MARK ROSKER

OFFICE DIRECTOR

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“The startling rate of change which microelectronics is producing in world societies has caused organizations to ponder how long this rate of change can endure and at what level of performance it might end.”

- George Heilmeier

MICROELECTRONICS: END OF THE BEGINNING OR BEGINNING OF THE END?

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The startling rate of change which microelectronics is producing in world societies has caused organizations to ponder how long this rate of change can endure and at what level of performance it might end. This paper traces the historical development of microelectronic capabilities, how this has fueled ever greater capabilities in electronic systems, which, in turn, created the explosive growth of the microelectronics industry.

It is projected that the factors which have produced the growth in microelectronic capabilities will reach maturity within the next decade and electronics may become a low-growth industry within 5 to 10 years following that event unless new revolutionary approaches to microelectronics are developed which bypass foreseen limitations. Some possible paths these revolutionary approaches might take are outlined.

MICROELECTRONICS: WHERE HAVE WE BEEN?

The most important factor in increasing the usefulness of integrated circuits (ICs) has been the increase in the number of devices that can be put on a single chip. The number of devices per chip has been increased by reducing the minimum feature size, increasing chip area, and increasing the efficiency with which devices are packed on the chip. Between 1959 and 1983, minimum feature size decreased 11% per year for a factor of 8.7 increase in devices per sq.cm. per decade; chip area increased 19% per year for a factor of 5.7 increase in devices per chip per decade; and packing efficiency increased by a factor of 2.1 in devices per chip per decade. Together, these three factors produced a 100-fold increase in devices per chip per decade.

The utility of the IC concept was proven during the 1960's but it was during the '70s that the awesomeness of their potential became widely recognized. At the end of the '70s, the NMOS process dominated the IC world, linear scaling of voltage, gate oxide thickness, source drain junctions, and channel doping were adequate to reduce device size, and local oxidation of silicon (LOCOS) was adequate for device isolation. Device delays dominated circuit speed. Interconnect delays were tolerable.

CMOS will dominate the VLSI world of the late '80s and a number of barriers to performance improvement will be approached. The linear scaling of active devices becomes impractical beyond the "1 micron discontinuity" and advancing into "submicron VLSI" requires structural enhancements and improved device and circuit design techniques. With greater device speeds, interconnect delays will dominate circuit response.

MICROELECTRONICS: THE SYSTEM ENABLER

Microelectronics has impacted electronic systems through reducing costs and increasing performance, where performance includes not only the ability of the system to do the job, but also its ability to do it within the allowable space, power, and environmental constraints. With discrete transistors, only mainframe computers are economically justifiable and their costs are dominated by cpu costs. The advent of TTL ICs made the minicomputer feasible and made mainframe cpu cost comparable to mainframe peripheral costs. The LSI circuits of the mid-'70s removed the cpu as a dominant cost item and left mini and mainframe computer purchase costs dominated by peripheral costs with the lifetime costs of mainframes dominated by the costs of software. The advent of the microprocessor and low-cost memory (DRAMs) made the microcomputer feasible with the cost dominated by peripherals. The increased memory for minicomputers resulted in large software systems that dominated life cycle costs and the workstations and terminals made possible by the microprocessor added communications costs to the mainframe as a major expense.

The impact that computer costs and capabilities have on their use can be seen from history. Computers arose out of the pressing need to solve complex engineering problems in WWII and could only be justified for large engineering problems until the IBM 360 provided efficient, low-cost computations which could be economically applied to many facets of business. A major new use for computers, increasing the productivity of indivi-uals, began with the emergence of the personal computer. It will begin in earnest with the advent of the first moderate-priced, high-performance symbolic processor with a stable software system and ease-of-use features. This will be the age of transparent complexity.

As microelectronics has progressed, it has become economically feasible to add features to computers which assist the nonexpert user in operating the machine. As computers become easier for the layman to operate, they become more widely used. The sophistication of user aids has progressed from prompts to icons to expert systems. When the cost of logic and memory has fallen sufficiently, we shall see the appearance of self-learning systems which accumulate

1.1

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MICROELECTRONICS: END OF THE BEGINNING OR BEGINNING OF THE END?

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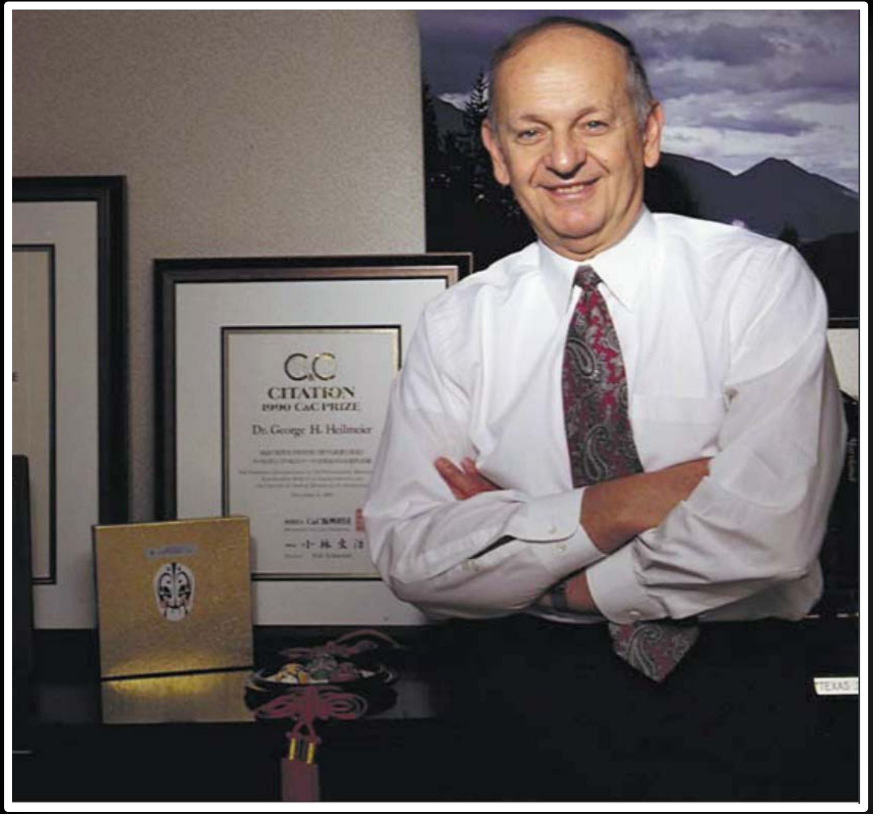


End of the Beginning or Beginning of the End?

"Stagnation of innovation"

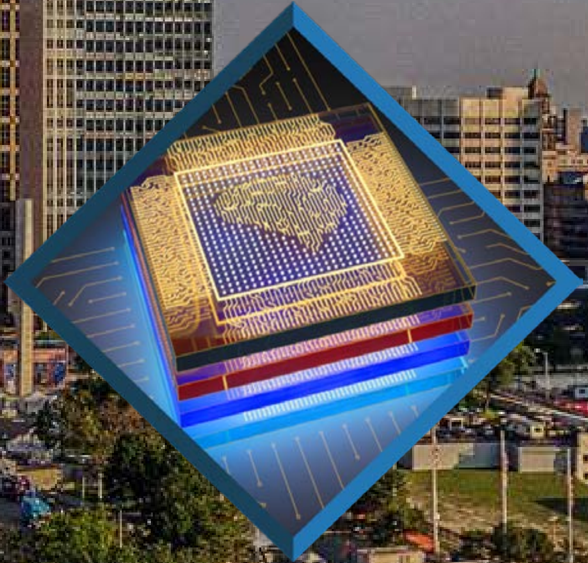
"The gap would narrow between the electronic 'haves' and 'have-nots' and electronic sophistication would become less of a 'differentiator' between societies."

"The U.S. defense strategy of using superior weapon performance to offset the numerical advantages of potential enemies could lose much of its validity."

THE ELECTRONICS RESURGENCE INITIATIVE

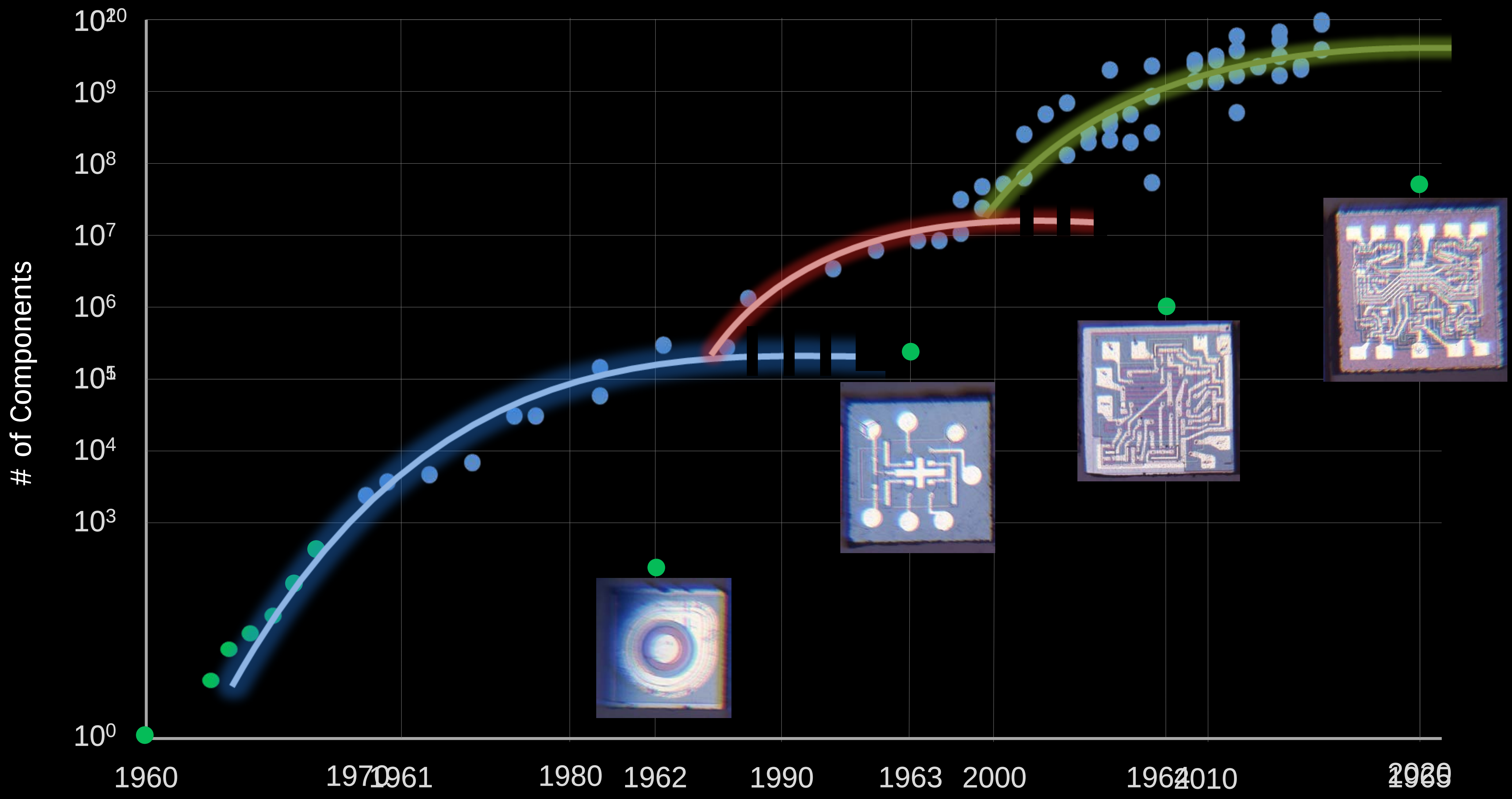
Collaboratively Innovating the 4th Wave of Electronics Development

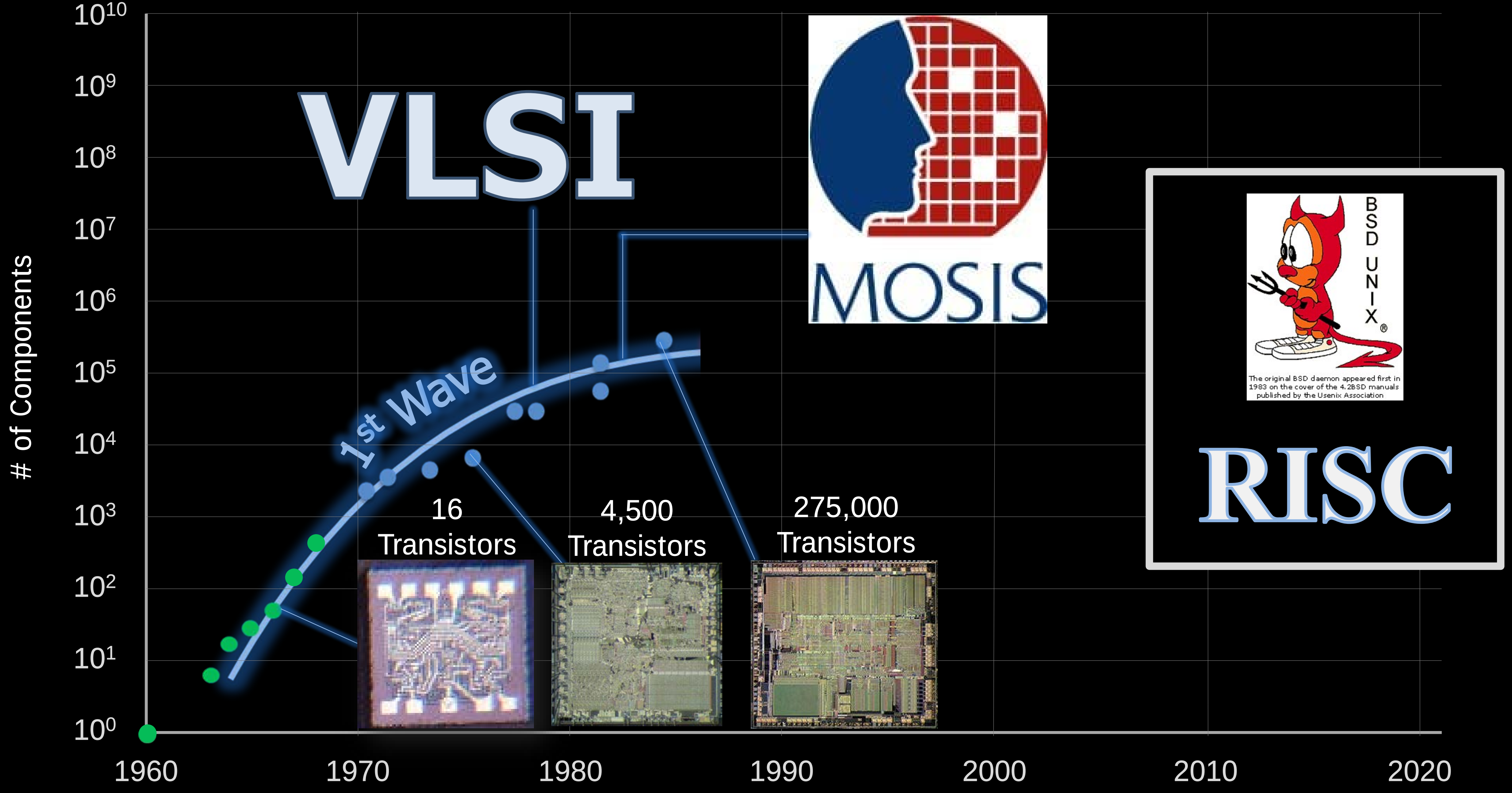
What is the 4th Wave?

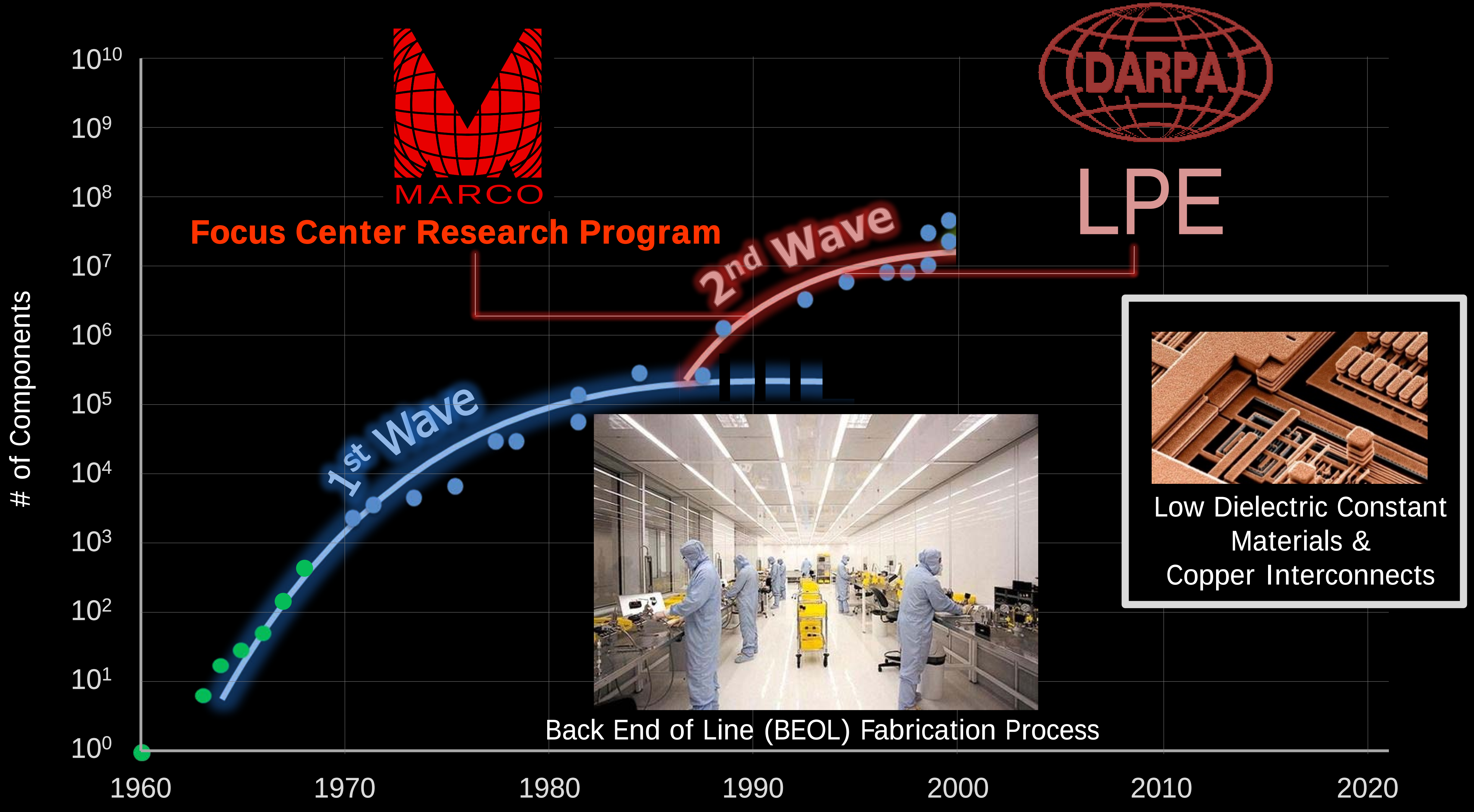


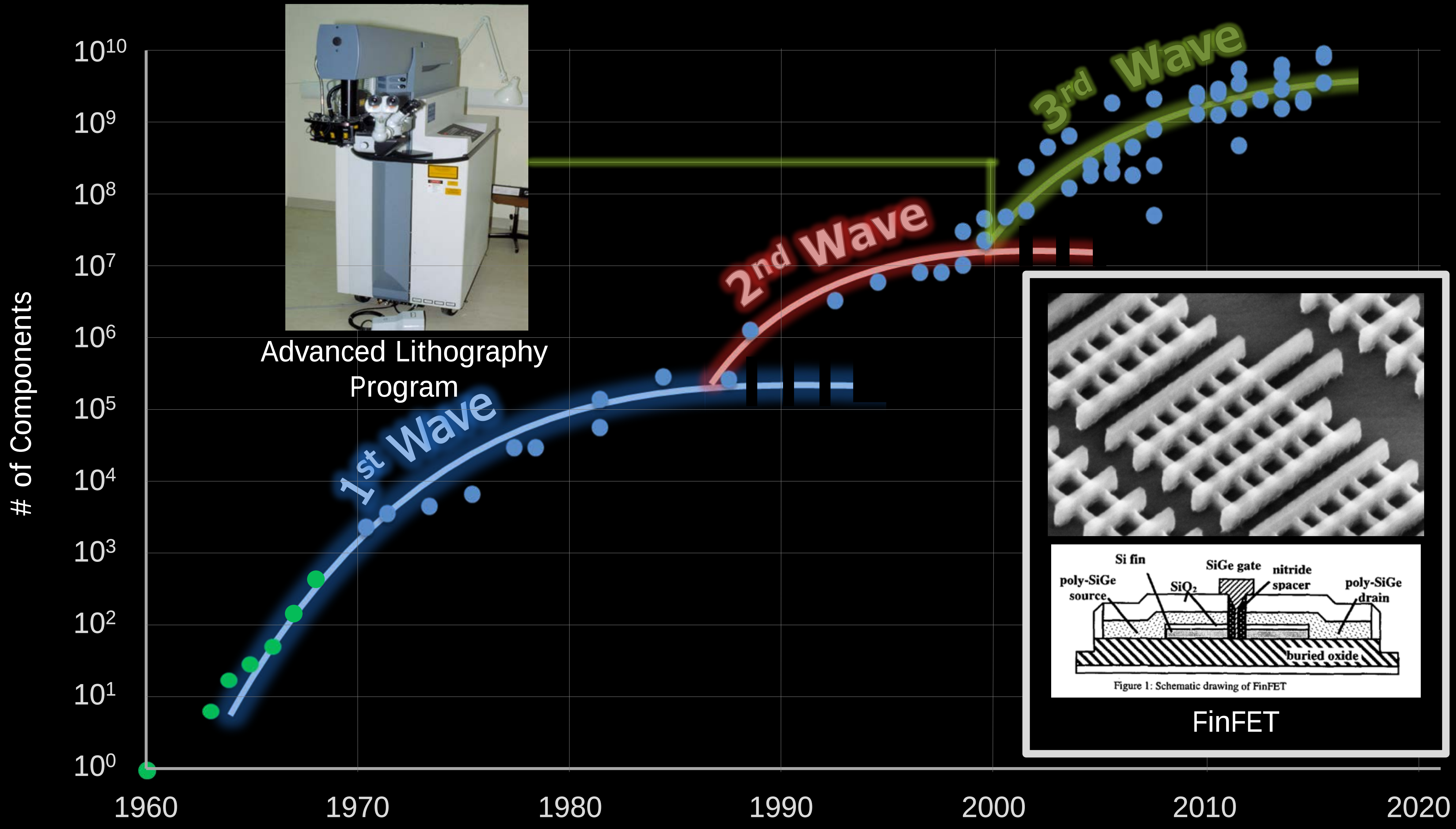
What are the Challenges?

What is the Vision?

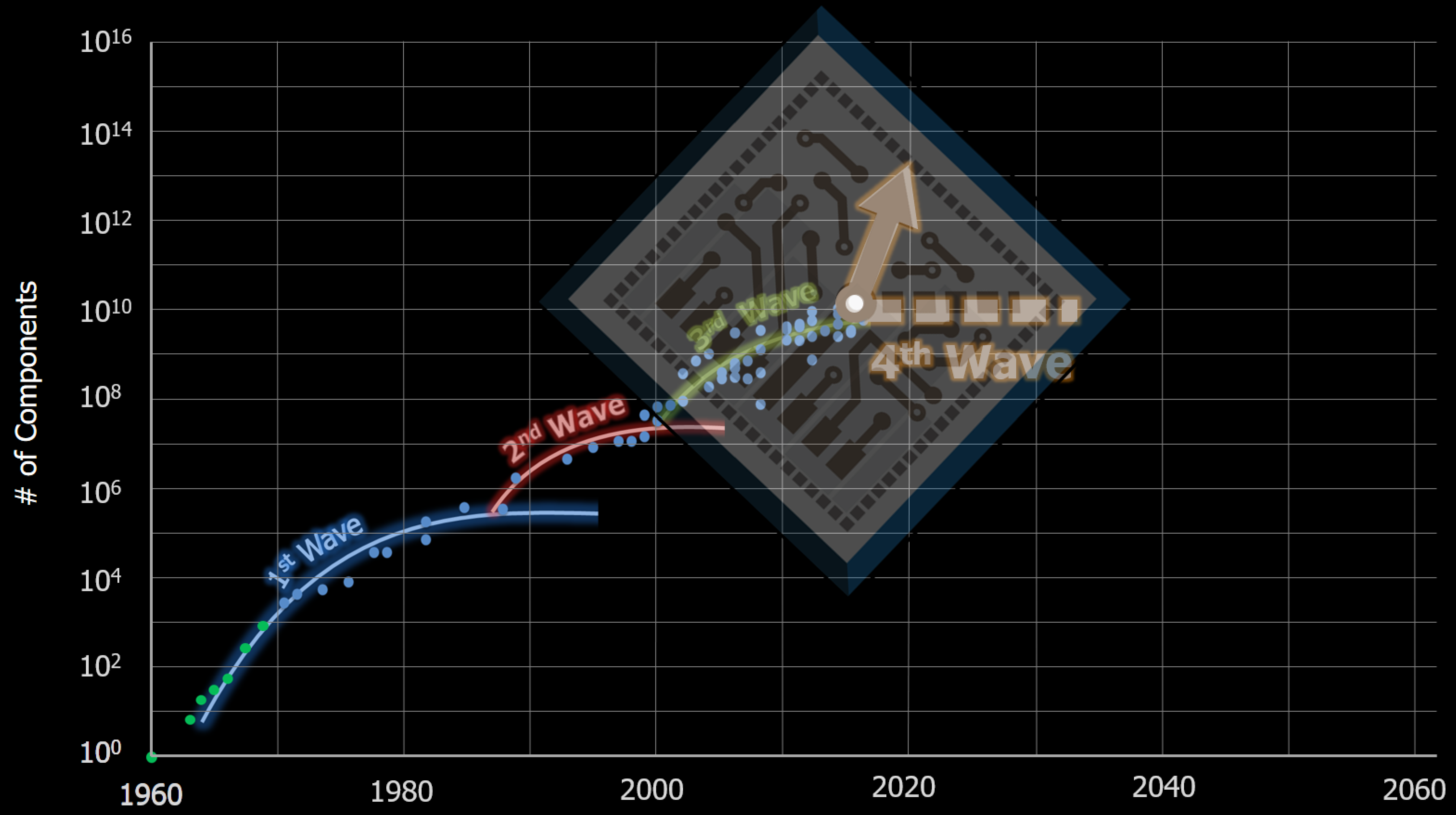

# of Components
10^0
10^3
10^4
10^5
10^6
10^7
10^8
10^9
1960
1970
1961
1980
1962
1990
1963
2000
1964
2010


VLSI
MOSIS
BSD UNIX®
The original BSD daemon appeared first in 1983 on the cover of the 4.2BSD manuals published by the Usenix Association
RISC
1st Wave
16 Transistors
4,500 Transistors
275,000 Transistors
# of Components
10^0
10^1
10^2
10^3
10^4
10^5
10^6
10^7
10^8
10^9
10^10
1960
1970
1980
1990
2000
2010
2020


MARCO
DARPA
LPE
Focus Center Research Program
2nd Wave
1st Wave
# of Components
10^10
10^9
10^8
10^7
10^6
10^5
10^4
10^3
10^2
10^1
10^0
1960
1970
1980
1990
2000
2010
2020
Low Dielectric Constant Materials & Copper Interconnects
Back End of Line (BEOL) Fabrication Process



# of Components
10^{10}
10^{9}
10^{8}
10^{7}
10^{6}
10^{5}
10^{4}
10^{3}
10^{2}
10^{1}
10^{0}
1960
1970
1980
1990
2000
2010
2020
1st Wave
2nd Wave
3rd Wave
Advanced Lithography Program
Si fin
SiGe gate
nitride spacer
poly-SiGe source
SiO2
poly-SiGe drain
buried oxide
Figure 1: Schematic drawing of FinFET
FinFET



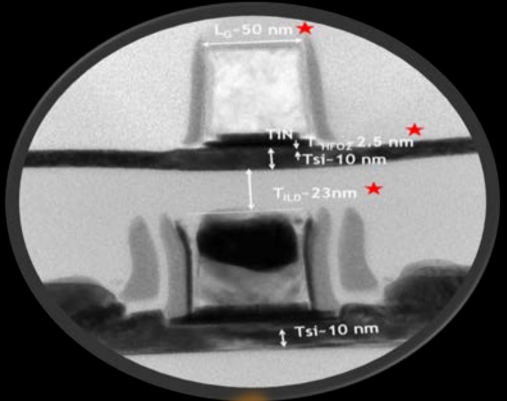
# of Components
10^16
10^14
10^12
10^10
10^8
10^6
10^4
10^2
10^0
1960
1980
2000
2020
2040
2060
1st Wave
2nd Wave
3rd Wave
4th Wave

Challenges

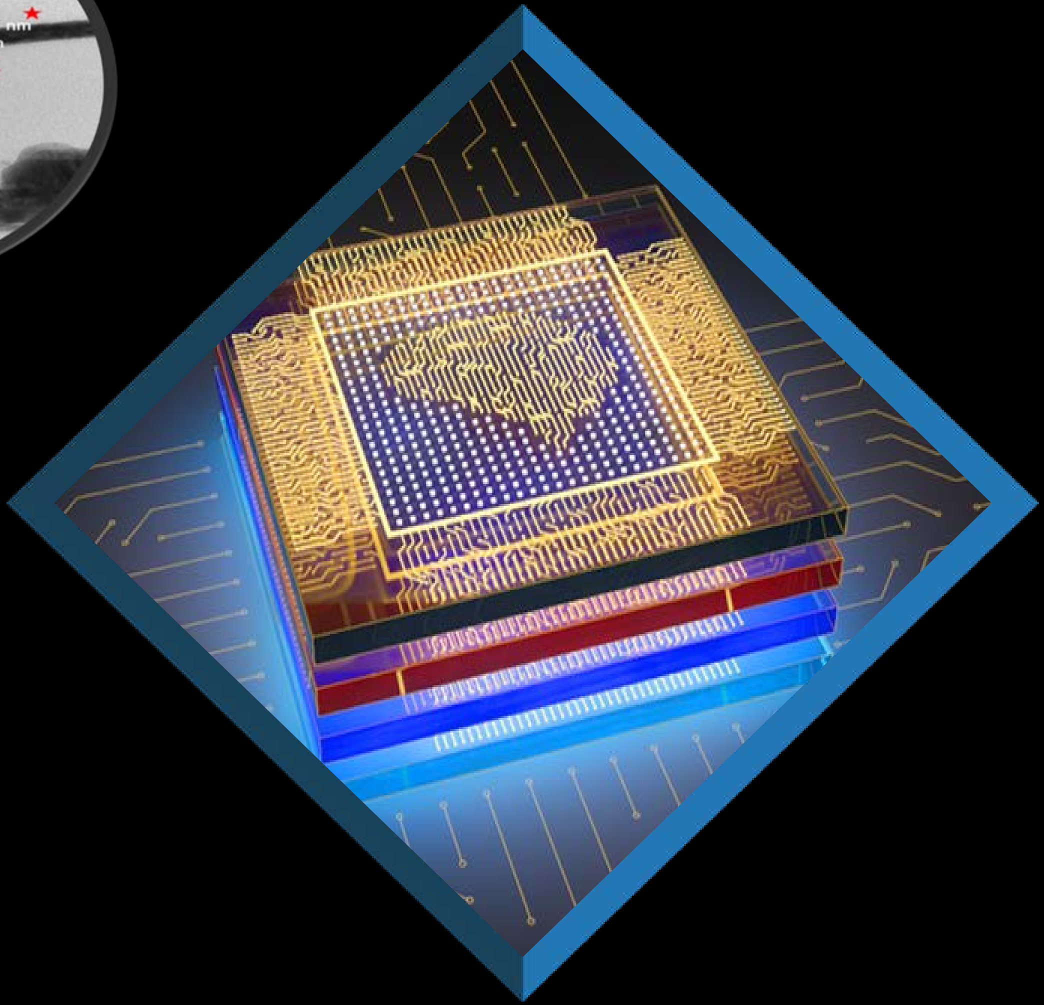
- Driving future circuit performance
- Addressing the data explosion
- Overcoming the skyrocketing cost of integrated circuit design
- Achieving microelectronic security

"Innovation depends in part on anticipating where technology and its applications are going in the future and daring to trust that intuition."

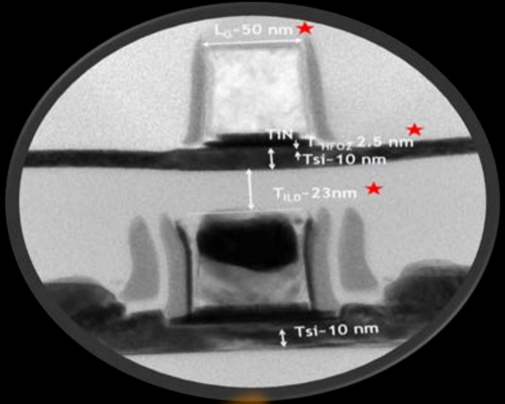
\- George Heilmeier

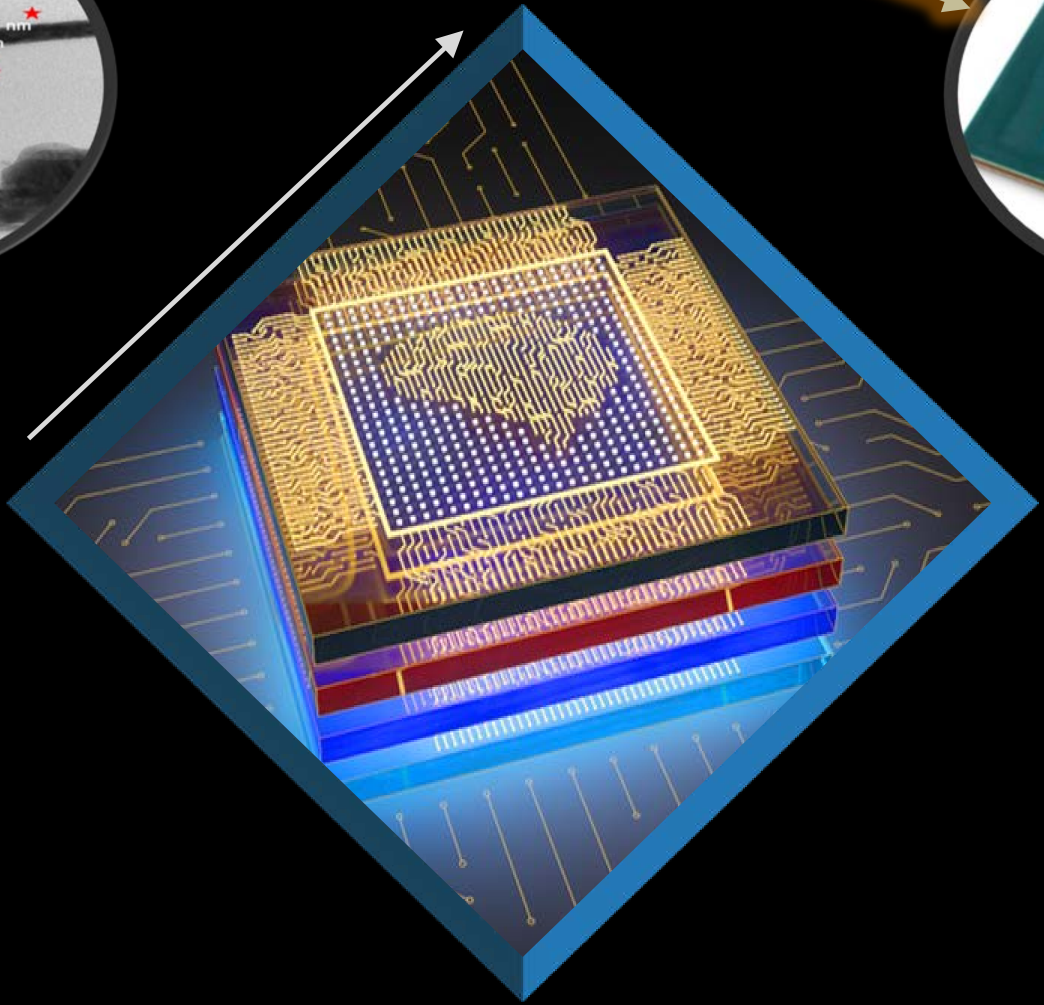


New Materials & Devices

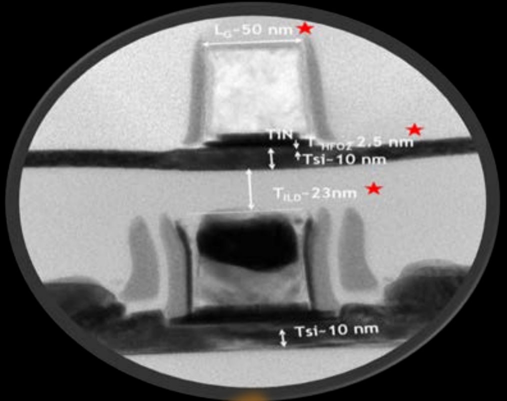


Specialized Functions



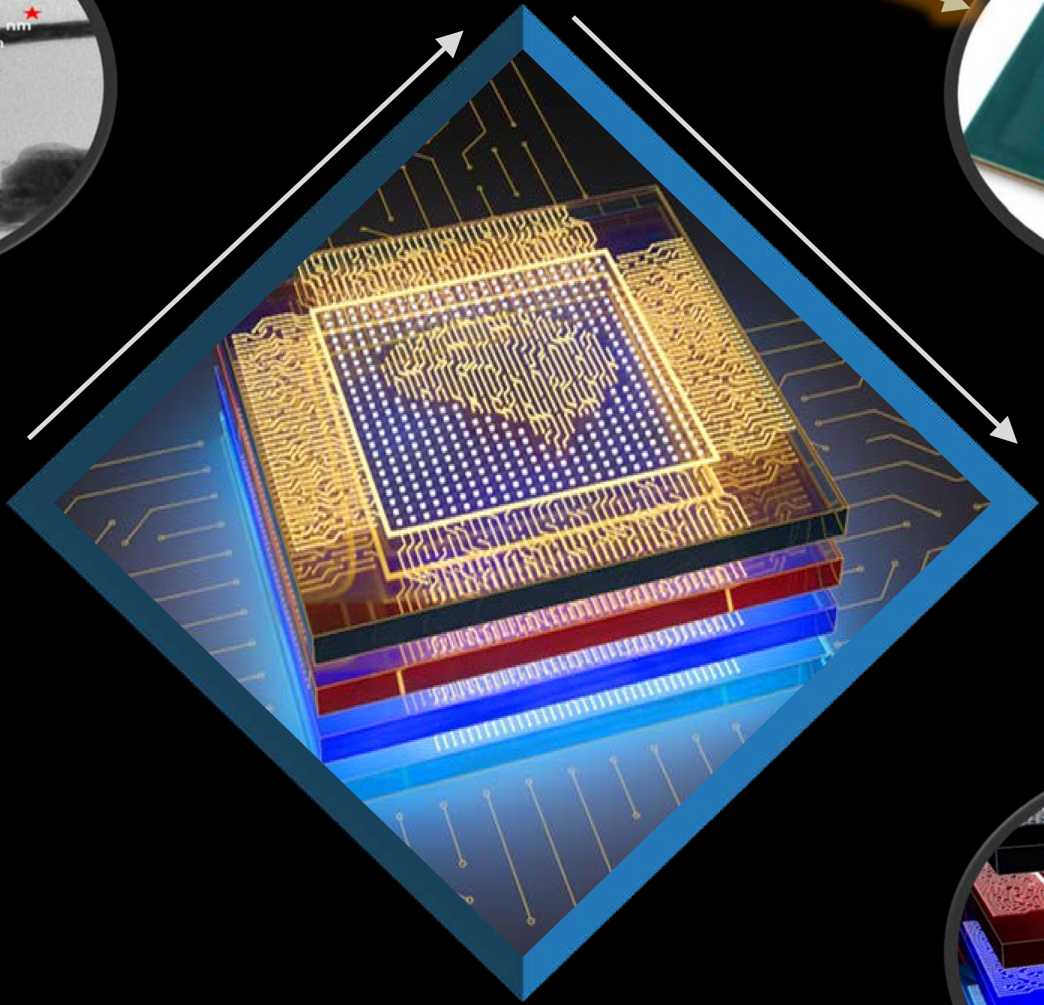


New Materials & Devices

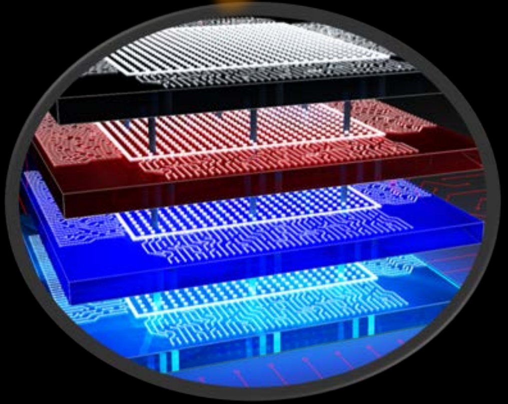


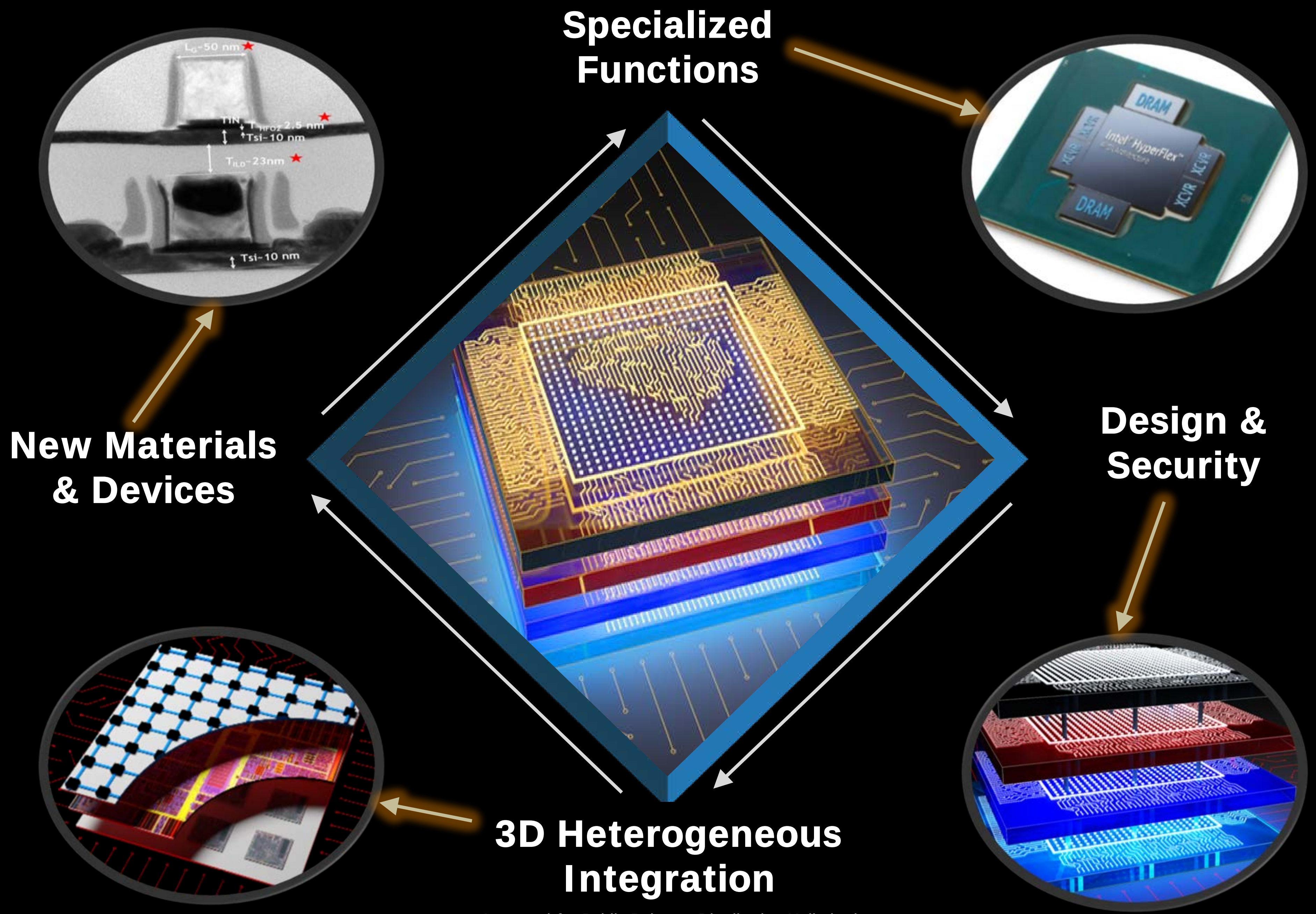
Specialized Functions

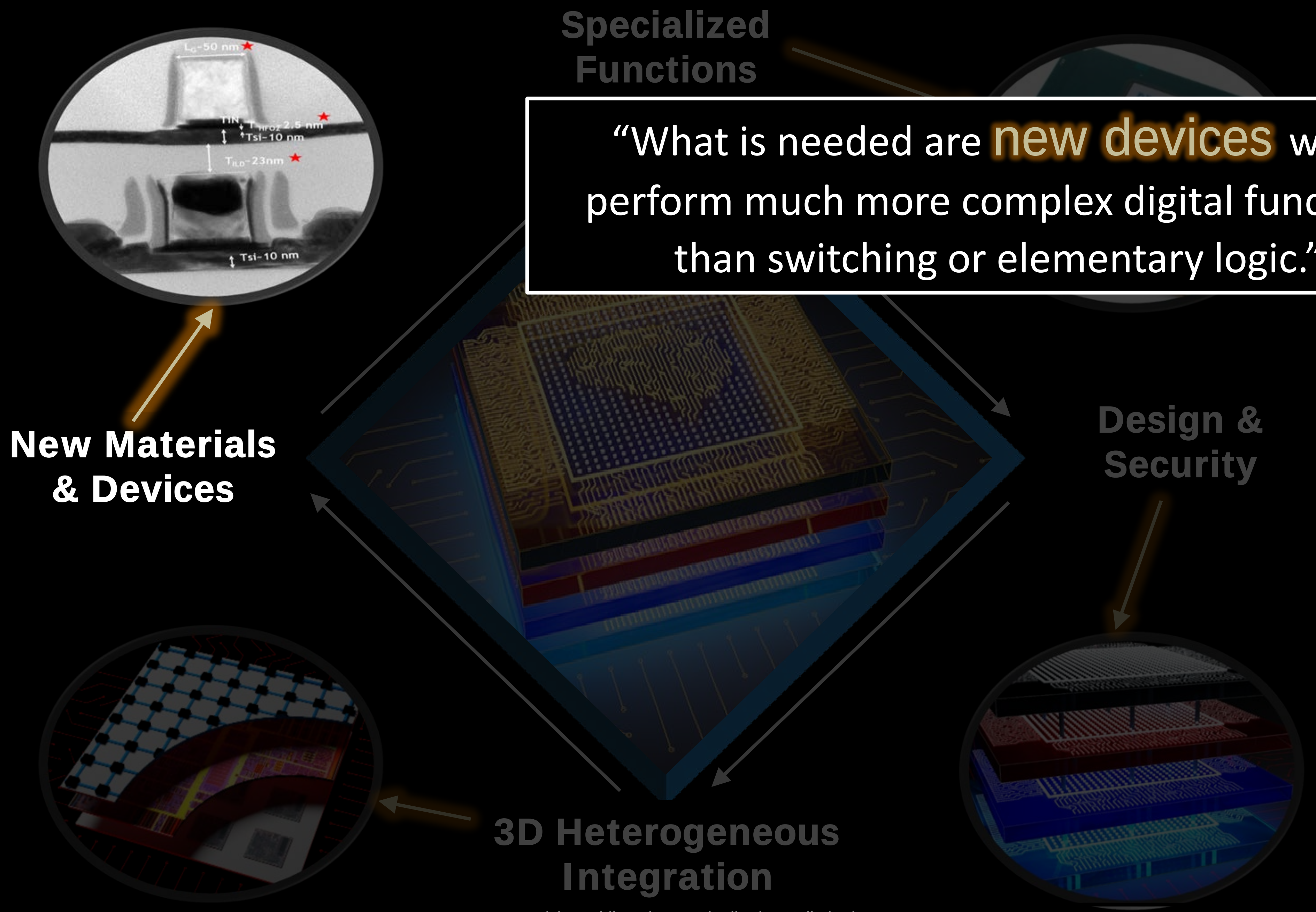
New Materials & Devices



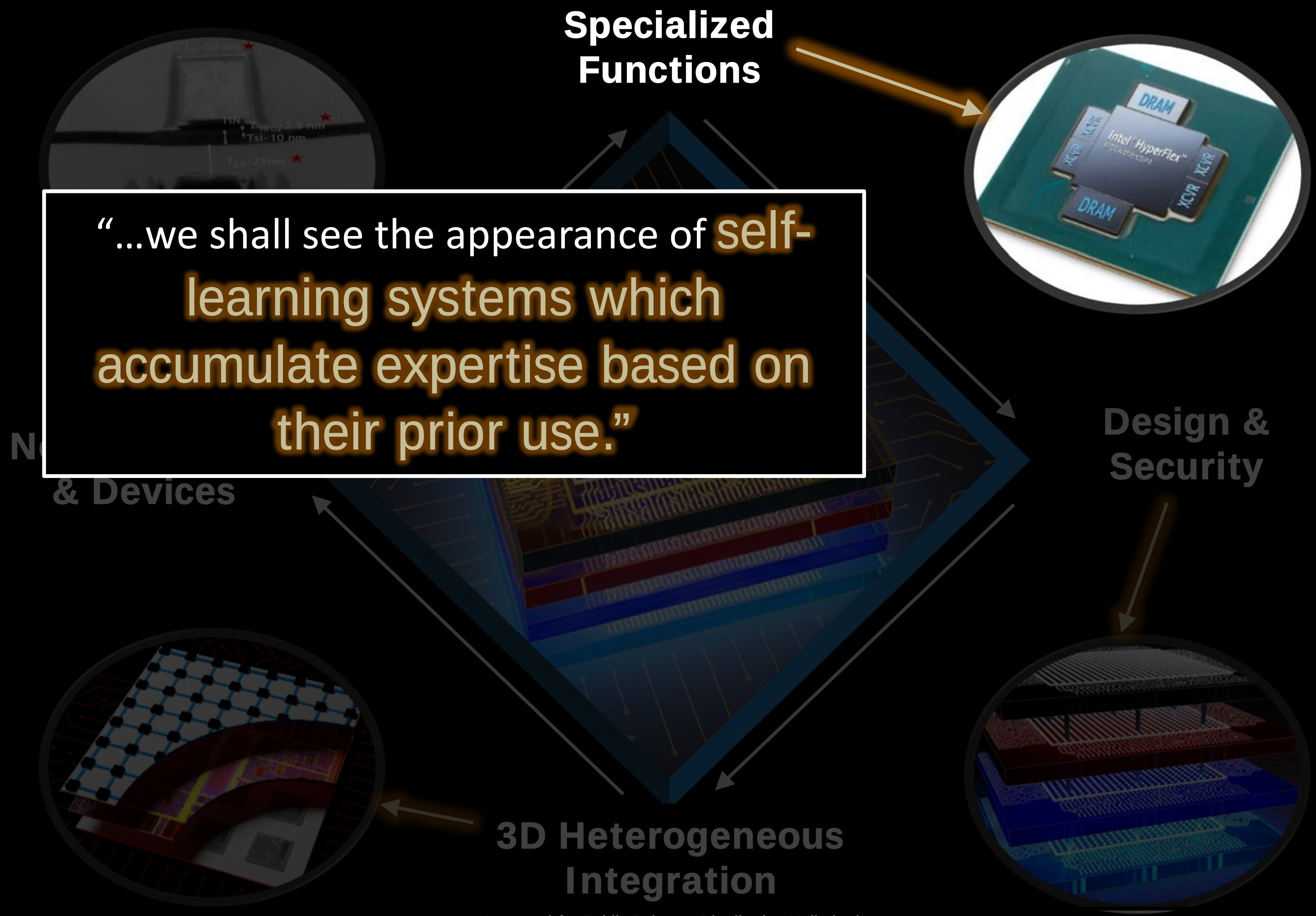
Design & Security



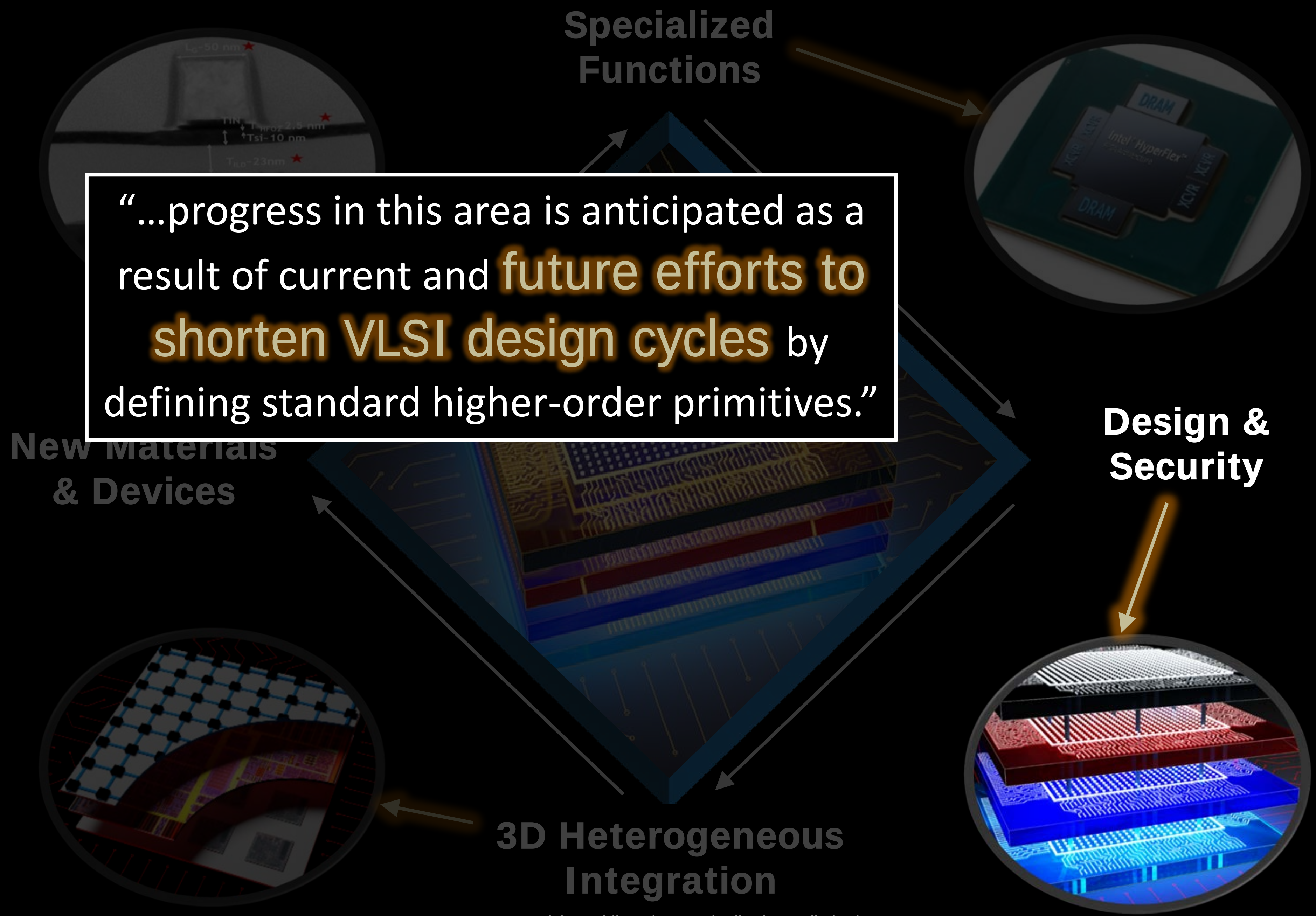

Specialized Functions
Design & Security
3D Heterogeneous Integration
New Materials & Devices
Tsi-10 nm
DRAM
XCVR
DRAM
XCVR

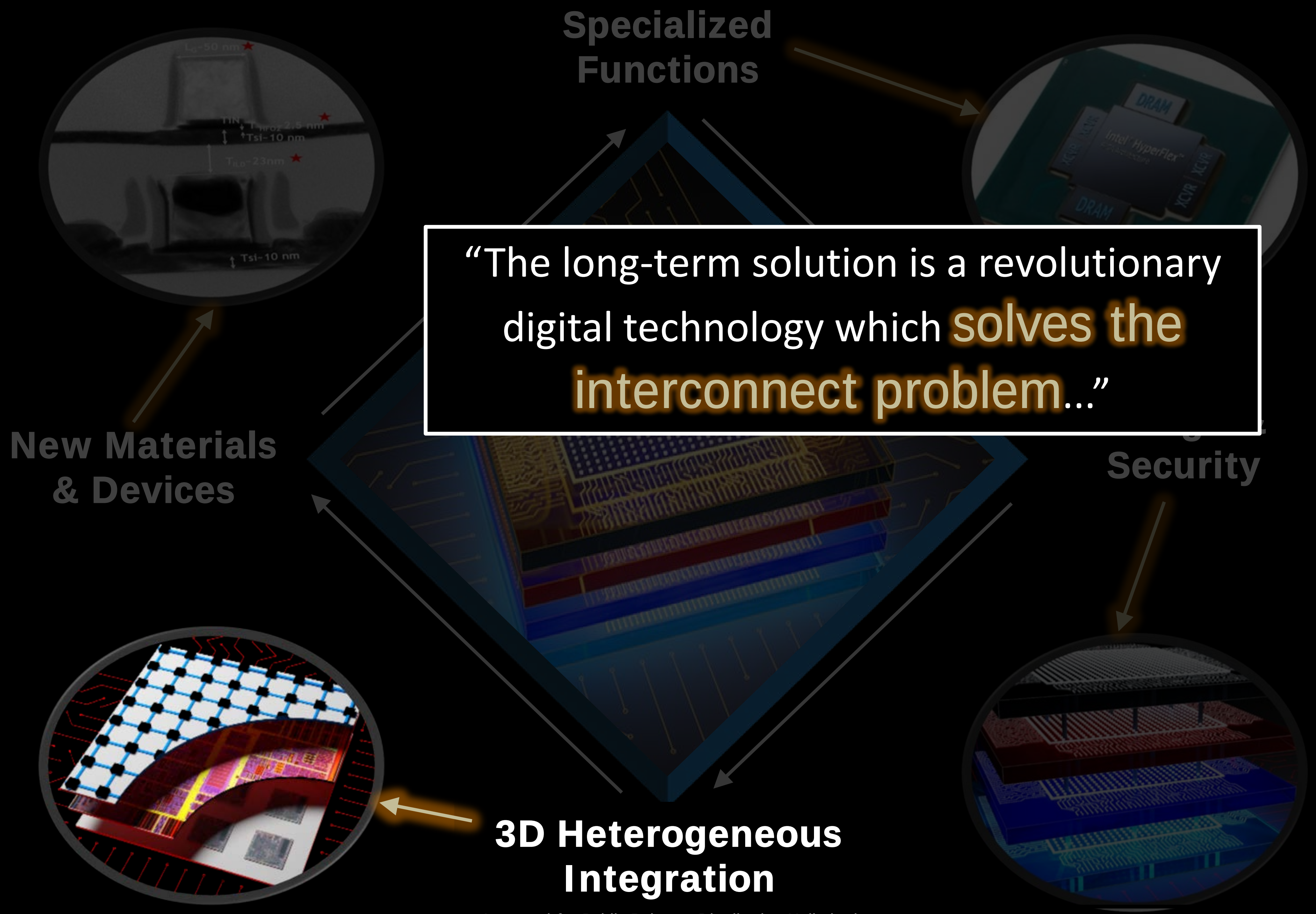


"What is needed are **new devices** which perform much more complex digital functions than switching or elementary logic."



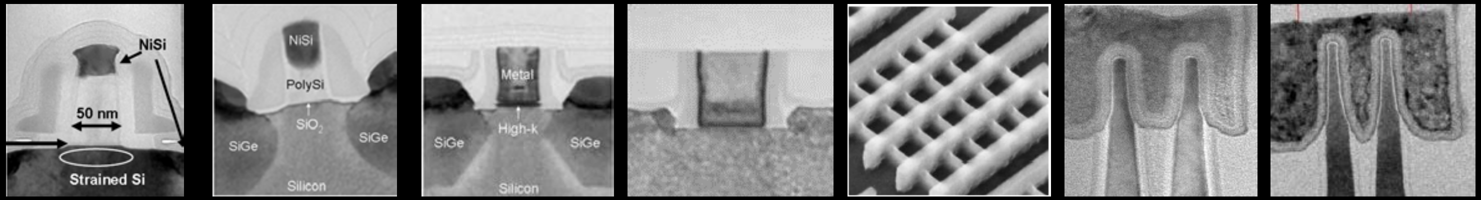
"…we shall see the appearance of self-learning systems which accumulate expertise based on their prior use."


Specialized Functions
"…progress in this area is anticipated as a result of current and future efforts to shorten VLSI design cycles by defining standard higher-order primitives."
Design & Security
New Materials & Devices
3D Heterogeneous Integration
DRAM
XCVR
Intel HyperFlex


Specialized
Functions
DRAM
XCVR
Intel HyperFlex
Tsi-10 nm
“The long-term solution is a revolutionary digital technology which solves the interconnect problem…”
New Materials
& Devices
Security
3D Heterogeneous
Integration

“It appears that minimum geometries for high-volume ICs will saturate in the range of 0.3 to 0.5 microns.”

90nm | 65nm | 45nm | 32nm | 22nm | 14nm | 10nm

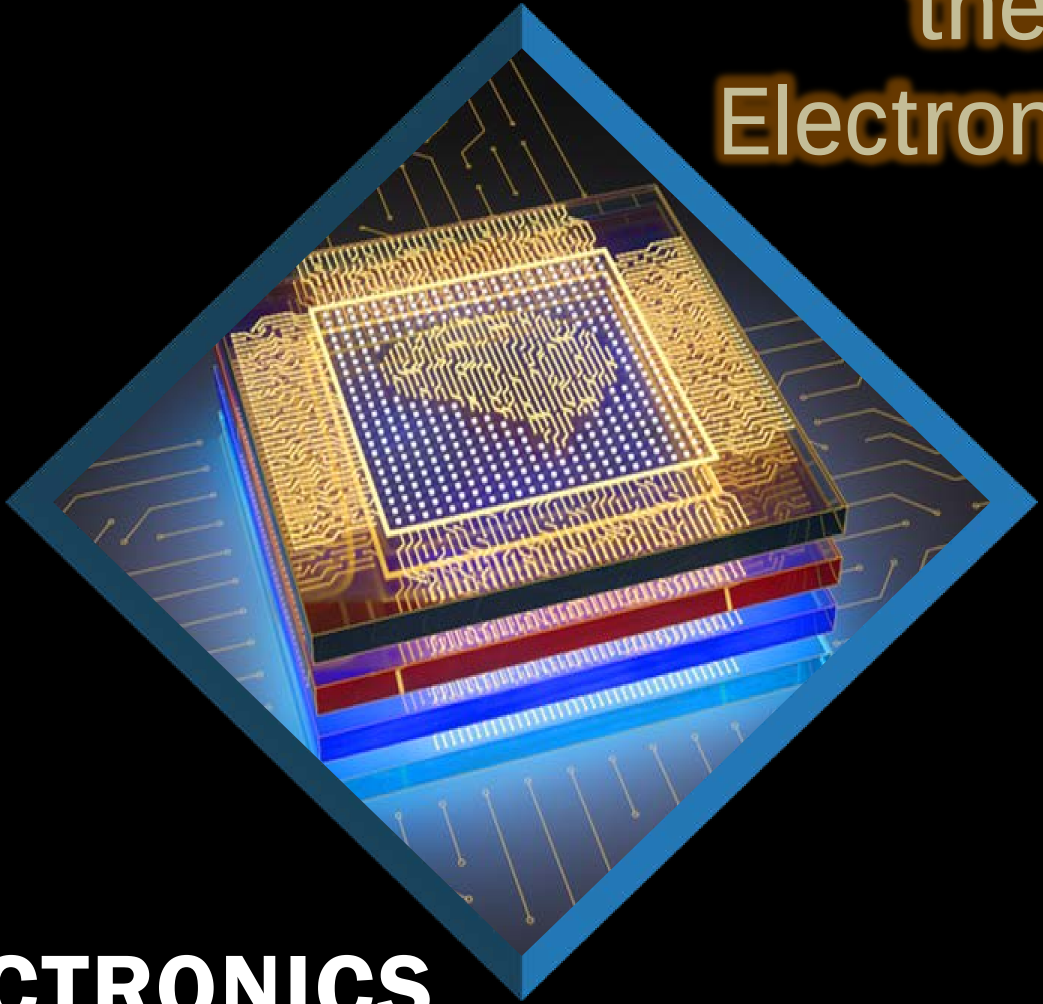


Strained Si (1^{st} Gen) | Strained Si (2^{nd} Gen) | HK/MG (1^{st} Gen) | HK/MG (2^{nd} Gen) | FinFET (1^{st} Gen) | FinFET (2^{nd} Gen) | FinFET (3^{rd} Gen)

Source: Intel

ERI ELECTRONICS RESURGENCE INITIATIVE

Collaboratively Innovating the 4th Wave of Electronics Development



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