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Transforming Microelectronics

Since the invention of the transistor 55 years ago, microelectronics technologies have enabled the way that we communicate, acquire, and process information playing one of the most important roles in today's information revolution. Over the last three decades, the Department of Defense has funded and conducted many programs that have served as catalysts for innovation in the semiconductor industry. These include DARPA's Gallium Arsenide Insertion Initiatives, the VHSIC program, MIMIC, MAFET, and more recently the Advanced Microelectronics programs. The results of these initiatives have enabled today's wireless communications, radar, electronic warfare, and information systems.

While DARPA has always focused on military unique problems, we have also benefited from the economies of scale that commercial markets provide. Today, the increasing demands for commercial electronics have resulted in a national semiconductor industry that remains strong and robust. Even with the current recession, last year's sales of semiconductor products exceeded $40 billion in the United States alone with an estimated global market of $141 billion.

While commercial technology developments are meeting the demands of the evolving consumer markets, they still fall short of satisfying many emerging requirements critical to future military systems. If we are to produce the multifunctional, highly adaptable systems of tomorrow, we cannot afford to be content with past microelectronics accomplishments or with the current directions and pace of commercial achievements. These emerging requirements for multifunctional and highly adaptable systems include particularly stringent demands on analog and mixed-signal component technologies.

At DARPA, we recognize the urgency of addressing these military system challenges and have launched three major microelectronics initiatives:

- The Wide Bandgap Semiconductor Technology
- The Intelligent Microsystems
- The Beyond Silicon Initiative

Today, I will describe two new MTO initiatives key to the future transformation of microelectronics: the Wide Bandgap Semiconductor Technology Initiative and the Intelligent Microsystems Initiative. Immediately after this presentation, Dr. Kwan Kwok will describe the Molecular Electronics Program and the Beyond Silicon Initiative.

Under the Wide Bandgap Semiconductor Technology Initiative, Dr. John Zolper and I are exploiting the properties of silicon carbide and III-Nitride compound semiconductor materials to enable a new generation of high-power, high frequency components for electric weapons and vehicles, sensors, electronic counter measure systems, and future mobile, wireless communication networks. This is a multi-year, multi-phase, effort beginning this year with providing materials that have the right stuff.

During the current phase, we are supporting activities that address fundamental issues related to material technologies. The results of this phase will provide us the path to make possible a new class of microelectronics devices capable of operating at higher voltage levels, higher power densities, and higher junction temperatures enabling more efficient, more linear, and higher power components.

As we make progress toward establishing dependable sources of high-quality, materials, our focus will shift to device-technology issues related to advanced designs, high-yield fabrication processes, and, finally, to the use of these advanced devices and components in high-power, highly integrated microsystems. Our ultimate goal is to realize the great potential of wide bandgap semiconductor technology for meeting the requirements of our high-power and high-frequency applications reliably, efficiently and affordably.

It is our mission to mitigate development risks but, more importantly, to transform the science of wide bandgap semiconductors into a viable technology—one that will enable new functionalities in future military systems not currently achievable with any of today's conventional semiconductor technologies.

While DoD has supported basic research on wide bandgap semiconductor materials for more than 30 years, recent progress has yielded laboratory devices that operate with unprecedented performances. The unique properties of these materials will enable a new class of high frequency components that are capable of operating at 10 to 100 times higher power densities and higher temperatures than ones made using silicon or gallium arsenide technologies.

However, until now, the quality of wide bandgap materials has been so non-uniform and unpredictable that only a few prototype or "hero" devices has been demonstrated, giving us just an idea of the potential and challenges of this technology. Therefore, in order to achieve the maturity level required for the manufacturing of components based on wide bandgap semiconductors, we must shift our focus from scientific experiments to technology development activities that will lead to the realization of larger diameter substrates and high yield component- fabrication processes.

Achieving this maturity level in semiconductor materials is a technology-intensive task that always requires the attention of the best researchers in our community. The specific objectives of this initiative are:

- The realization of four-inch substrates. This substrate diameter corresponds to an area 200% larger than the current state-of-practice.
- One order of magnitude improvements in epitaxial layer uniformity and electronic quality.
- Understand the correlation of material properties to device and component performances.

Assuming success with the material development phase, which is expected to last 24 months, the program will proceed to a second phase. At that time DARPA will request your ideas for using these material results to achieve affordable, reliable, exceptionally high-performance microwave and millimeter wave-integrated components and devices and modules for power control and distribution applications. The results of this initiative will transform compound semiconductors for high power and high frequency applications enhancing the performance of future military capabilities such as:

- Multifunctional sensors and wireless communication networks for space, airborne, ground, and maritime applications.
- In radar systems, solid-state power amplifiers based on wide bandgap semiconductor technology are expected to considerably increase the power-density per element to levels well beyond those achievable with current Gallium Arsenide MMIC technology. This will enable platforms that are capable of discriminating among very small targets in the presence of clutter and jamming at ranges well beyond enemy reach.
- In the electronic counter-measures area, very broadband, wide bandgap microwave components could replace vacuum electronics modules leading to reductions of the size, weight, and volume of decoys and jammers by orders of magnitude with the added benefit of increased signal agility.

For power electronics applications, mega-watt class devices fabricated from wide bandgap semiconductor materials will enhance the conversion and efficient distribution of electric energy in systems and platforms enabling a new generation of efficient electro-magnetic weapons, and electric vehicles for ground, maritime, and airborne applications.

While the Wide Bandgap Semiconductor Technology Initiative is focusing on raw analog performance improvements, the ability to precisely control the performance of analog and mixed-signal devices to achieve real-time optimization and adaptability is the objective of the Intelligent Microsystems Initiative. In simple words: chips that can think.

The concept of Intelligent Microsystems represents a second type of transformation in microelectronics that will have a radical impact on future military systems. Our vision is to enable a new generation of mixed-signal integrated circuit technologies with the ability to exploit embedded information and convert it into knowledge to achieve superior levels of system performance and adaptability.

In the future we envision military systems capable to adapt to changes in the environment and operational requirements in the same way that Mother Nature has equipped biological systems to adapt to external stimuli. In order to achieve the degrees of freedom required for full system adaptability, we anticipate a new generation of Intelligent Microsystems with the ability to self-sense and intelligently optimize their performance in real time. This unprecedented level of component functionality will be achieved by integrating analog, digital, and micro-electro-mechanical sensors, actuators and control devices, creating a mixed-signal environment in which the performance of analog devices is controlled and optimized by digital functions.

This is the motivation of the Intelligent Microsystem Initiative—cognitive chips that can think. As part of this effort, the Intelligent RF Front-end program will demonstrate a new class of highly adaptable, highly integrated RF components in which the analog function is digitally controlled providing the component with the ability to self-assess and in real time, adapt its performance to meet changes in operational requirements.

This by itself is a departure from conventional MMIC technology where the adapting or tuning ability is currently absent. Like in MMICs, the core of these intelligent components is a conventional RF device. These components will be able to reconfigure themselves through the implementation of MEMs devices enabling the demonstration of these highly adaptable microsystems.

To achieve self-assessment and the intelligent control of the reconfiguration process, embedded sensors and digital technologies will be introduced heterogeneously or monolithically into the MMIC architecture. Intelligent adaptability will enable integrated circuits to meet multifunctional system requirements more effectively and efficiently than with any of today's microelectronics concepts.

The digital control or intelligence in the integrated circuit will be capable of optimizing the component architecture and performance at any given frequency within the operating bandwidth of their core active device. This will transform future system architectures providing our fighters the ability needed to rapidly and effectively respond and react to unforeseeable, continual changes in battlefield environments and operational demands.

Intelligent Microsystems will enable military system concepts with higher levels of functionality and operational bandwidth, at a reduced size, weight, power, and cost. We are also anticipating radical changes in training and in-battlefield reconfiguration as more adaptable systems are enabled by the concept of Intelligent Microsystems.

At the component level, other benefits could include auto-calibration to compensate for aging effects, transient faults, or design and manufacturing errors resulting in more reliable system concepts and lower component cost.

Finally, a new revolution in microelectronics is anticipated resulting in higher component manufacturing yields, lower unit cost, and enhanced system functionalities and reliability. In support of this vision, many MTO program managers are currently focusing their program activities to transform the future of microelectronics and therefore enable the concept of Intelligent Microsystems.

For example:

- Dr. Anantha Krishnan is leading the development of new design methodologies and tools for mixed-signal systems under the NeoCad Program. We anticipate that this program will lead to a new generation of tools and methodologies that will reduce the time to design mixed-signal systems by orders of magnitude.

- Dr. Robert Reuss is leading the TEAM program, or Technology for Efficient Agile Microelectronics Program, which is promoting the coming-of-age of silicon nanotechnology into the RF domain, enabling new mixed-signal concepts for military systems-on-chips.

- Dr. John Zolper, under the Technology for Frequency Agile Digitally Synthesized program, or T-FAST, is exploring the scaling limits of indium phosphide bipolar devices for very high-speed and mixed-signal applications, and finally

- Dr. James Murphy, under the Vertical Interconnected Sensor Array Program, or VISA, is pursuing the development of advanced interconnect concepts to bridge the gap between the analog and the digital domain in three-dimensional mixed-signal microsystems.

Of course, the job of transforming military system capabilities is never finished. In the future, initiatives such as, Wide Bandgap Semiconductor Technology and Intelligent Microsystems will be joined by others that will exploit nanotechnologies, sophisticated adaptable software, and even more exotic materials to extend the performance of intelligent electronic microsystems. New opportunities and ideas in these areas are currently being examined.

The following is a list of relevant topics of interest that you can help us with to transform the future of microelectronics. I encourage you to join Anantha, Jim, Bob, John, and myself to discuss your ideas about these areas of research.

Thank you for your attention and have a good day.