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Life Beyond Moore: More Moore or More than Moore – A Review

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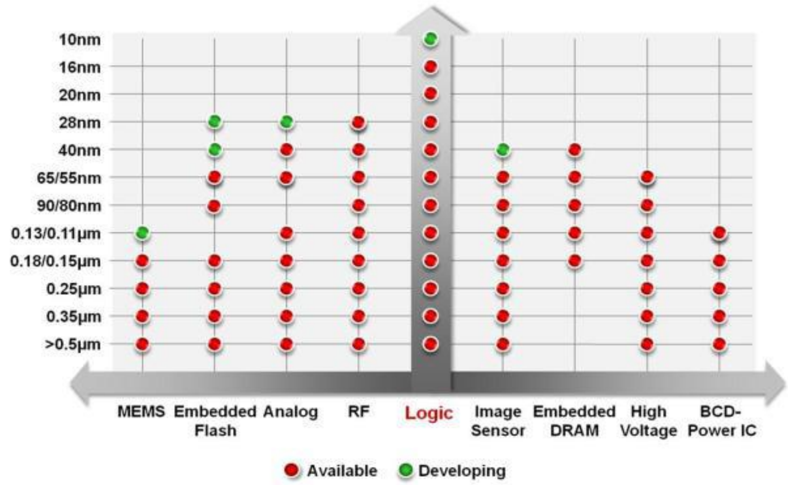
Abstract: For the past 50 years, the main stream of microelectronics progresses is mainly powered by Moore's law, with two focused development arenas, namely, IC miniaturization down to nanodimension, and SoC based system integration. While microelectronics community continues to invent new solutions around the world to keep Moore's law alive, there are ever-increasing awareness, R&D effort and business drivers to push the development and application of "More than Moore" (MtM) that are based upon or derived from silicon technologies but do not scale with Moore's law (with typical examples as RF, Power, Sensor and actuator, SiP, heterogeneous integration, etc.). The future business opportunities and technology challenges will be the innovations and effective integration of Moore's law focusing mainly on digital function with MtM focusing mainly on non-digital function and heterogeneous integration." MtM" refers to all technologies based on or derived from silicon technologies but do not simply scale with Moore's law.

Keywords: *More than Moore, Moore, sensors, radio frequency, TSMC*

1. Introduction:

As the semiconductor industry accelerates on a collision course with physical and electrical roadblocks on the scaling roadmap, non-Si materials and non-traditional devices are increasingly being considered for heterogeneous integration on silicon CMOS platforms. High-k metal gates and Ge/III-V high mobility channels are some examples of materials under consideration. In addition, strong interest in low power technologies, coupled with need for increased functional diversity at the chip and system level, has lead to the investigation of devices such as MEMS integrated with CMOS and tunneling FET devices (life beyond silicon).

TSMC (Taiwan Semiconductors Manufacturing Company) provides a complete portfolio of technologies covering leading-edge technology, specialty technology, and 3D IC system integration technology to fulfill customer product needs in various market segments. While the leading-edge CMOS technology continues to extend Moore's law as a driver for business growth, More-than-Moore specialty technology leverages the logic technology platform with value-added components to enable various functionalities for a wide range of applications (TSMC) [1]. TSMC's overall technology coverage is shown in Fig. 1, including leading-edge technology and specialty technology.



Since Gordon Moore observed in 1965 that the number of transistors doubles approximately every two years, microelectronics has been pervading our lives, with massive penetration into health, mobility, security, communication, education, entertainment, and virtually every aspect of human lives. Innovation in mainstream silicon microelectronics has been following the path of Moore's law all the way down to the nano-electronics size regime. However, to meet the need of Ambient Intelligence (the digital environments that are sensitive and responsive to the presence and needs of peoples) [2] and to cope with the fast transition from microelectronics to the nano era, Moore's law on its own is not enough. What will also be needed is "More than Moore" (MtM) in the form of multi-functionality enhanced by heterogeneous technologies that do not simply scale in accordance with Moore's Law and cannot therefore be integrated easily in the 'baseline' CMOS processes used for state-of-the-art digital logic and memories.

The term "More-than-Moore" was invented by Europe in the early 2000's to stress the fact that the value of a packaged system doesn't rely only on the performance of the CMOS technology for the digital information processing, but also on diversified technologies which doesn't necessarily perform better through a dimensional scaling. MtM in the form of multi-functionality enhanced by heterogeneous technologies that do not simply scale in accordance with Moore's Law and cannot therefore be integrated easily in the 'baseline' CMOS processes used for state-of-the-art digital logic and memories [3]**.** Figure 2 shows an example of a typical system composition, wherein MtM plays an unmissble role. Figure 3 shows the intelligent systems requiring both computing and interacting functionalities.

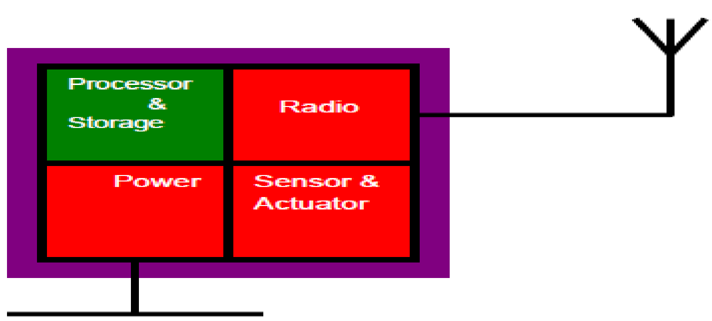


Figure 2. An example of system composition, wherein green block follows Moore's law, red blocks are MtM

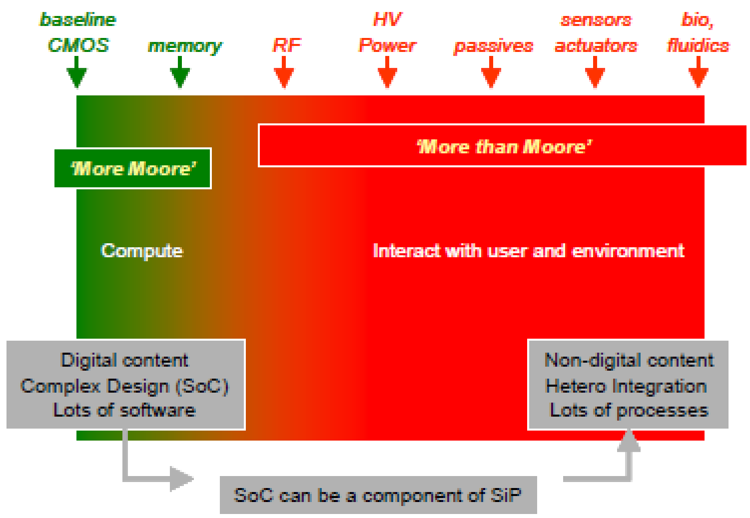


Figure 3. Intelligent systems requiring both computing and interacting functionalities

2. Society Needs and Application Drive Technology Development:

The society of the future expects environments that are sensitive and responsive to the presence and needs of people, characterized by many invisible devices distributed and connected throughout the environment. Devices that know about their situational state, that can recognize individual users, tailor themselves to each user's needs, and anticipate each user's desires without conscious mediation [5]. In other words, environments based on the concept of Ambient Intelligence. In the world of Ambient Intelligence, ENIAC has recognized five application domains, each of them driven by clearly recognizable societal needs:

- Health
- Mobility / Transport
- Security
- Communication
- Education / Entertainment

Based on these society needs and application domains, ENIAC divided all the relevant key technologies into six different technology domains:

- More Moore to further scale down CMOS technology
- Beyond Moore to develop and exploit innovative technologies as both complimentary to CMOS and more importantly as to overcome the limit of CMOS
- More than Moore to develop the physical enabler of Ambience Intelligence, via developing and integrating multi-functionalities equivalent of ears, eyes, noses, arms and legs.
- Heterogeneous Integration to bring various components with both digital and non-digital functions together into one package and also to provide an interface to the application environment.
- Equipment and Materials to provide development guidance for equipment and materials, based on the specific needs of nanoelectronics.
- Design Automation to further develop the Electronic Design Automation (EDA) tools for the needs and development of future nanoelectronics, and to reduce the existing design gap.

3. Research Subjects Associated With The More Than Moore:

Radio Frequency Technology:

Many of today's electronic systems utilize radiofrequency (RF) circuits to transmit data internally or externally. Typical RF application includes wireless communication, wire-line communication and short-range connectivity and mobility. Mobile RF applications range from GSM, 3G and 4G cellular communications, to Wi-Fi access and 60 GHz wireless LANs, providing point-to-point and multi-point connections for voice and data, video distribution and internet access. Convergence means that many products are now multi-band and multimode, not only using RF communications for voice and data transmission but also for localization and navigation. As a result, many feature multiple air interfaces and advanced antenna systems [6]. The higher bandwidth demanded by voice, data, music, image, video transmission requires higher frequency wireless links, while the need for handheld mobile devices to operate from smaller battery packs demands low-power wireless operation. This requires innovation in the analog RF front-end section (active and passive functions) as well as in the digital section to achieve higher processing speed and computing power for lower power consumption.

High Voltage and Power:

High-voltage (HV) can be defined as any voltage higher than that used in the classical digital I/Os within state-of–the-art semiconductor processes, i.e., starting at 3.3 or 5 volt. HV interfaces and functions are important parts of most (small) systems, usually as part of an input/output (IO) system that interfaces the system to the real world. They are usually needed when the I/O device requires a high power or high voltage drive (e.g. mechanical actuators or LCD displays), or when high voltage capability is required in protection circuitry that allows sensitive electronic circuits to be used in harsh environments (e.g. automotive systems). High voltage capabilities are also required in power management, power conversion and power distribution circuits. Power management solutions are required to drive low voltage CMOS circuitry from battery or AC-line power sources in a wide range of consumer products. Automotive systems need to drive mechanical actuators such as in fuel injection systems, solenoid drivers, starter engines and electric windows, but are also increasingly typified by low-voltage electronic systems in body control and drive-by-wire systems that need protection from voltage spikes. The emergence of engine-assist and electric vehicle technology is moving car battery systems from 14 V to 42 V , with circuitry capable of handling 200 V being needed in electric motor drives. High voltage capabilities are also needed in solid-sate lighting systems and battery chargers. Power generation and distribution systems include new portable energy sources such as micro-fuel cells and micro-batteries, high power DC-to-AC converters (e.g for solar cells) and decentralised and regenerative energy supplies (Wind power plants, fuel cells, micro-turbine, solar panels etc.)

Sensors and Actuators:

Sensors and actuators play an essential role as the interface between electronic systems and the user/environment, particularly in Ambient Intelligence environments. The majority of the sensors in use today are stand-alone devices measuring parameters such as pressure, magnetic field strength rotational speed or acceleration / tilt. Most of these physical parameters are measured in an indirect way. For example, rotational speed is often measured using magnetic field variations induced by a toothed wheel. Integration into larger systems has only just begun and new functionalities are emerging. Sensors and actuators are employed in a vast range of applications, each having its own application requirements. Typical applications include audio systems, tyre pressure monitoring, personal navigation, positioning, pre-crash detection, distance measurement, 3D-imaging using ultrasound, bio-chemical detection, and human interface devices (touch pads, finger print).

Different competing sensor technologies may co-exist, often pursued by different players with proprietary solutions, and often implemented as dedicated system solutions. Added value in the sensor market is at the module or system level, which is highlighted by the trend towards smarter, more highly integrated, miniaturized and hence more compact sensor systems and modules.

Biochips and Fluids:

Micro-and nano-technologies will provide powerful devices for biological applications. For more than ten years, DNA micro-arrays have revolutionized genetic analysis in life science laboratories. However, it is widely accepted that beyond this breakthrough there is real potential to create totally new analytical tools for biological applications. Many of these will generate mass markets in areas such as in-vitro diagnostics and healthcare, drugs and drug delivery systems, environment control (air, water, soil), agriculture and food, defense and civil security. A wide range of sensor types ill be required, such as bio-chemical sensors, spectroscopic sensors, Ion- Sensitive Field Effect Transistors and media ensors for detecting parameters such as CO2 levels, fuel and oil condition, ozone concentrations, particulate matter, hydrocarbons, gas, etc.) Typical applications will include measuring devices for clinical 'observation' such as blood pressure. monitoring (sphygmomanometer) [9], volume of inspired/expired air (spirometer), oxygen consumption (ergospirometer) and heart (ECG) and brain (EEG) function; devices for minimally invasive surgery and drug delivery; bio-hazard detection and DNA/protein assays. Applications such as DNA/protein assaying in the form of a lab-on-a-chip will also require the development of micro-fluidic systems such as micro-pumps, valves and mixers.

4. Conclusion:

MtM is much more than just miniaturization. It is multi-application/market, multi-supply chain, multi-infrastructure, multi-functionality, multi-discipline, multi-scale, multi-technology, multi-material/interface, multi-process, multi-damage and failure mode, multi-organization, multi-culture. The success of MtM business depends on not only the technological progress, but also the establishment and implementation of industrial vision, strategy and eventually suitable business models wherein the associated total value chain has to be optimized according to the needs and characteristics of the specific application.

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