Christian Werner Loesch

Technologies Changing Our World

21 Perspectives 2000 bis 2020

PREFACE AND INTRODUCTION

This book is an extended version of the Book ‘ICT Trends and Scenarios´ [1] of 2017. Three more lectures have been added to the volume, covering now the years 2000 to 2020. It is a perspective view and venture that, as far as we know has never been tried before. A more than a duo- decennial overview of the evolution, status and future of ICT transgressing technology to economy, sociology and its way of changing our life personally and as society.

The lectures are designed to satisfy both the interested nontechnical as well as the knowledgeable audience, bridging this gap without compromising on the scientific depth, thus contributing to a better understanding of the present developments and the direction of future developments and the emerging dramatic changes.

It offers a powerful instrument of comprehension and an opportunity to analyze evolution, status, the challenges and expectations over this dramatic period. The multidiscipline approach enables an unbiased view on the successes and failures in technological, economic and other developments, as well as a documentation of the astonishing quality of technological forecasts. It could thus be the basis of a better understanding and prognosis.

Highlighting the dramatic improvement potential of the revolutionary developments from the computer becoming a network and the network becoming a social network or how information technology is even changing the way the world changes.

Many deep-impact innovations are reviewed. How information technology enabled advances in many fields from decoding the genetics to social networks, deep computing, robotics or emerging paradigms as Quantum technologies, Neuromorphic architectures to mention a few. Giving such a holistic view.

The impact literally reaches reaching from on the bottom of the sea beyond the sky, where ICT has enabled an unprecedented level of communications turning the world into a global village covered by a communication and but equally surveillance umbrella associated exposures and hazards threatening to our personal sovereignty and social life. Emphasizing the dramatic potential through rebooting the next IT revolution.

Commenting the scenario of the last decennia, we have the privilege of the presence of personalities who were eyewitnesses and even contributors to these developments enabling these lectures.

Special appreciation for their engagement and many valuable discussions goes “in parts pro toto“ to Prof. Gerhard Chroust and Prof. Petr Doucek and their teams.

Christian Werner Loesch
September 2020

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1 LOESCH, C.W. , G. CHROUST (ED.) ICT Trends and Scenarios: Lectures 2000 - 2017 Books on Demand, Norderstedt, Germany, 2017 (hard copy and e-book).

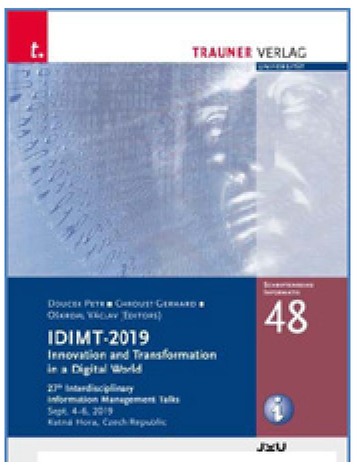
A Word of Thanks

The innovations, observations, and analyses which are reported at conferences like IDIMT are based on the rapid growth of Information and Communication Technologies (ICT). It has caused the dramatic and often unbelievable increase in speed and capacity of the underlying computer hardware (transistors, chips, processors, and memory, etc.) . Despite the dramatic reduction of the price of mass produced circuits and storage units, the explosion of the costs for the total production (factories etc.) are also growing and this reduces the production market to a few big players. The economic parameters define which development roads are to be taken and at what speed. This broader context is essential in order to understand some of the widening directions into which the technological advances will take our economy, our technical activities and our society.

Since the year 2000 a special highlight of the yearly IDIMT–Conferences has been Christian Loesch's overviews of global technical, economic and/or business developments. In now 21 presentations Christian Loesch has provided the participants with broad and and insightful presentations explaining the major dependencies, driving forces, and obstacles for the future of ICT. Thanks to Christian's profound knowledge and his deep understanding of the international situation he has been able to imbed our discussion within the broader context of technological innovation and economic infrastructure.

Christian Loesch, 2007

As a service we reproduce his 21 presentations in this collection, It offers an excellent chance for a retrospective of the ICT scene and the associated technologies.



IDIMT 2019 -Proceedings

We want to thank Christian for his efforts in collecting the material and presenting it to the participants of the IDIMT conferences in short but important view beyond our immediate field of expertise. It has allowed us to take look behind the evolving scenes of the computer industry . and also offer an interesting view of the past evolution of this key technology. field.

Gerhard Chroust and Petr Doucek

Co-chairmen of the IDIMT Conferences

IDIMT

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The State of ICT, Some Eco- Technological Aspects and Trends (IDIMT-2014)

CMOS, alternative materials Ge, GeSi and other III-Vs, architecture, Digital dementia

ICT Today and Tomorrow, Some Eco- Technological Aspects and Trends (IDIMT-2013)

Lithography, 450mm wafer, directed self-assembly, phase change memory, Watson

20 Years IDIMT, ICT Trends and Scenarios reflected in IDIMT Conferences (IDIMT-2012)

Retrospective: Developments meeting forecasts vs. not meeting forecasts or surprises

ICT Trends, Scenarios in Microelectronics and their Impact (IDIMT-2011)

Classical to equivalent scaling, FET, STT, MRAM etc., nanowire, photonics, photovoltaic

Some Eco-Technological Aspects of the Future of Information Technology (IDIMT-2010)

Roadmap for semiconductors, beyond silicon, quantum physics and computer

Technological Outlook: The Future of Information Technology (IDIMT-2009)

Lithography, new materials, power challenge and interconnections

Open Source Software and IBM - Some Comments (IDIMT-2009)

Historical sources, charging strategies, unbundling

Technological Forecasts in Perspective (IDIMT-2008)

Limits of forecasting, cloud computing, holography, nano, racetrack memory, spintronics

15 Years moving in Fascinating Scenarios (IDIMT-2007)

Retrospective 15 years, computer + communication, the rise of e-business

Do we need a new Information Technology? (IDIMT-2006)

ICT demography by people and skills, Opto, single electron and molecular electronics

Future Trends and Scenarios of Information Technology (IDIMT-2005)

Limits of downscaling, alternative organic + nano materials, network and sensor revolution

Information Technology: From Trends to Horizons (IDIMT-2004)

Silicon technology ctd., nanotechnology and electronics, quantum coherent system QC

Trends in Information Technology (IDIMT-2003)

Moore, Lithography, design and interconnection, MP, SoC, global communication skin

Safety, Security and Privacy in IS/ IT (IDIMT-2002)

Security and technology, privacy exposures by software and communication, biometrics

Trends in Business, Technology, and Resaerch u. develpment (IDIMT-2001)

congruence of computer and communication, future of CMOS , communication, e-business

Ethics, Enforcement and Information Technology (IDIMT-2000)

Freedom of expression and privacy vs. censorship, information acquisition, cybercrime

IDIMT Conferences containing Papers by Christian W. Loesch

Christian W. Loesch - Curriculum Vitae

The Seven locations of IDIMT Conferences

1993, 1994	Kubova Huť
2003 - 2007	České Budějovice
2008 - 2012	Jindřichův Hradec
1995 - 2002:	Zadov
2013	Praha
2014 - 2017	Poděbrady
2018 - 2020	Kutná Hora

IDIMT 2020

TECHNOLOGIES CHANGING OUR WORLD

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Keywords:

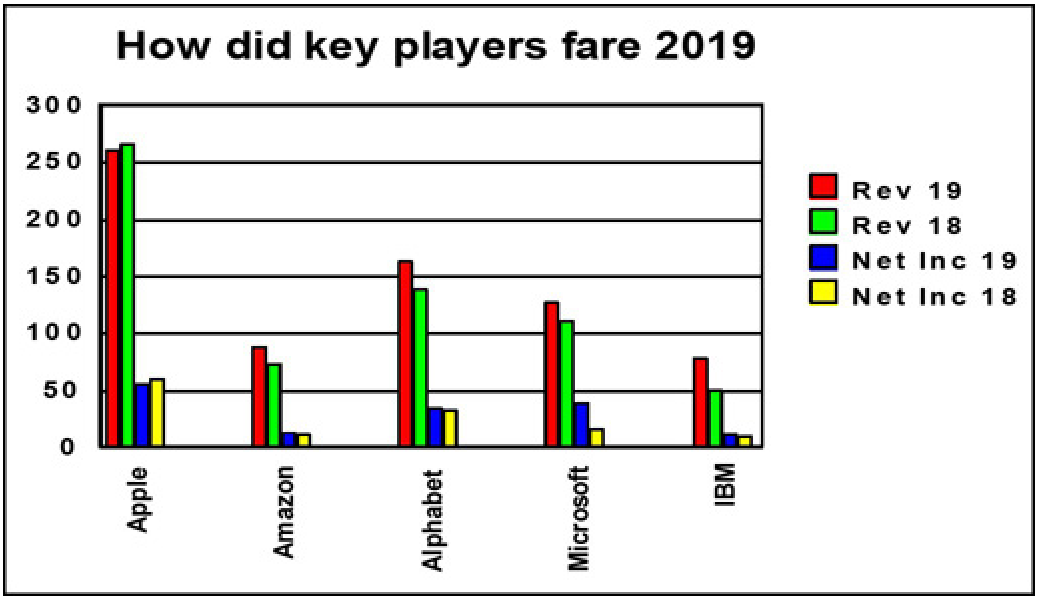
ICT industry and economy, future of microelectronics, more Moore and beyond Moore, emerging technologies, quantum, neurocomputing, sensors.

Abstract:

Based on an analysis of the economic status of the ICT industry, we will peruse the present status and future developments of microelectronics from “more Moore” to” beyond Moore”. On the threshold of new computing paradigms we will look at emerging technologies, progressively important areas as communication and sensor technology as well as the arising challenges and problems.

1. ECONOMIC SCENARIO

ICT industry has changed dramatically in the last few years, with 2019 being a turnaround year as shown by the economic developments of some key players of the industry below.



How and where are they achieving their impressive results:

Apple	- 4%
Amazon	+11%
Alphabet	+18%
Microsoft	+14%
IBM	+48%

- Apple: Diversifying
- Alphabet: Google, YouTube, etc. Adv.> 85% of rev.
- Microsoft: Most diversified, tax, five divisions each 20 %
- IBM: Not comparable due to new accounting standards

The worldwide market for chips has reached in 2017 the impressive volume of 412 b$ representing a rise of 21,6%. The IC market forecast (by IC Insights) for 2020 expected strong growth again of 8,0% and units shipments up 7,0%. In parallel a concentration process has reduced the number of leading edge chip manufacturing companies from 28 in 2001 to 5 in 2018.

Let’s hope that these successes have been used by the industry to build the resilience needed to overcome the events of 2020.

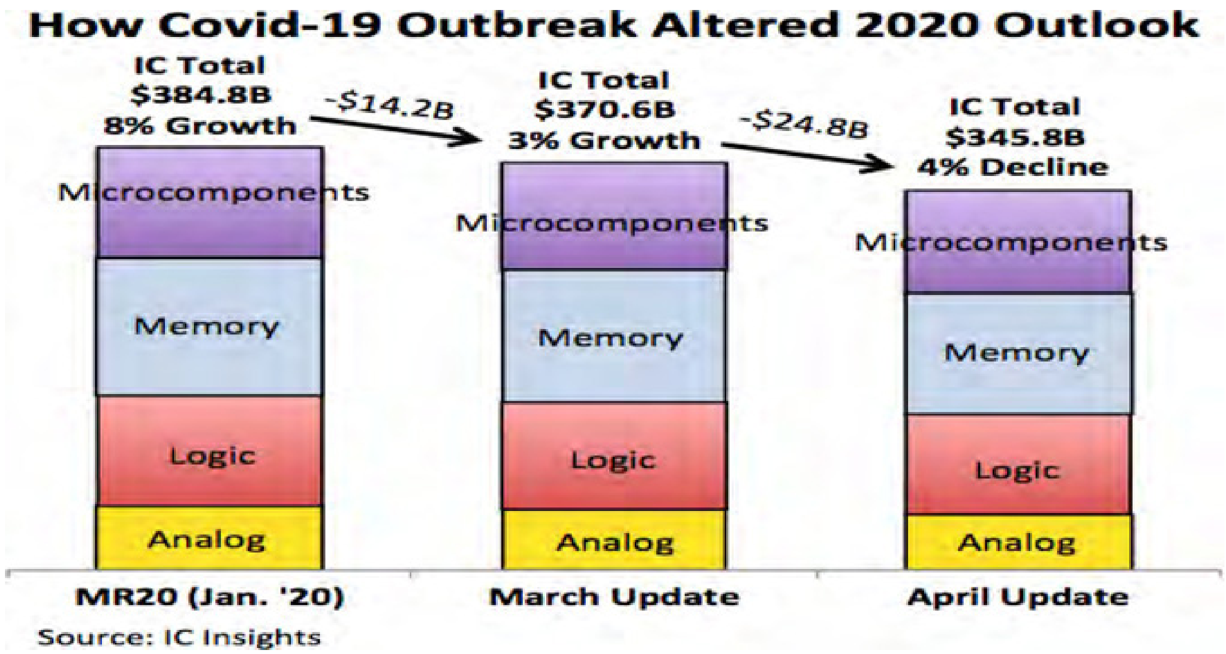
1Q20 Top 10 Semiconductor Sales Leaders ($M, Including Foundries)

1Q20 Rank	1Q19 Rank	Company	Headquarters	1Q19 Total IC	1Q19 Total O-S-D	1Q19 Total Semi	1Q20 Total IC	1Q20 Total O-S-D	1Q20 Total Semi	1Q20/1Q19 % Change
1	1	Intel	U.S.	15,799	0	15,799	19,508	0	19,508	23%
2	2	Samsung	South Korea	11,992	875	12,867	13,939	858	14,797	15%
3	3	TSMC (1)	Taiwan	7,096	0	7,096	10,319	0	10,319	45%
4	4	SK Hynix	South Korea	5,903	120	6,023	5,829	210	6,039	0%
5	5	Micron	U.S.	5,465	0	5,465	4,795	0	4,795	-12%
6	6	Broadcom Inc. (2)	U.S.	3,764	419	4,183	3,700	410	4,110	-2%
7	7	Qualcomm (2)	U.S.	3,753	0	3,753	4,050	0	4,050	8%
8	8	TI	U.S.	3,199	208	3,407	2,974	190	3,164	-7%
9	11	Nvidia (2)	U.S.	2,215	0	2,215	3,035	0	3,035	37%
10	15	HiSilicon (2)	China	1,735	0	1,735	2,670	0	2,670	54%
—	—	Top-10 Total		60,921	1,622	62,543	70,819	1,668	72,487	16%

(1) Foundry (2) Fabless

Source: Company reports, IC Insights' *Strategic Reviews* database

But the events of 2020 are changing the previous assumptions dramatically as shown below.



2. TECHNOLOGY

The twilight of Moore's law does not mean the end of progress. Innovation will continue, but it will be more sophisticated and complicated. Remember what happened to airplanes? A Boeing 787 doesn't go faster than a 707 did in the 1950s, but they are very different airplanes, with innovations ranging from fully electronic controls to a carbon-fiber fuselage. That may happen with computers. New EUV scanners will expand Moore's law for the anticipatable future, but nobody should overlook the equally impressive tacit advances in performance, e.g. the current Intel Core i3 processor is 32% faster than the first top of the line Intel Core i7 at half the power consumption only.

The chip making process is getting exceedingly complex, often involving hundreds of stages, meaning that taking the next step down in scale requires a closely intertwined network of materials suppliers and apparatus developers and manufacturers etc. to deliver the right new developments at the right time. If you need 40 kinds of equipment and only 39 are ready, then everything stops.

Leading companies, are trying to shrink components until they limits of the wall of quantum effects. The more we shrink, the more it costs. Every time the scale is halved, manufacturers need a whole new generation of ever more precise photolithography machines. Building a new fab line today requires an investment typically measured in billions of dollars, an investment only few companies can risk and afford this like INTEL, GLOBALFOUNDRIES, Samsung or TSMC. All of these companies rely on high volume manufacturing to finance the capital and the enormous R&D requirements to maintain their competitiveness,

Worlwide Wafer Capacity Leaders

(Monthly Installed Capacity in Dec 2019, 200mm-equivalents)

2019 Rank	2018 Rank	Company	Headquarters Region	Dec-2018 Capacity (K w/m)	Dec-2019 Capacity (K w/m)	Yr/Yr Change	Share of Worldwide Total	Inclusion or Exclusion of Capacity Shares from JV Fabs
1	1	Samsung	South Korea	2,934	2,935	0%	15.0%	
2	2	TSMC	Taiwan	2,439	2,505	3%	12.8%	shares of SSMC & VIS
3	3	Micron	North America	1,685	1,841	9%	9.4%	share of IM Flash in '18
4	4	SK Hynix	South Korea	1,630	1,743	7%	8.9%	
5	5	Kioxia/WD	Japan	1,361	1,406	3%	7.2%	

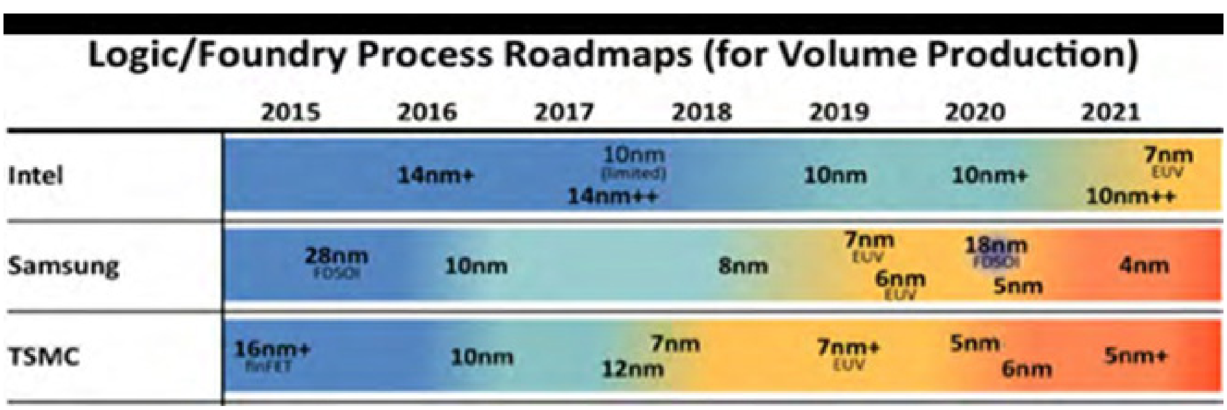
Source: Companies, IC Insights' *Global Wafer Capacity 2020-2024 Report*

The old market was characterized by producing a few different products, selling large quantities of them. The new market is producing a huge variety of products, but selling a few hundred thousand apiece, so costs of design and production has to be low. The fragmentation of the market triggered by mobile devices is making it additionally harder to recoup the investments. As soon as the cost per transistor at the next node exceeds the existing cost, the scaling stops. We may run out of money before we run out of physics.

Computing is increasingly defined by high-end smartphones, tablets, and other wearables, as well as by the exploding number of smart devices everywhere from bridges to the human body. These mobile devices have requirements different from their more sedentary cousins. The chips in a typical smartphone must send and receive signals for voice calls, Wi-Fi, Bluetooth and GPS, while also sensing touch, proximity, acceleration, magnetic fields, even fingerprints, demanding the device to host special purpose circuits. In this form the user value doubles every two years, Moore’s law will continue as long as the industry can keep successfully marketing devices with new functionality.

Advanced Digital Computing (More Moore)

As shown below leading companies expect Moore to continue for years. Digital CMOS is currently at the 14 nm node with potential to scale to 3 nm by 2022. The challenges are materials and process variation to achieve these with new technology at acceptable tool and fabrication costs.



2.1 Emerging technologies and paradigms.

We are on the threshold of revolutionary new computing paradigms. We can look forward to a decade of multiple technologies going to revolutionize the world of computing over the next 5-10 years.

Over the last decades, intensive efforts have been made on enhancing the capabilities and performance potential of III-V wide bandgap material systems such as Indium Phosphide, Gallium Arsenide, Silicon Germanium, Silicon Carbide, Gallium Nitride, and Aluminum Nitride.

Parallel to this evolves the architectural approach: stick with silicon, but configure it in new ways to using 3D to pack more computational power into the same space. 3D sequential integration is an alternative to conventional device scaling. Compared to TSV-based 3D ICs, 3D sequential process flow offers the possibility to stack devices with a lithographic alignment precision (few nm) enabling a density >100 million/mm^2 between transistors tiers (for 14nm), to merge several technologies and materials with 3D sequential integration of various devices.

However, this rather works with memory chips, which do not have the thermal problem as they use circuits consuming power only when a memory cell is accessed.

We will also address some farther out are options and paradigmata like quantum computing, or neuromorphic computing. But most of these alternative paradigms has made it very far out of the laboratory.

Compound Semiconductor

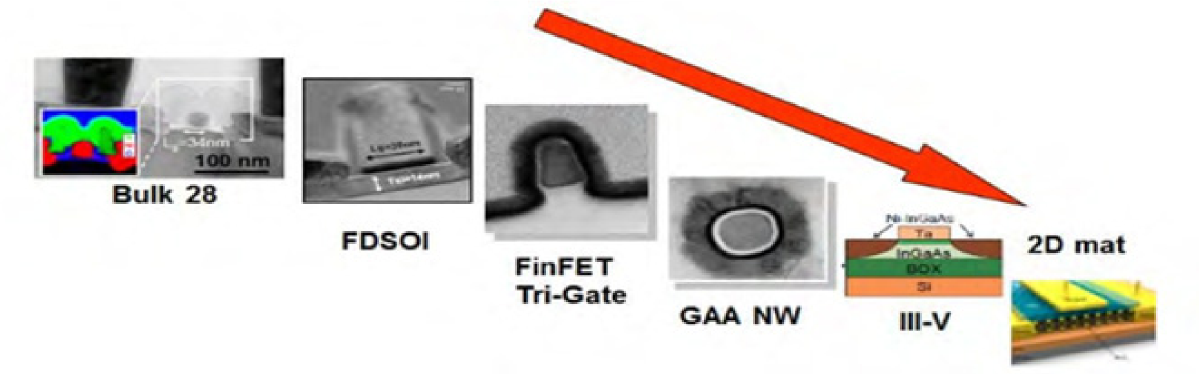
Over the last several decades, industry, academia and government have collaborated to deliver the enhanced capabilities and performance potential of III-V wide bandgap material systems such as Indium Phosphide, Gallium Arsenide, Silicon Germanium, Silicon Carbide, Gallium Nitride, and Aluminum Nitride as well as recent work on ultra-wide bandgap compound semiconductors, subsystem and system levels.

Despite the potential for enhanced performance of III-V compound semiconductors, it has not been generally adopted for integration into consumer products. This is due to material complexity, high cost and a lack of requirements for the high power and advanced capability offered.

However, certain sectors in the commercial market have transitioned to compound semiconductor technology replacing silicon technology, specifically in wireless mobile communication infrastructure (base stations), CATV, IoT, automotive and energy sectors. As availability of compound semiconductor material continues to grow, specifically GaN/SiC, costs will decrease and integration into consumers' systems will gain popularity.

Emerging technologies that may radically change the IT scenario are paradigms that diverge from simple transistor based logic and operations. Advanced Research is apparent for spintronic majority gate technologies including spin-based logic, graphene-based Tunneling Field Effect Transistor (TFET) technology and novel material FETs technology.

The evolution of transistor architecture and channel materials (MOSFET)



G. Ghibaubo, CNRS Grenoble

What makes these Nanotechnologies so appealing?

Remember: Carbon nanotubes (CNTs) are hollow cylinders composed of one or more concentric layers of carbon atoms in a honeycomb lattice arrangement, with a typical diameter of 1-2nm. Depending on the arrangement of the carbon atoms, the CNTs can be either metallic or semiconducting, and are considered both for interconnect or as field effect transistors (FETs).

The expected benefits of FETs over Silicon based devices are:

- High mobility is very high in carbon nanotubes, significantly higher than in any other material, enabling higher speed, or reduction of the operating voltage and lower active power (heat).
- The tube diameter is controlled by chemistry not by printing, allowing to reduce the body dimension beyond what is achievable lithography. This allows the fabrication of aligned arrays with high packing density.
- The intrinsic capacitance is a quantum capacitance related to the density of states and independent of electrostatics. The device capacitance could hence be much lower than the FinFETs gate to channel capacitances, reducing the switching energy.

Ferroelectric semiconductors and two-dimensional devices

Engineers at Purdue University and Georgia Tech constructed devices from a new two-dimensional material that combines memory-retaining properties and semiconductor properties using a newly developed ferroelectric semiconductor, alpha indium selenide. Noticeable applications would be: a type of transistor that stores memory as the amount of amplification it produces; and a two-terminal device that could act as a component in future computers using neuromorphic low-power AI chips as memristors as the neural synapses in their networks. Under the influence of an electric field, the molecule undergoes a structural change that holds the polarization. Even better, the material is ferroelectric even as a single-molecule layer only about a nanometer thick.

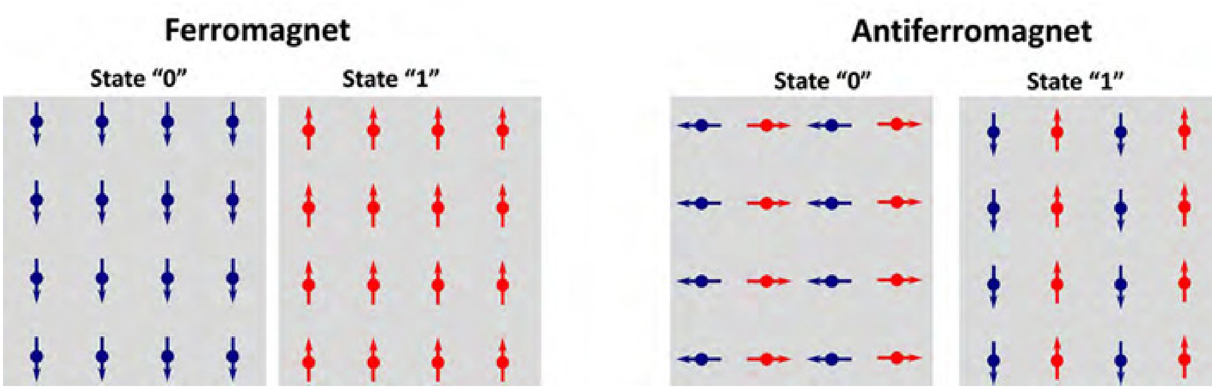
Digital reality, cognitive technologies, and blockchain are growing fast in importance. Virtual reality and augmented reality are redefining the fundamental ways humans interact with their surroundings, with data, and with each other. Cognitive technologies such as machine learning, robotic process automation, natural language processing, neural nets, and AI moved from highly special capabilities to tenets of strategy. These trends are poised to become as familiar and impactful as cloud, analytics, and digital experience are today.

Future memory technologies

MRAM has advantages over other memory technologies. Reading and writing data can be done at speeds similar to volatile technologies but consumes less power and, is nonvolatile, does not need a steady power supply to retain data.

MRAM stores information as the spins of electrons—a property related to an electron's intrinsic angular momentum. Most electrons in a ferromagnet point in the same direction. A currents magnetic field can cause most of those electrons to change their spins. The magnet records a "1" or a "0" depending on which direction they point.

But ferromagnets can be influenced by external magnetic fields, and the spins of adjacent ferromagnets can influence one another requesting enough space between them, limiting MRAM's ability to scale to higher densities for lower costs.



Pete Wadley

Ferromagnets [left] and antiferromagnets [right] can both store information in the spins of their electrons. But the orientations of those spins and their magnetic moments cancel out in antiferromagnets, making them impervious to external magnetic fields.

Antiferromagnets (metals such as Mn, Pl, Sn) do not have that problem. Electrons on neighboring atoms point opposite to each other and due to the dynamics of the spin in antiferromagnets are much faster, bits can be switched in picoseconds with terahertz frequencies. Theoretically, antiferromagnets could increase the writing speed of MRAM by three orders of magnitude. .

Analog Computing and Neuro-inspired computing

Analog, neuromorphic and quantum computing paradigms each involve alternative gate sets and architectures facilitating new computing paradigms. However new computing paradigms will also create additional security challenges beyond the ones already present with advanced CMOS. Current interests focus on machine learning and AI enabling applications, and the search for the hardware implementations.

- Analog computing is receiving increasing attention with advanced SiGe RF technology, hybrid digital/analog platforms, NEMs, photonics and superconducting electronics. This paradigm is particularly well suited for sensor applications and has significant power advantages for certain other applications as well.
- Neuromorphic and Neuro-inspired computing is experiencing rapid growth with major companies having intensive R&D efforts in this area (Google, Amazon, IBM, Microsoft etc.).
- The present digital technology falls short, partly because device scaling gains are no longer easy to come by, and the intractable energy costs of computation. Deep learning, using labeled data, can be mapped onto artificial neural networks, arrays where the inputs and outputs are connected by programmable weights, which can perform pattern recognition functions. The learning process consists of finding the optimum weights, however this learning process is very slow for large problems. Exploiting the fact that weights do not need to be determined with high precision, research has recognized that analog computation approaches, using physical arrays of memristor (programmable resistor) type devices could offer significant speedup and power advantages compared to pure digital, or pure software approaches

- Machine vision

  Machine vision technology has made great progress in recent years, and is now becoming an integral part of various intelligent systems, including autonomous vehicles and robotics. Usually, visual information is captured by a frame-based camera, converted into a digital format and processed afterwards using a machine-learning algorithm such as an artificial neural network (ANN). A large amount of (mostly redundant) data passes through the entire signal chain, however, results in low frame rates and high power consumption. Various visual data preprocessing techniques have thus been developed to increase the efficiency of the subsequent signal processing in an ANN demonstrating that an image sensor can itself constitute an ANN that can simultaneously sense and process optical images without latency. L. Mennel and his team (TU Vienna) demonstrated trained sensors to classify and encode images optically projected onto the chip with a dramatically increased throughput.

Impressed by these technological advances we have to keep in mind that most have evolved yet past the phase of a lab prototypes. The challenge may be 3D integration at affordable cost making organic materials an attractive candidate.

3. From Electronics to Photonics

Silicon photonics for optical quantum technologies is both technological as well as economically highly attractive. A fast expanding market both long-term with a CAGR 78–20 Fc of 8,6% and an accelerating growth rate in the last ten years up to 100%.This results in a continuous emphasis on future investment in R&D.(Statistics 2017).

Modern silicon photonics opens new possibilities for high-performance quantum information processing, such as quantum simulation and high-speed quantum cryptography.

- Solid state quantum memories based on electronic and nuclear spins are now becoming competitive for quantum repeater networks and distributed quantum computing
- Opto-electronic devices and 2D materials

2D materials, such as graphene, provide new capabilities in communications, sensing, imaging, nonlinear optics, and quantum information devices. There are theoretically about 16000 materials are eligible as candidates for single or combined 2D i.e. multilayer materials.

- Silicon Lasers

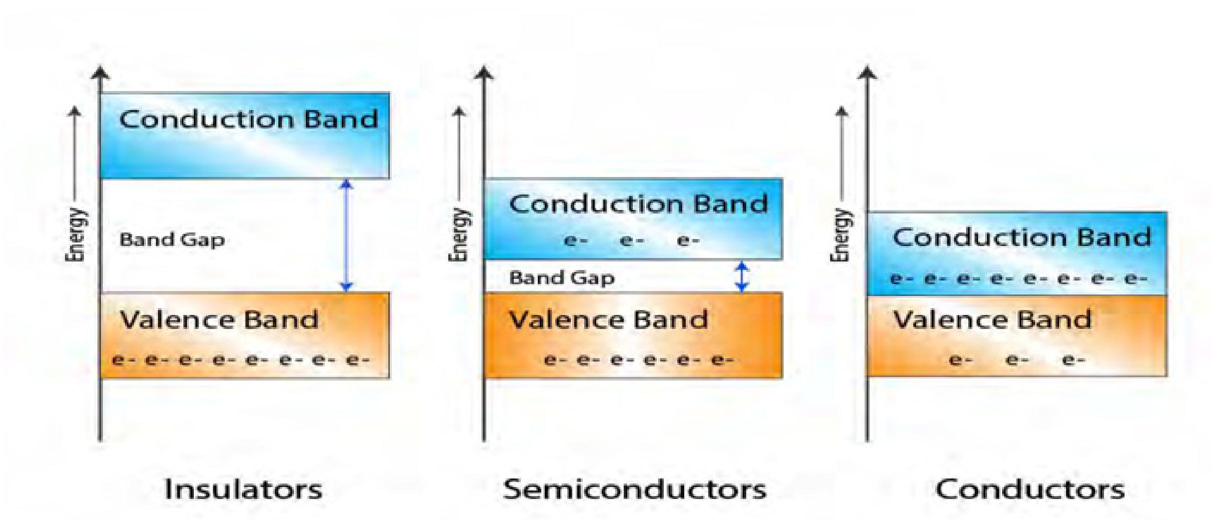
Silicon is the dominating and most thoroughly investigated material of microelectronics, seems to have another encouraging surprise ready. Emitting light from silicon has been the 'Holy Grail' in the microelectronics industry for decades.

Current technology, based on electronic chips, is reaching its ceiling. A limiting factor being heat, resulting from the resistance that electrons experience when traveling through the copper lines connecting the many transistors on a chip. To continue transferring more and more data, we need a new technique that does not produce heat as photonics.

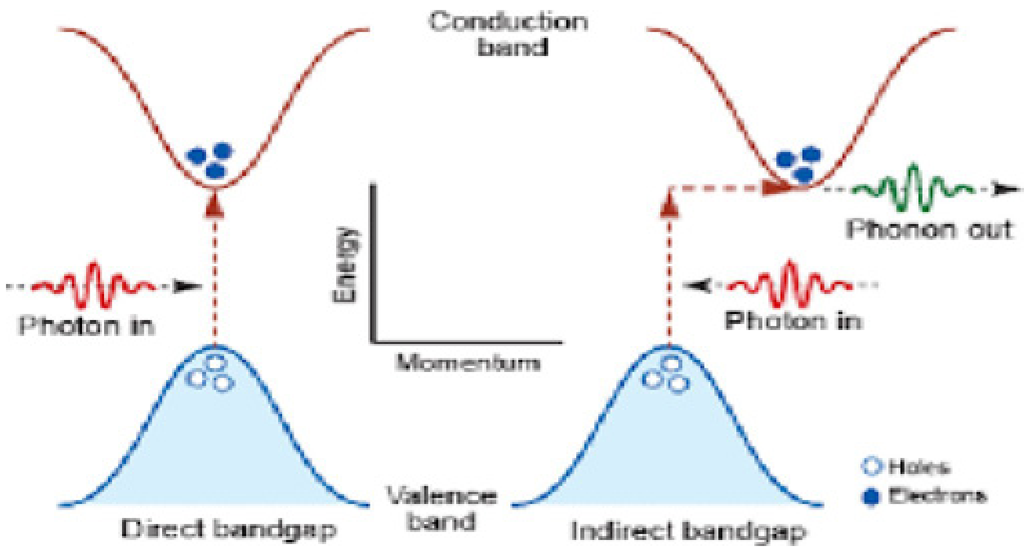
In contrast to electrons, photons do not experience resistance. As they have no mass or charge, they will scatter less within the material they travel through, and therefore no heat is produced. The energy consumption will therefore be reduced. Moreover, by replacing electrical communication within a chip by optical communication, the speed of on-chip and chip-to-chip communication can be increased by a factor 1000. Data centers would benefit especially, with faster data transfer and less energy usage for their cooling system. But these photonic chips will also bring new applications within reach. Think of laser-based radar for self-driving cars and chemical sensors for medical diagnosis or for measuring air and food quality

Silicon’s mature and large-scale manufacturing base could lead to implement a much needed reduction in the cost of photonic devices. Such a cost reduction can bring the power of optical networks to the desktop computer and to home systems. It could enable a new generation of electro-opto-mechanical chips that perform the job of today’s complex systems at a fraction of the cost, size, and power dissipation.

Let us make a short review of the basic principles to explain the problem.



But reality is more sophisticated because unfortunately for our purposes, direct band gap light emission is necessary whereas Si has the property of only indirect bandgap emission.



Unfortunately indirect bandgap semiconductors are usually very inefficient emitters. This problem been approached and resolved by an unusual approach. Researchers from TU of Eindhoven developed an alloy with silicon that has the desired properties to emit light and are now starting to create a silicon laser to be integrated into current chips.

Since QC and AI and related subjects have been covered in preceding IDIMT sessions only some additional comments:

Quantum-enhanced sensing

Quantum sensors enable unpaired precision measurements of time, fields, and forces for applications in the physical and life sciences.

QC (Quantum Computing**)**

QC continues to be perused with remarkable R&D (and PR) efforts to take advantage of the large parallelisms possible for complex optimization and factoring problems. It will not replace conventional computing but potentially offer superior performance for specific niche applications, rather than for the everyday digital computing tasks.

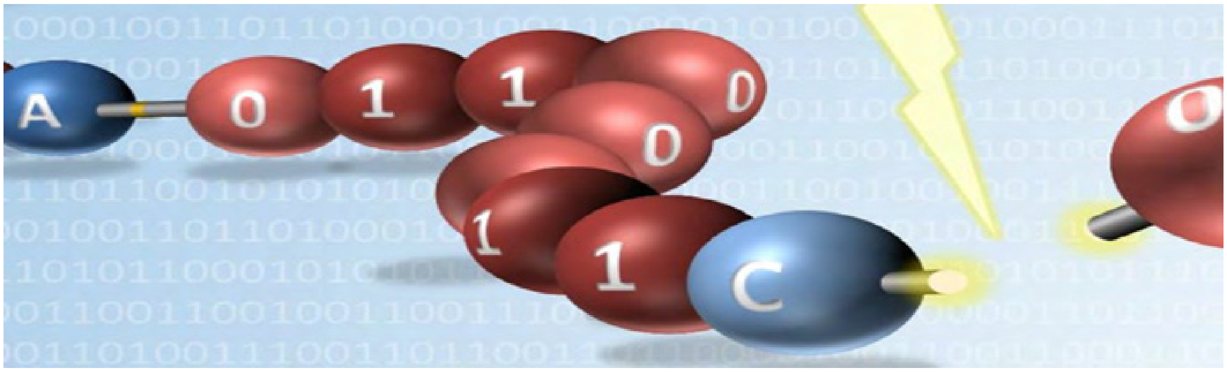
AI

AI is showing an impressive development. Factors responsible of its triumphal march are: more data, cheaper storage capacities and higher computing power (e.g. graphics card farms). They enable the use of AI processes in increasingly complex configurations. Experts differentiate between "strong AI", aiming to imitate human intelligence and "weak AI", which is used to make intelligent decisions for specific areas, such as the automation of processes, but strong AI is yet beyond the current technical possibilities. Unresolved fundamental problems ensure that it remains a theoretical game of thought for the foreseeable future, even if some of the reporting suggests otherwise. Weak AI, on the other hand, is an approach that plays a role in many applications today.

Further out in the long range future are “wet” technologies as the

Molecular computer

French scientists have built the first molecular computer using polymers to store data. They encoded and read the word the word “Sequence” in ASCII code using a synthetic polymer sequence, thus proving that it is possible to store information in polymer molecules. Given the size of each monomer unit of the molecule, this method would make the storage required for of each bit of information, a hundred times smaller than that of current hard drives.



Source: NDIA

3.2. Lateral challenges, problems and risks emerging

New computing paradigms will create new security challenges. Analog computing, neuromorphic computing and quantum computing paradigms each involve alternative gate sets and architectures.

The advancement of such emerging technologies will likely outpace industry's ability to understand the related security threats as well as the readiness of adequate legislation.

Ecology is another important aspect i.e. finding alternatives for rare or toxic materials, and processes.

4. Communication (Connectivity and Advanced Logic)

Networking has lived in the shadow of the high profile technologies but this is changing even more drastically than forecasted Communication is overtaking the computer IC market segment already and is expected to race ahead of all other end-uses (2020 McClean Report).

The connectivity functions will be everywhere in the connected world, from the physical world, (things and persons, autonomous objects, (factory 4.0, autonomous