N/MEMS: small components enable powerful microsystems

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ABSTRACT

DARPA's programs in Micro/Nanoelectromechanical Systems development since the mid 1990s have highlighted a number of recurring themes. The valuable lessons learned from these programs have yielded not only useful commercial and defense microsystems components, but they are also positive indicators for the upcoming technological revolution in nanosystems.

Keywords: MEMS, NEMS, sensors, fundamental research

1. INTRODUCTION

The last 15 years of MEMS technology investment has led to the creation of diverse products driven by developments in manufacturing methodologies, new materials, and component integration strategies resulting in versatile and powerful microsystems. Both commercial and defense products with MEMS inside are now beginning to dramatically impact our lives.

Both physical and chemical microsystems leverage the key principles of multi-domain scaling and heterogeneous integration of sub-components. N/MEMS, or nano/micro-electromechanical systems, include the integration of small sensors, actuators, electronics, photonics, energy, fluidics, plasmonics, chemistry, and biology into meaningful systems enabled by nanotechnologies, sub-micrometer structures, and engineering precision. This talk will describe some selected examples where opportunities have been demonstrated for enabling new component capabilities and significantly enhanced performance over macroscale sensor approaches.

Some general characteristics of N/MEMS technology demonstrated over the past decade have brought out five important themes: (1) MEMS and nanotechnology enable significant new levels of performance, (2) "smaller is better" is a consequence of multi-domain scaling, (3) MEMS technology commitment drives systems integration and innovation, (4) N/MEMS enable completely new opportunities, and (5) a national MEMS basic research infrastructure is important to continued U.S. leadership. These valuable lessons have brought about not only useful commercial and defense microsystems components, but also show the way to the next technological revolution realizing powerful micro/nanosystems.

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2. KEY LESSONS LEARNED

2.1 N/MEMS Enables Significant New Levels of Performance

MEMS and nanotechnology enable performance unattainable at macroscopic scales. The Chip Scale Micro Gas Analyzers (MGA) program has shown remarkable progress, demonstrating a 2 cm^3 system with performance orders of magnitude better than standard bench-top (e.g. 40,000 cm^3) laboratory systems. By nature of the reduced system scale, the sample analysis time is substantially reduced, and the energy cost per analysis is likewise reduced by a factor of 1000. In addition, this program has demonstrated detection sensitivity of parts per trillion, orders of magnitude more sensitive than benchtop parts per billion systems.

To develop these chip-scale MGA systems, each fundamental portion of a gas analyzer has been redesigned and implemented with microfabrication technology, from the preconcentrator and separator all the way through to the mass spectrometer detector.

2.2 Scaling – "Smaller is Better"

Multi-domain scaling is the key to performance-driven MEMS and nanotechnology. Dimensional scaling of resonator structures leads to a substantial reduction in dissipative resonator losses to the substrate, increases in operational frequency, and substantial improvements in mechanical compliance. Similarly, thermomechanical noise scales linearly with decreasing base dimensions.

To further DARPA's goals, we have fostered development of more mature simulation and modeling tools at the nanoscale, in addition to material and device development.

2.3 N/MEMS Integration

Substantial MEMS technology commitment drives systems integration and innovation. DARPA has invested in monolithic and discretely packaged MEMS components to enable applications that demand low power consumption and low-loss, high-speed operation, such as phased array radar, tunable filters, and switching matrices. Among the most interesting integration programs is Nano Electro Mechanical Switches (NEMS). By harnessing the advantages of mechanical switches with nano-scale features, compact digital logic can be fabricated and operated in harsh environments and with very low leakage current, overcoming some of the key weaknesses of transistor-based computation. There have been successful demonstrations of hybrid CMOS/mechanical systems merging the advantageous properties of each to develop FPGAs with substantially reduced size and power consumption. Complex mechanical systems are also possible with nano-switch technology, including analog-to-digital and digital-to-analog conversion circuitry.

2.4 Enabling Completely New Opportunities

Many important sensor technologies require controlled temperatures to operate efficiently and reliably. The Micro Cryogenic Coolers (MCC) program has demonstrated a 3.6 cm^3 system capable of reducing mm-scale sensor temperature below 130 K. This new approach to sensor thermal cooling reduces overall system size and power consumption to enable portable sensing.

The Chip-Scale Mechanical Spectrum Analyzers (CSSA) program will produce ultra-fast, low-power, software-defined spectrum analysis. This capability will be used to identify unused spectrum, remove interferers prior to amplification, and rapidly switch channels. These capabilities are not currently possible with existing portable components due to the large size and power consumption of traditional GHz filters.

2.5 Basic Research Infrastructure is Important

A national basic research infrastructure is essential to the continued advancement of MEMS and NEMS technology. Through growth of the basic research infrastructure under the N/MEMS S&T Fundamentals program, we can ensure vibrant academic collaboration with industry guidance to serve the DoD's future needs.

The N/MEMS S&T Fundamentals program has yielded a profound effect, establishing a broad N/MEMS community and accelerating technical progress important to transitioning emerging capabilities. Among its many accomplishments to date, this program has resulted in:

- More than 350 publications derived from supported research in technical journals and conference proceedings
- Approximately 200 additional conference presentations
- More than 30 patents – pending or issued
- Research is contributing to the education of ~200 graduate students; involving participation of 48 post-docs
- Program research oversight and guidance provided by 90 faculty
- Cost-sharing support in Phase I provided by 68 industry program partners; industry funding met DARPA expectations

3. CONCLUSION

DARPA is charting a course to develop essential technologies critical to the future. We are not seeking to drive down component cost, but are instead targeting several opportunities for MEMS and nanotechnology that will enable new systems and revolutionize performance levels. A number of important fundamental science and technology issues are being explored in tandem with aggressively targeted applications, thus avoiding undirected fundamental research. Multi-domain scaling is the key to performance-driven nanotechnology (i.e. there remains plenty of room at the bottom). Viewed together, this work will establish new benchmarks and lay the foundation for a clear path to the future of N/MEMS. These programs have developed an N/MEMS basic science research infrastructure with a highly interactive community of academic, industrial, and government researchers.

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