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Introduction

The 2010 Micro- and Nanotechnology Sensors, Systems, and Applications II conference continued its successful approach of having focused thematic sessions on a wide range of MEMS and Nanotechnology topics. Each session was designed to address three "cornerstones" namely, programmatic investments that set the overall context for the cutting-edge research and development being presented, and the challenges involved in transitioning these exciting concepts to applications in defense, homeland security, and space. We were fortunate to showcase advanced micro and nanoscale research being conducted by the Air Force Office of Scientific Research, National Institutes of Health, Department of Energy, Office of Naval Research and the Naval Research Laboratory, Army Research Office and the Army Research Laboratory, NASA, and the Defense Advanced Research Projects Agency.

Thanks to our distinguished contributors, in this proceedings volume you will find papers covering a breathtaking range of topics from graphene-based nanoelectronics to advanced standoff detection of chemical and biological agents. This year we have continued an exploration of the component technologies required for ARL's Micro Autonomous Systems. The availability of long-lived, miniaturized power sources for these systems has been identified as a critical challenge that needs to be addressed for various mission applications. Attempting to answer this need are efforts aimed at harvesting and storage of energy using micro and nanoscale devices.

Micro and nano sensors continue to be an important focus of this conference, with exciting developments in non-silicon materials development, micro/nano fabrication techniques, and new device architectures for mechanical, chemical, and biological sensors. In the MEMS-based optical devices arena, our authors have reported the creation of new devices for imagers and detectors in the visible and infrared spectral ranges. Last but not least, exciting developments in nanophotonics were reported including the demonstration of the first nanoscale laser based on plasmonics.

Thomas George
M. Saif Islam
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Opportunities in Basic Research for Battlefield Sensing (Overview)

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ABSTRACT

Battlefield sensing is a complex, crucial tool that allows the soldier to sense/detect potential threats in order to maintain a safe environment. Its technological development is typically driven by a myriad of field requirements. A variety of chemical sensing technologies currently exist, and there are also many prospects for the development of new, revolutionary technologies.

Keywords: chemical sensing, surface chemistry, molecular recognition

DISCUSSION

Detecting the presence of threats on the battlefield is of great importance to the Department of Defense (DoD). Most agencies have specific detection programs aimed at addressing the critical detection needs of their missions. The Joint Science and Technology Office for Chemical and Biological Defense (JSTO-CBD) invests specifically in development of novel chemical and biological (CB) threat capabilities. Other agencies such as DARPA, AFOSR, ONR, and JIEDDO also support detection and sensing related research. Even non-DoD organizations such as the Department of Homeland Security (DHS), the National Institutes of Health (NIH), and the National Science Foundation (NSF) recognize and manage research programs relevant to detection of hazardous materials.
While the programs mentioned above are vitally important for the development of detection systems, fundamental research to support technology development is needed. The mission of the Army Research Office (ARO) is to serve as the premier extramural research agency of the Army. ARO executes this mission by funding innovative basic research that can enable next generation advances in Army systems. In fulfilling its mission, ARO has developed a track record of funding academic and industrial researchers that advance the long term capability of the Army to mitigate existing and emerging chemical, biological, and explosive threats.

Defense detection systems are designed for many scenarios. Point detection is required to detect potentially hazardous substances in close proximity whereas standoff detection is required to detect extremely hazardous material from a distance. DoD detection systems must be able to function reliably in desert (high temperature, low humidity), jungle (moderate temperature, high humidity), and urban (among many industrial materials that would interfere with a detector signal) environments. In developing detector systems, it is imperative that the user has the ability to quantitatively and repeatedly detect threats on the battlefield in a timely manner. Not only must a threat be identified in the midst of other chemicals and substances that may interfere with the operation of the detector, the contaminant must be quantified such that an appropriate mitigation strategy can be developed. In order to appropriately perform these operations, one must design detector systems that sense a threat based on its unique physical or chemical properties and transmit the sensor response over a system that can be easily deciphered by a general operator. Key technical features associated with developing these systems are sensitivity (the concentration range over which a threat can be detected), response time, and selectivity. Optimizing one of these features in a detector usually requires a sacrifice in performance of another. The aforementioned technical features also must be integrated into systems with optimized field attributes such as cost, power consumption, reliability, maintenance, weight, and ease of operation (creating decipherable response). Efforts in electronics and signal processing, materials science, as well as fundamental physical, biological, and chemical studies aimed toward detecting.

N/MEMS: small components enable powerful Microsystems (Overview)

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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

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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KEY LESSONS LEARNED

1.1 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.

1.2 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.

1.3 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.

1.4 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.

1.5 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

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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