Making Semiconductors for the AI Future: DFMsim

Kevin Kimberlin
Chairman, Spencer Trask & Co.

ABSTRACT

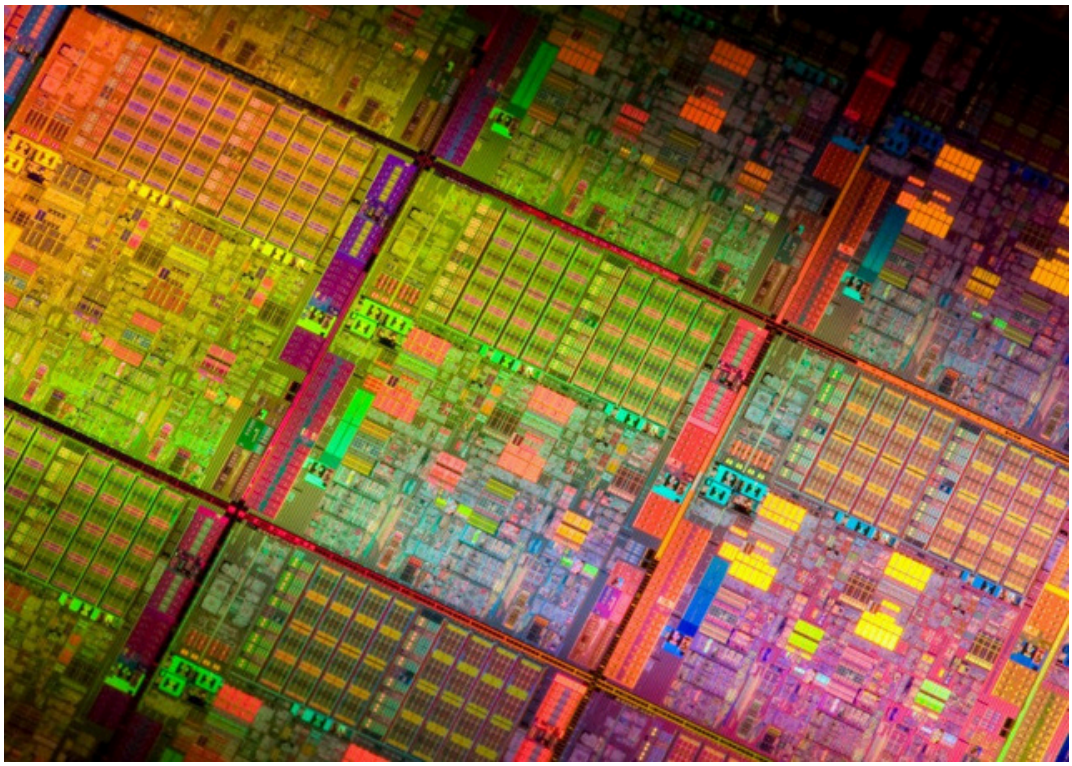
DFMsim Inc., co-founded by Spencer Trask & Co., introduced the first AI-driven solution in semiconductor manufacturing – a feat the firm accomplished by simulating the design and production of integrated circuits. Applied Materials, in its quest to enhance chip yield standards, acquired DFMsim and integrated its simulation technology into the AIx platform. As a global leader providing the materials, equipment, and engineering solutions for nearly every chip produced today, Applied Materials is now leveraging DFMsim's simulations to drive the Age of Intelligence.

In the bustling world of tech innovation, where the frenzied dash for the next breakthrough often overshadows the journey, a festive greeting from Anantha Sethuraman, CEO of DFMsim, to Kevin Kimberlin, offers a glimpse into the personal side of technological revolutions.

> *"Hello Kevin- Merry Christmas to you and the family. We are all doing well. Our DFMsim technology has been integrated into the AI platform of AMAT called AIx.*
>
> *We started the first AI company in semiconductor manufacturing! One more feather in your cap.*
>
> *The whole team is still together, and we have added more people. Things are going well. Anantha."*

This message, brimming with warmth and pride, serves as a prelude to a story of innovation, collaboration, and foresight that is quietly changing the semiconductor industry.
The Nanoscale Challenge:

Operating at the bleeding edge of physics, modern integrated circuit manufacturers face unprecedented challenges as transistors approach atomic scales. Moore's Law, the doubling of transistor density every 18 months, has slowed to a three-year cycle due to diminishing yields amid the immense complexity of manufacturing at nanoscale dimensions.



In terms of the sheer number of components at this minuscule scale, ICs are strong contenders for the most complex products ever made.

To appreciate the scale of the challenge, consider that state-of-the-art chips contain over 4 trillion transistors, each smaller than bacteria. The manufacturing processes involve over 1,000 precisely controlled steps, with tolerances measured in atoms. For the $600 billion semiconductor industry ($1 trillion in revenues by decade's end; McKinsey estimate), this intricacy manifests in escalating costs from yield challenges with each new generation.

The Genesis of DFMsim

The solution to this monumental problem emerged from a confluence of visionary minds. After Regis McKenna, the marketing genius behind Apple and many other Silicon Valley successes, resigned as partner at Kleiner Perkins, he started a venture fund with Kevin Kimberlin as his largest investing partner. Its managing partners, Amiel Kornel and Steve McGrath, joined Spencer Trask & Co. and introduced Kimberlin to Raj Raheja.

Raheja, who built the first U.S. fab in 1967 for IBM in Fishkill, NY, had an incredible solution for the industry. He wanted to create a virtual factory to simulate the entire semiconductor design and manufacturing process. This audacious idea took root when he and Spencer Trask & Co. formed DFMsim Inc., supported by a $3 million investment from Trask and Tom Caulfield, now CEO of GlobalFoundries.

Building the Dream

Under the leadership of Trask and Raheja, DFMsim assembled a team with over 120 years of combined experience making semiconductors, including CEO Anantha Sethuraman. Over the next four years, the team did the near impossible by developing 300 simulation modules, each addressing a specific aspect of the design-to-manufacturing process. A big break came in 2008, as board member Amiel Kornel recalled, when, "We acquired GPU technology to deliver 3-D simulations using NVIDIA chips, an industry first that transformed silicon design visualization." This move presaged the critical role that GPUs would play in the future of AI.

DFMsim CEO Anantha Sethuraman

The Power of AI-Driven Simulation

In its simulations, DFMsim uses real manufacturing data rather than relying on theoretical equations, another major innovation. With this real data, chip designers optimized for any specific manufacturing line, each as unique as a fingerprint, where their chip would be made, thus bridging the long-standing gap between chip design and production. The dramatically reduced process variability, and improved plant performance.

This groundbreaking work is protected by the numerous patents by its employees, including inventions in:

> Process simulation frameworks (US patent 20090106002A1), Semiconductor process control (US patent 10579041B2), Predictive modeling in semiconductor processes (Patent number 11187992), and Data management and mining to correlate wafer alignment, design, defect, process, tool, and metrology data (US Patent 11088039).

(12) **United States Patent**
Nurani et al.

(10) **Patent No.: US 10,579,041 B2**
(45) **Date of Patent: Mar. 3, 2020**

(54) **SEMICONDUCTOR PROCESS CONTROL METHOD**

(71) Applicant: **Applied Materials, Inc.**, Santa Clara, CA (US)

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(73) Assignee: **APPLIED MATERIALS, INC.**, Santa Clara, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 4 days.

(21) Appl. No.: **15/829,626**

(22) Filed: **Dec. 1, 2017**

(65) **Prior Publication Data**

US 2019/0171181 A1 Jun. 6, 2019

(51) **Int. Cl.**

G05B 19/406	(2006.01)
H01L 21/67	(2006.01)
H01L 21/66	(2006.01)
G06N 20/00	(2019.01)

(52) **U.S. Cl.**

CPC ***G05B 19/406*** (2013.01); ***G06N 20/00*** (2019.01); ***H01L 21/67115*** (2013.01); ***H01L 21/67184*** (2013.01); ***H01L 21/67248*** (2013.01); ***H01L 21/67253*** (2013.01); ***H01L 21/67276*** (2013.01); ***H01L 22/12*** (2013.01); ***H01L 22/20*** (2013.01); *G05B 2219/45031* (2013.01); *H01L 21/67167* (2013.01)

(58) **Field of Classification Search**

CPC G05B 19/406; G05B 2219/45031; G06N 20/00; H01L 21/67248; H01L 21/67253;

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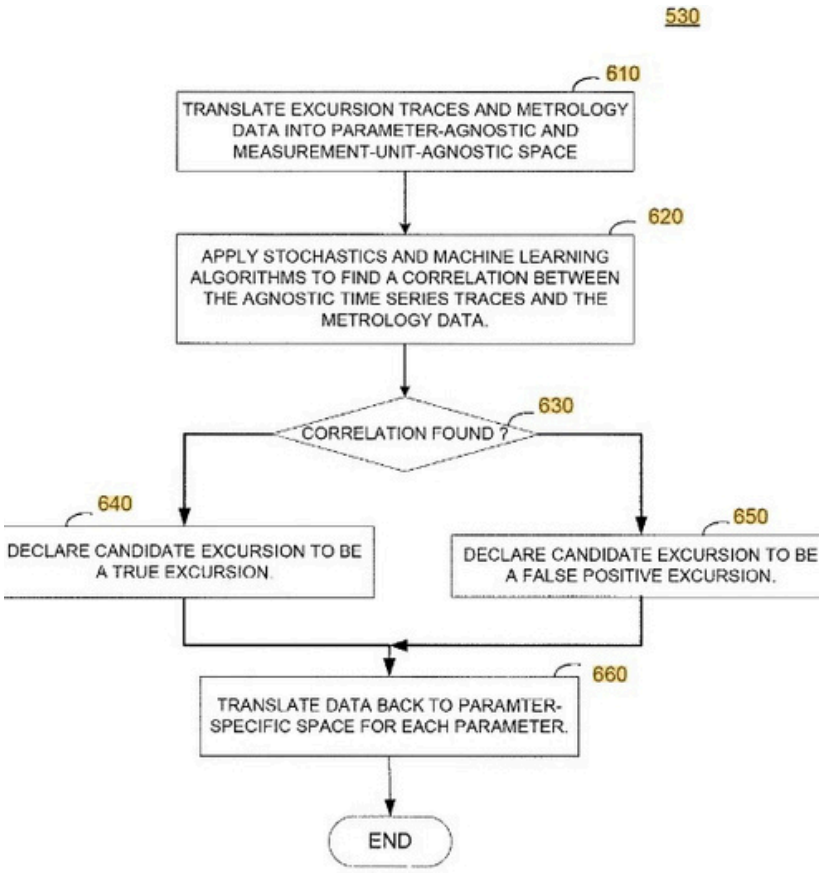
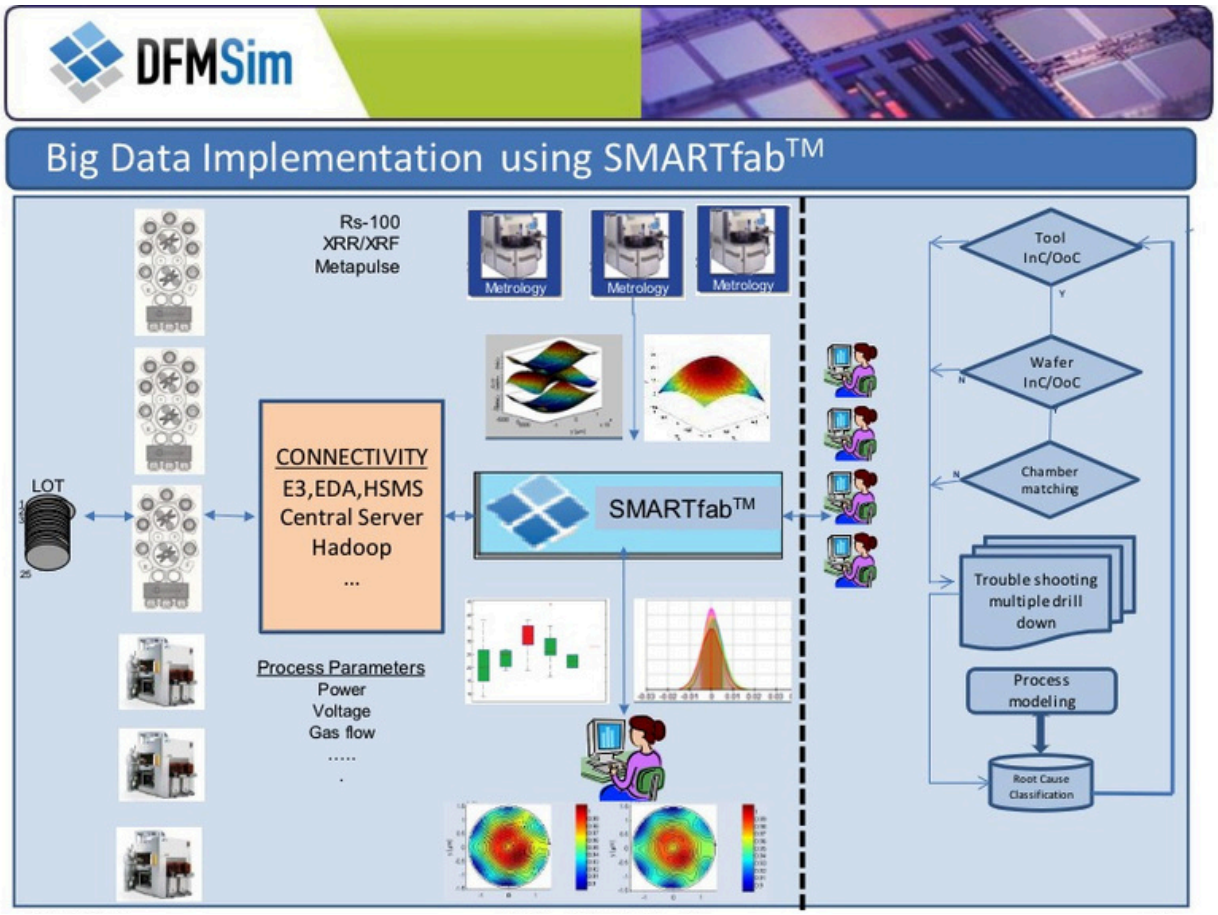
(57) **ABSTRACT**

Implementations described herein generally relate method for detecting excursions in time-series traces received from sensors of manufacturing tools. A server extracts one or more time series traces and metrology data collected from one or more sensors associated with one or more manufacturing tools configured to produce a silicon substrate. The server identifies one or more candidate excursions of the one or more time series traces by comparing the one or more time series traces to one or more traces associated with a working reference sensor. The server verifies that a candidate excursion of the one or more candidate excursions is a true excursion based on correlating the one or more time series traces to the metrology data. The server instructs a manufacturing system to take corrective action to remove the selected true excursion.



DFMsim Anantha's Machine Learning Algorithms: (see step 620)

Incorporated into the flagship Virtual Factory simulation solutions, these innovations were called SMARTdepo, SMARTlitho, and SMARTyield (SMART is the acronym for Simulation with Manufacturing and Analysis in Real Time). As the first firm to put the entire chip design and production process in a virtual environment, DFMsim also became the first AI company in semiconductor manufacturing.



Integration into Applied Materials

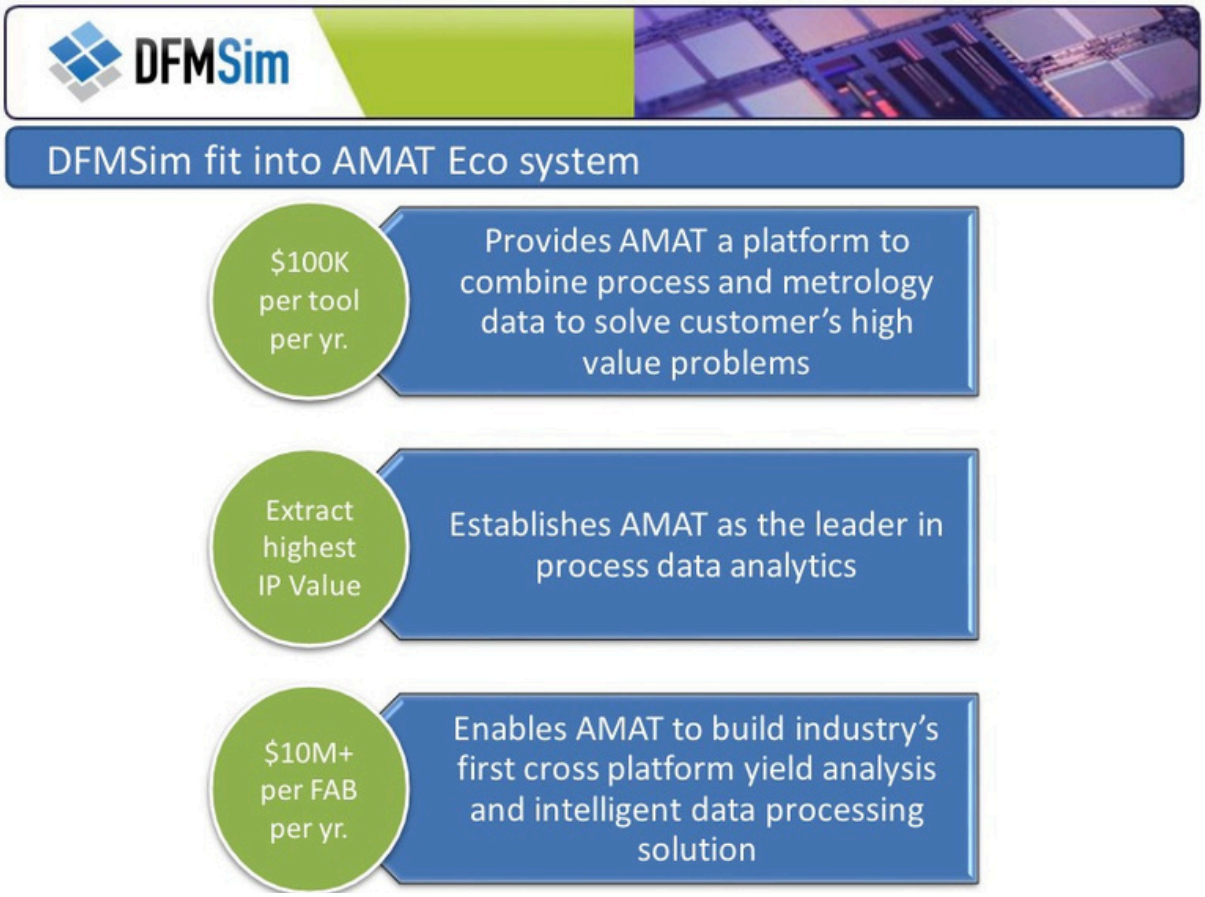
Despite positive reviews from early customers – Cypress, Elmos Semiconductor and AMAT – DFMsim faced a significant hurdle in the notorious secrecy of the semiconductor industry. As Sethuraman explained, "Foundries were extremely reluctant to share their proprietary process information, which was crucial for our simulations."

Kevin Kimberlin, a key figure in the DFMsim journey, elaborated: "Although we solved their fundamental problem, we found the industry's 'only the paranoid survive' mentality as our biggest obstacle. We needed to partner with a firm that had the trust of all the major players."

That turned out to be Applied Materials, the firm that provides materials, engineering solutions, and equipment used to produce virtually every chip in the world.

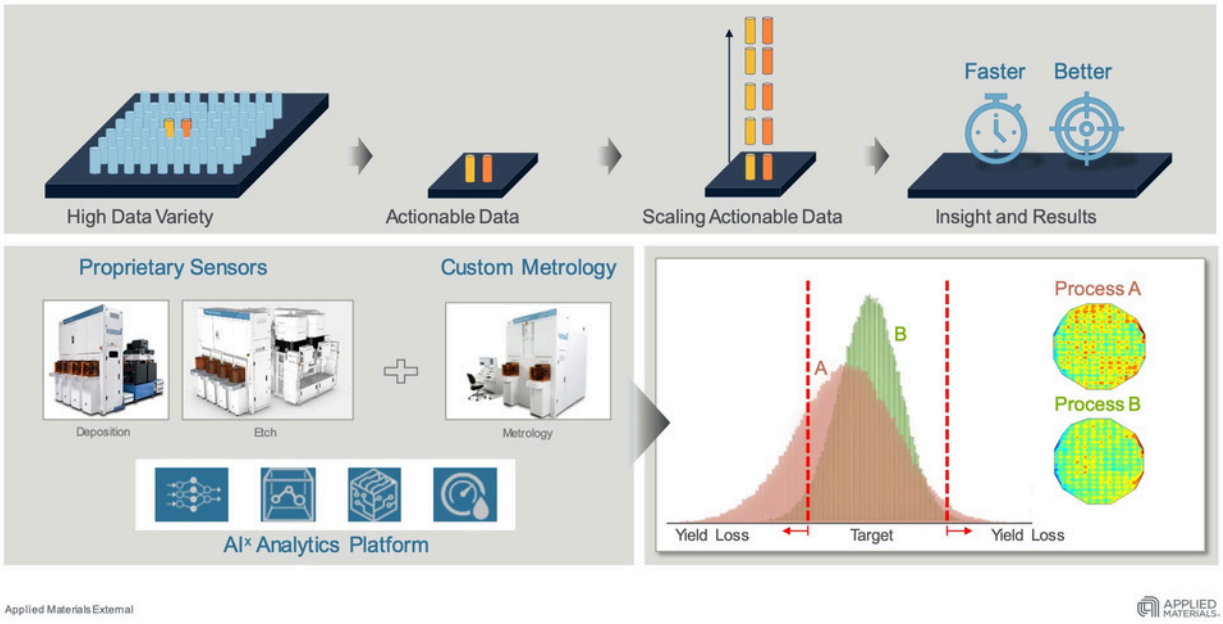
Kornel laid out the path into the inner sanctum of Applied Materials. "In 2012, we demoed the first SMART module at AMAT and installed V1.0 in June 2013. Within a year we were "becoming an integral part of AMAT software.."

Convinced by this division-level proof point, Tom Caulfield, now running GlobalFoundries, the third largest chip foundry, introduced DFMsim to the CEO of Applied Materials. Sethuraman's pitch was compelling: "With DFMsim, Applied could build the industry's first cross-platform intelligent data process solution to make AMAT the leader in process data analytics."



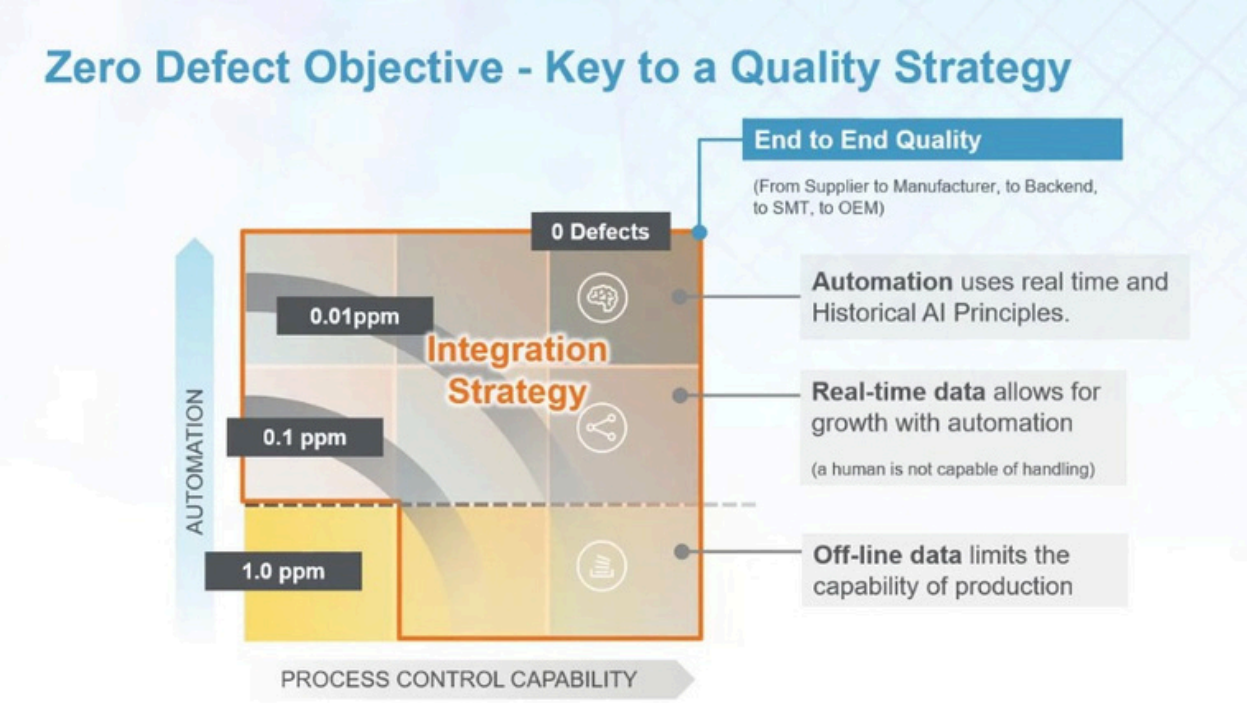
The AIx Revolution

That pitch and our technology worked so well that in 2015, Applied Materials acquired DFMsim, advised by Needham & Co. As Sethuraman wrote to Kimberlin, "DFMsim technology has been integrated into the AI platform of AMAT called AIx."



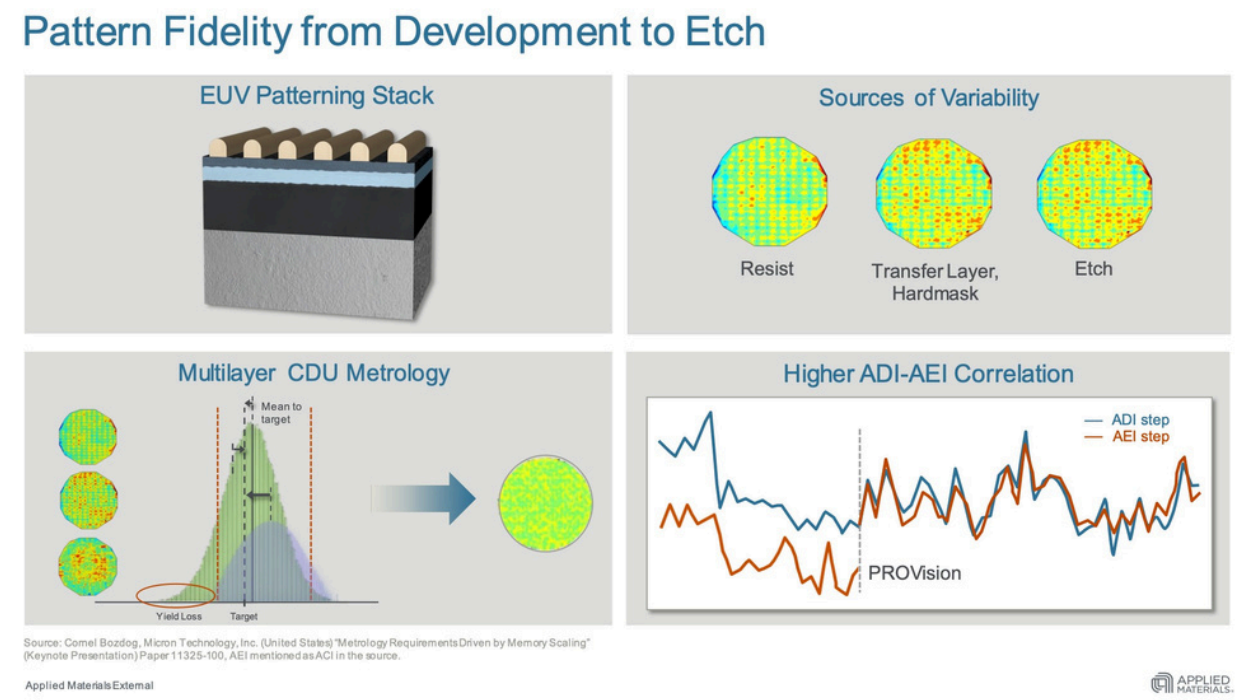
The AIx (Actionable Insight Accelerator) platform is a powerhouse in making semiconductors with capabilities including:

- Angstrom-Level Metrology: In-vacuum and inline systems capable of over one million 3D wafer measurements per hour, with precision at the angstrom (0.1 nanometer) scale.
- Real-Time Process Optimization: AI algorithms analyze data in real-time, suggesting process adjustments to maximize yield and performance.
- Predictive Maintenance: Machine learning models predict equipment failures before they occur, minimizing costly downtime.
- Design for Manufacturability (DFM): Integrated simulation tools allow chip designers to optimize their designs for specific manufacturing processes.
- Virtual Prototyping: Comprehensive simulation of entire chip designs, including thermal, electrical, and mechanical properties.



Using AIx, engineers can obtain over one million 3D wafer measurements per hour to make nanometer-scale assessments. Crucially, as seen in an Applied post, “The AIx platform works across all Applied Materials process equipment. AIx uses the power of big data and AI to give customers better outcomes at every stage of the semiconductor technology lifecycle….from R&D to ramp.”

The CEO of Applied Materials, Gary Dickerson, rated one of the “World’s Best CEOs” by Barron’s puts the lifecycle in perspective: "This year, there'll be about 14 zettabytes of data generated, that's 10 to the power of 21. That's up 150 times over just a six-year period of time. Ten trillion dollars of economic value being created this decade, and we're still in the early innings of that transformation."



Industry Impact and Future Prospects

The impact of the DFMsim-Applied Materials combination extends far beyond improving chip yields as we enter the angstrom era of chip design. The AIx ability to simulate and optimize at nano-scale will become ever more essential for advances in quantum computing, neuromorphic chips, and innovations such as IBM's size-of-a-fingernail 50 billion transistor chip, or Cerebras Systems' laptop- sized chip, which holds a staggering 4 trillion transistors. The improved yields enabled by AIx are crucial for specialized machine learning and artificial intelligence GPUs.

The journey of DFMsim, from a bold startup idea to a cornerstone of the world's leading semiconductor supplier, exemplifies the transformative power of AI and simulation in solving the most complex challenges facing "the world's most important industry," as NVIDIA CEO Jensen Huang calls it.

While we stand on the brink of this new era – the Age of Artificial Intelligence – the technologies pioneered by DFMsim and refined at Applied Materials are not just participating in this revolution – they are actively shaping it – chip design by chip design, fab by fab.

Name of Beneficial Owner	Shares of Common Stock Beneficially Owned Prior to this Offering No. of Shares	%	% of Shares of Common Stock Beneficially Owned After Maximum Offering
Spencer Trask Emerging Technologies Group, LLC and affiliates[1]	2,821,670	19.67	12.8
Raj K. Raheja and Kanak Raheja	2,821,670	19.67	12.8
Signature Property Investment LLC	1,025,500	7.2	1.9
David L. Brown and Nancy E. Budorick	852,856	5.9	2.8
Jeffrey A. Eckmann	825,000	5.7	3.4
Stephen McGrath[2]	72,510	.5	-
Amiel Kornel[3]	72,510	.5	-
Anantha Sethuraman[4]	1,185,779	8	5
Nungavaram S. Viswanathan[4]	120,392	.8	.5
Matthias Frank[4]	90,293	.6	.4
James T. Healy[5]	330,000	2.2	1.4
Directors and executive officers as a group (seven persons)	1,871,484	12.6	7.3

November 6, 2006

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