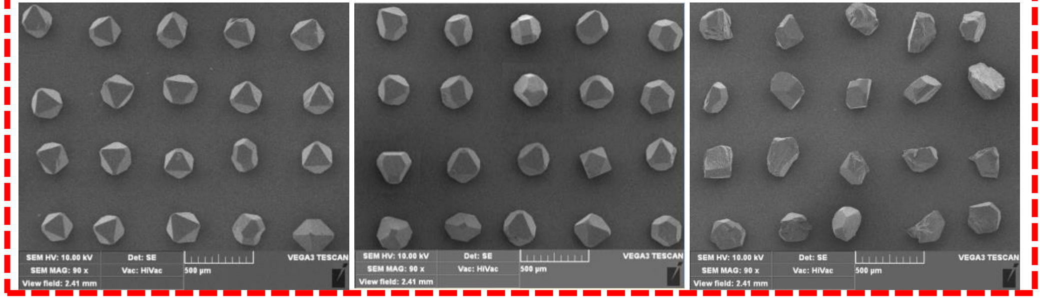
Twin Sorting
Diamond strength

EST.1953 KINIK®

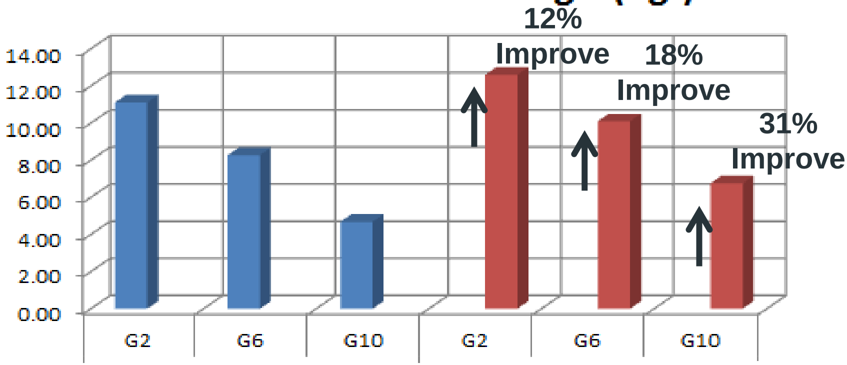
Low C/R Diamond (G2)	Medium C/R Diamond (G6)	High C/R Diamond (G10)



Twin sorting



Static Pressure Strength(Kgf)



Before Twin sorting After Twin sorting

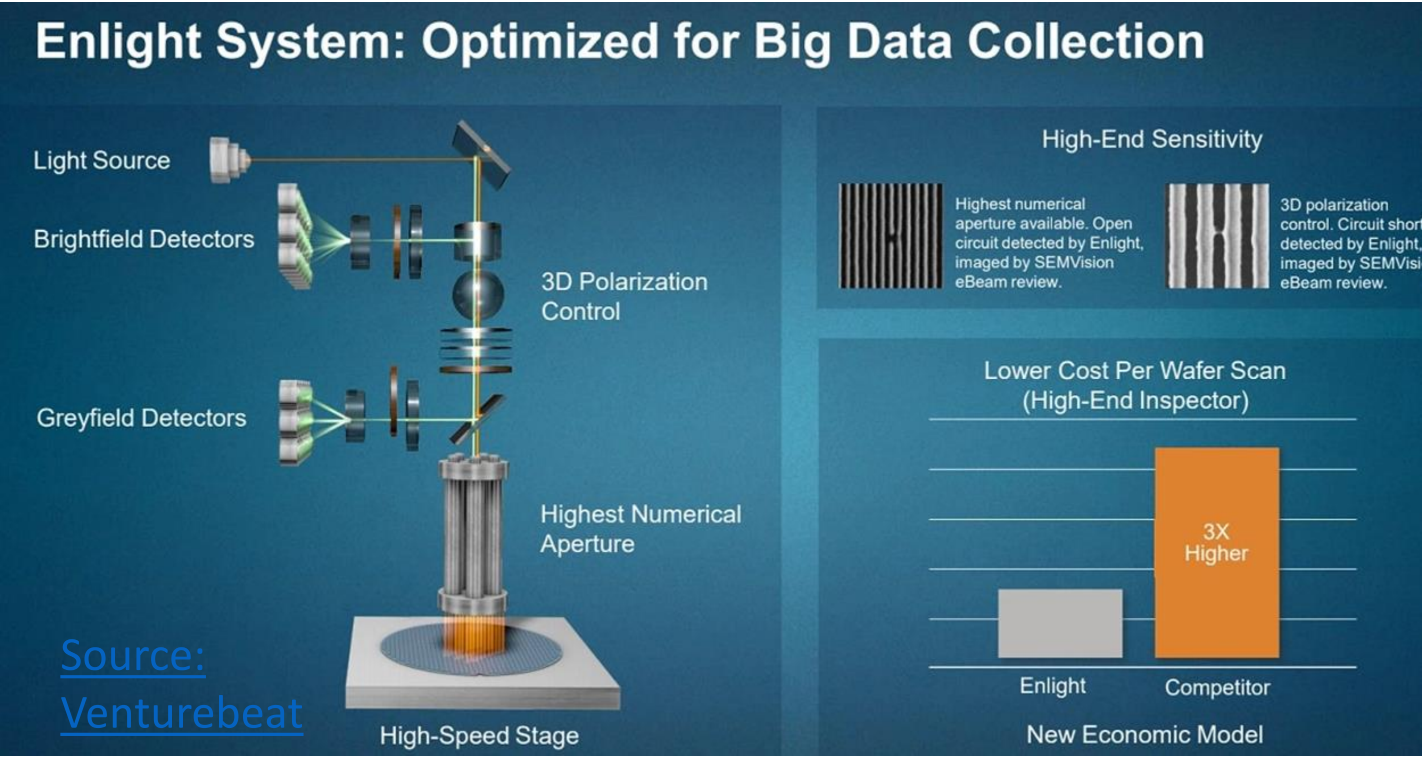
- No twin crystal for different crystal types.
- Improve diamond strength by 12~31% (especially higher C/R diamond).

Twin Sorting
Summary

- The new generation Twin Sorting system (AI & Image Recognition) can inspect all diamonds and remove twin crystals during IQC.
- Twin Sorting Gen3 : eliminate the twin crystal, Twin ratio is 0%
- Improve diamond strength by 12~31% (especially higher C/R diamond).

Twin Sorting	Gen 1	Gen 2	Gen 3
Twin ratio (%)	0.51	0.49	0
camera	2	2	3
Size Analysis	-	√	√

Infrastructure



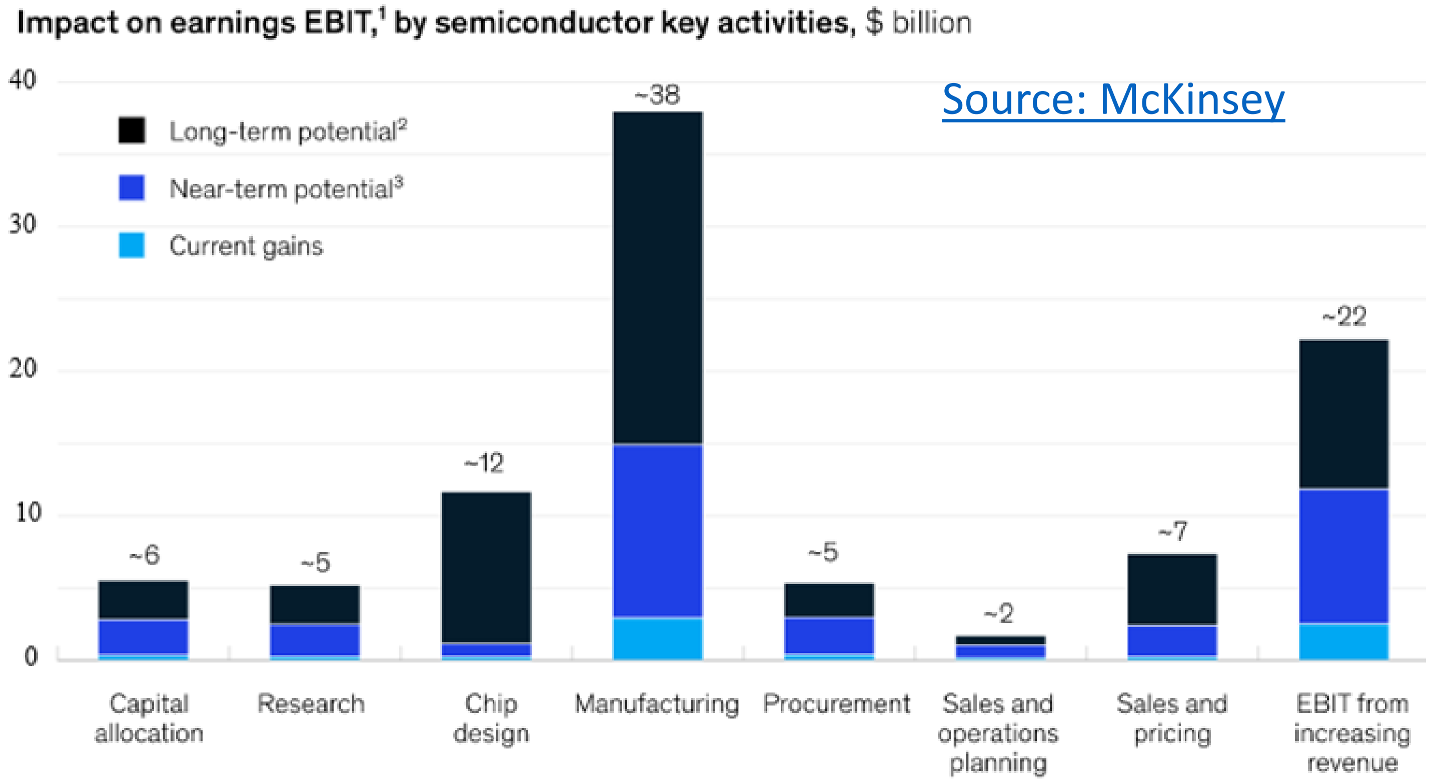
[Source: Venturebeat]

- AMAT has introduced the Extract AI system that, coupled with its inspection and e-beam systems, “closes the loop” on pattern related defectivity
- Their AIx system provides a fab wide infrastructure for tools to communicate

Applications of AI in CMP

- Large amounts of high quality data
  - Wafer thickness maps
  - Defect maps
  - Die scale thickness maps
  - Film spectral information (ellipsometry, etc)
  - Pad thickness maps
  - Temperatures
  - Slurry conditions
  - Vibration
  - Tool based indicators (motor current, flow rates, etc)
  - Process variables
  - ….
- Difficult control problems
- High level of interactivity with other processes and steps

Extracting Value Through Improvements



[Source: McKinsey]

- McKinsey projects that AI based process and system improvements can generate over 100 billion dollars of value annually

Where and How to Apply?

6 enablers of artificial-intelligence (AI) implementation

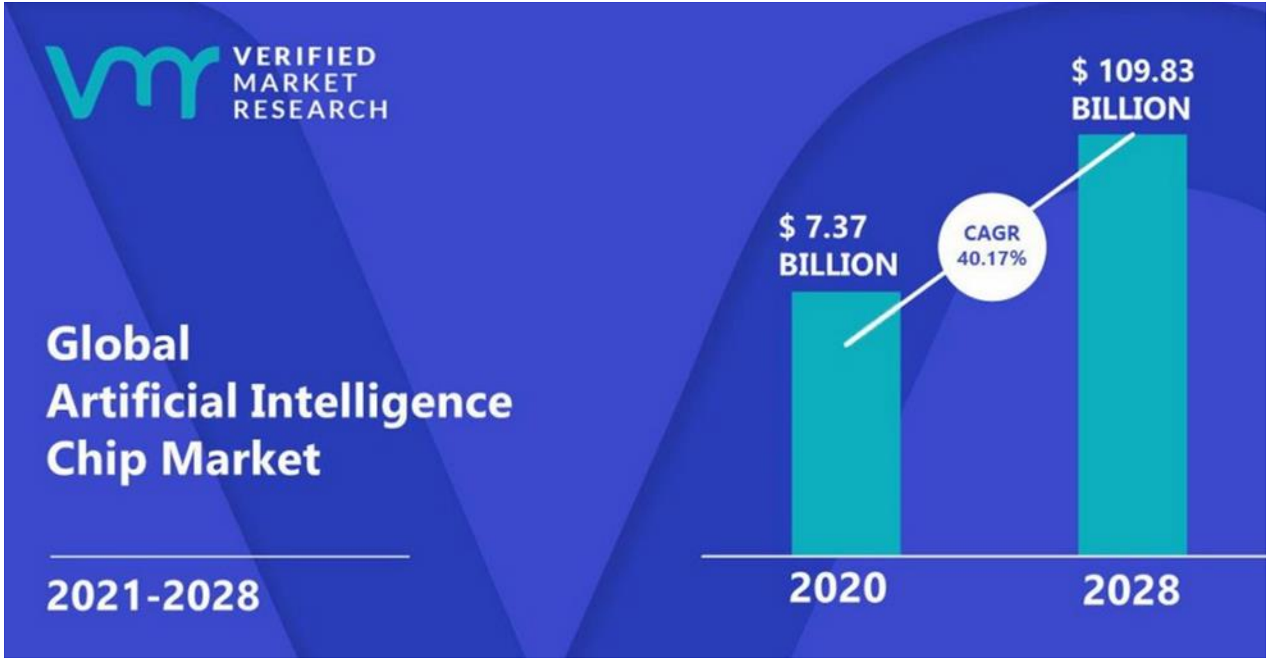
Strategic road map	Talent and organization	Technology	Data	Adoption and scaling	Agile delivery
• Make AI a top priority • Prioritize value and time to value • Don't reinvent the wheel	• Centralize AI capabilities for critical mass • Assemble various team capabili-ties/profiles • Add business expertise in central AI team • Add data-science expertise in local teams	• Connect the fab • Leverage the cloud • Build out the edge in fabs	• Unlock your data and systems • Remember that not all data are relevant • Establish rigid data governance	• Design use cases for scale from the beginning • Demand use of best-known methods across sites • Ensure smooth integration of use cases into digital workflows	• Conduct development sprints and encourage rapid learning

Source: McKinsey

- **What are the barriers to implementing AI?**
  - **Data management**
  - **Instrumentation**
  - **Expertise**
- **AI will likely only be "back-filled" into processes if/where high efficiency gains can be realized**
  - **Control, fault detection, preventive maintenance**
- **Most AI applications will be in new fabs and state-of-art processes/tool sets where it is effectively "built-in"**
- **Much of the AI will be happening "in the background" in a more integrated fashion and upstream in the supply chain**

Chip Market

- The global semiconductor market is projected to grow from $452.25 billion in 2021 to $803.15 billion in 2028 at a CAGR of 8.6% in forecast period, 2021-2028
- Chips for AI represented only a few percent of the total market in 2020 but are projected to grow to over 10% of the total by 2028
- Chips for AI are projected to grow 5x faster than the general chip market



Summary

- AI, Big Data and Machine (Deep) Learning are currently generating quite a buzz in CMP, semiconductor manufacturing and society in general
- Due to the complex and interactive nature of CMP, AI has the potential to address some of the most vexing issues with CMP
- AI seems to have taken hold, enabled by the maturation of computing power, storage capability and the digitization of information
  - But, in a note of caution, AI has experienced boom and bust cycles of interest and funding in the past
  - It seems that this time AI will likely live up to the promise
- The deeper the learning, the blacker the box
  - AI is a "brute force" computational approach taken to the extreme
  - The basis of decision making can be lost in the depths of the algorithm
- Regardless of whether or not AI changes the life of any given CMP process engineer, it seems poised to drive a large portion of the chip market in the next decade, so it will increase the number of wafers going through the fab in addition to the technological requirements