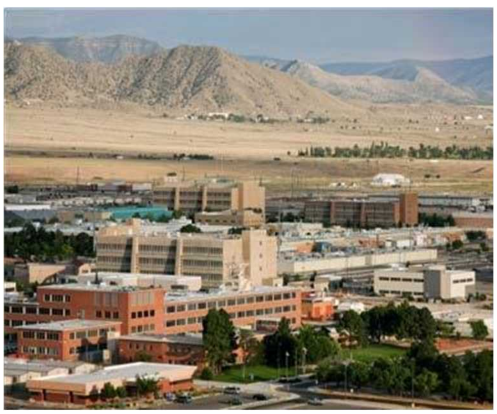
SAND2015-3604R

Nanodevices and Microsystems Research Foundation External Review Panel



February

2015

Abstracts for Presentations

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Contents

Monday, February 9, 2015 Presentations

Welcome and Nanodevices & Microsystems Research Foundation Update

Gilbert Herrera, Director, Microsystems Science & Technology

The purpose of this talk is to provide an update on the Nanodevices and Microsystems Research Foundation. Major events, key accomplishments, and statistics on the foundation will be presented.

CINT / IBL Status and State-of-Health

Grant Heffelfinger, Director, Physical, Chemical & Nano Sciences Center

The Center for Integrated Nanotechnologies (CINT) and the Ion Beam Laboratory (IBL) are key facilities within the Nanodevices and Microsystems Research Foundation (NMRF) which support the full range of Sandia mission areas. This brief provides an update on the status and operational health of these two facilities and shares recent technical advances. It will also highlight their current and future programmatic ties to the NMRF in the context of Sandia's new Strategic Plan, including Mission Areas and Research Challenges.

Customer Session

NW Firing and Embedded Subsystem Development Program and Challenges

Rita Gonzales, Sr. Manager, Firing & Embedded Systems

The B61-12 LEP, W88 ALT 370 and W87/Mk21 AFA programs are major DoD/DOE programs intended to extend the operational life of current stockpile weapon systems to maintain the U.S. strategic nuclear deterrent. Sandia's Nuclear Weapons (NW) Firing and Embedded Systems Group is responsible for development of new firing subsystems to modernize critical components for these three programs. These Firing systems are dependent on the integrated circuit development capability as well as successful creation of multiple application specific integrated circuits (ASICs) and heterojunction bipolar transistors (HBTs) developed and manufactured through Sandia's MESA facilities. The ASICs and HBTs support the execution of critical firing system operations. This talk will give an overview of the major weapon program Firing System components focusing on the critical role of the ASICs and HBTs technologies.

FPA Future Directions and DATL

Bob Habbit, Sr. Manager, Predictive Sensing Systems

The presentation will discuss emerging Remote Sensing demands and the related Focal Plane Array (FPA) requirements opening new avenues for Sandia research. The presentation will also discuss how advances in FPA capabilities will drive requirements for new approaches to next generation computing, data analytics, and power systems.

Programs Enabled by NMRF

DARPA PASCAL project and Micro-Inertial Sensors

Murat Okandan, R&D S&E, Electronics Engineer, MEMS Technologies

Micro-inertial sensors provide key performance benefits for critical Sandia systems and customer applications, such as reduced volume, higher resolution, enhanced stability and lower power. Certain configurations and integration options enable new system level approaches that are not feasible with conventional sensor assemblies. This talk will highlight:

- why we are developing these sensors (unique capabilities),
- how we are leveraging Sandia's microsystems capability that has been developed over the last two decades (MEMS, microelectronics, optoelectronics, hybrid assembly)
- what is specifically being done (PASCAL project example, ppm stable optically transduced MEMS)

Transdermal Microneedle Sensors for Medical Diagnostics and to Evaluate Human Performance

Ronen Polsky, R&D S&E, Materials Science, Biosensors and Nanomaterials

Wearable medical sensors represent a new paradigm for health care. We are developing an on-body point diagnostic system capable of monitoring an individual's local and systemic physiological state based on transdermal microneedle sensors. Microneedle-based analysis systems enable minimally-invasive interrogation due to their ability to puncture the skin's stratum corneum and access interstitial fluid without irritating deeper layers of the skin associated with pain, blood flow, or sensation. The predominant use of these microneedles has been drug delivery, and there has been little research on the use of microneedles for minimally invasive point-of-care sensing. Additionally, no current forms of microneedles are capable of performing long term sensing or providing drug injection feedback loops for a “sense-respond“ platform. We have previously tailored hollow polymeric microneedles for the ex-vivo detection of glucose, lactate, ascorbic acid, peroxide, and electrolytes such as K+. The realization of an onbody microneedle diagnostic device would allow for real time and long term analysis of physiological markers to measure an individual’s immediate state of health and report on human performance.

Revolutionary SWaP Capability from Ultra-Wide-Bandgap Power Electronics

Robert Kaplar, R&D S&E, Electrical Engineer, Rad Hard CMOS Technology

Wide-bandgap semiconductors, defined as materials with bandgaps greater than about 3 eV, have already revolutionized several fields including lighting and high-frequency electronics. More recently, wide-bandgap materials such as Silicon Carbide and Gallium Nitride have been applied to power electronics, where high voltages and currents must be converted from one form to another. The superior properties of the wide-bandgap materials compared to Silicon, such as high critical electric field and low intrinsic carrier concentration, lead to system-level advantages for power conversion, for example increased conversion efficiency and higher power density. The ubiquity of power conversion and the potential advantages of WBG materials have thus generated great interest in power devices made from these new semiconductors. However, even greater gains may be achieved through a revolutionary new class of “ultra” wide-bandgap materials such as Aluminum Nitride with bandgaps approaching 6 eV. Research into ultra-wide-bandgap materials is still in its infancy, and many fundamental materials science and device physics challenges must be solved before these new materials can fulfill their potential. This presentation will describe Sandia’s new Grand Challenge LaboratoryDirected Research and Development project focused on ultra-wide-bandgap semiconductors for power electronics.

Overview of the Hardware Acceleration of Adaptive Neural Algorithms Grand Challenge

Brad Aimone, R&D S&E, Cognitive Systems, Data-driven & Neural Computing

The Hardware Acceleration of Adaptive Neural Algorithms (HAANA) Grand Challenge is a new LDRD project at Sandia that is aiming to develop sophisticated neural-inspired computing solutions to cyber security and other national security challenges. HAANA consists of three primary efforts: (1) neural algorithms research with the goal of advanced functionality and performance in pattern recognition, feature detection, and decision making; (2) neural architecture development, which targets the development of new computing architectures which enable our envisioned algorithmic solutions to be practically deployed; and (3) novel resistive memory device research focused on the development of future hardware that is capable of learning and adaptation on chip. Supporting these efforts is a crosscutting model and simulation effort that will help guide our developments. Here, I will summarize the broader landscape of the neural computing field and where HAANA fits in, survey the technical challenges of the HAANA project, and highlight the motivations for our efforts as well as HAANA's near-term and long-term goals.

Photonics and Optoelectronics

Electrically Tunable Metamaterials for Agile Filtering in the Infrared

Igal Brener, R&D S&E, Optical Engineering, Applied Photonic Microsystems

Multispectral infrared (IR) imaging systems use multiple detector arrays and static filters that increase their weight, cost and complexity. Such systems could be greatly improved through the incorporation of fast, pixilated, electrically tunable filter arrays that are tightly integrated with focal plane arrays. Previous attempts at tunable IR filters have used Fabry-Perot cavities, photonic crystals or other multi-stacks in conjunction with MEMS, mechanical or temperature tuning approaches. None of these approaches can provide microscale, thin, high optical performance, and electrically and individually tunable IR filter arrays.

In this project we proposed to create compact semiconductor based tunable infrared filters using electrically tunable planar metamaterials. we used two approaches: i) coupling metamaterials to epsilonnear-zero (ENZ) modes in doped semiconductors; ii) use engineered transitions between conduction subbands in coupled semiconductor quantum wells and superlattices to obtain electrically induced permittivity changes, for example by Stark tuning the electronic levels

Tuesday, February 10, 2015 Presentations

Photonics and Optoelectronics (Continued)

GaN Unipolar Optical Modulators

Allen Vawter, R&D S&E, Optical Engineering, RF/Optoelectronics

The GaN Unipolar Modulator LDRD explores a new class of optical data using intersubband transitions in GaN/AlN materials. Conventional optical modulators change transmitted light intensity by modulating the interband (electron to hole, e-h) absorption energy and are made from InGaAsP/InP materials at telecom wavelengths (~1.5 µm). The small band-gap, long carrier-recombination lifetime and smearing of the e-h energy separation versus carrier density limit the operating temperature, saturation power and recovery time of the modulation. We are using the extremely fast phonon-assisted relaxation times (~100 fs) and the high density-of-states of the intersubband (ISB) transitions (electrons in the conduction band) in GaN/AlN quantum well (QW) structures to create a pathway to improved saturation power, recovery from saturation, and operating temperature in optical intensity modulators operating at ~1.5 um.

Early Career

Nano-Structured Silicon Phononic Crystals with Metal Inclusions for ZT Enhancement Proof-of-Concept

Charles Reinke, R&D S&E, Optical Engineering, Applied Photonic Microsystems

In this work, we demonstrated engineered modification of the propagation of thermal phonons in silicon using phononic crystals. This work continued previous activities at Sandia National Laboratories on micro-scale thermal conductivity, and extended that work to address the electrical conductivity as well. These efforts culminated in a significant reduction in the thermal conductivity of silicon using phononic crystals with metal inclusions to concurrently enhance the electrical conductivity, resulting in a theoretical improvement of the thermoelectric figure-of-merit by a factor of 5 as compared to the bulk value. A theoretical model was also developed that includes the phonon dispersion of the structures and the mean free path distribution of thermal phonons to provide the most accurate prediction of thermal conductivity in periodic micro-scale structures published to-date.

Surface and Area Effects on Leakage Current of Group III-V Heterojunction Bipolar Transistors (HBTs)

Darin Leonhardt, R&D S&E, Materials Science, RF/Optoelectronics

The group III-V heterojunction bipolar transistors are an important class of devices with high relevance to Sandia's nuclear weapons missions. However, III-V based devices are particularly vulnerable to surface leakage currents stemming from poorly passivated surface states, which is a well-known problem in III-V device research. In this work, we focused on characterizing sources of leakage current in these devices. We discovered that the dominant leakage current at large reverse biases stems from band-to-band tunneling, while surface leakage current dominates at small biases and lower temperatures. Electrostatics modeling indicates that tunneling is likely occurring at the interface of the base/graded layer/collector of the device. Furthermore, our model indicated that tunneling could be significantly reduced by adding donors to the graded layer or reducing the doping in the collector. Lastly, we present some promising new material combinations for next-generation HBTs.

Beyond Moore Technologies

Understanding TaOx Memristors: An Atoms Up Approach

Matthew Marinella, R&D S&E, Electrical Engineering, Rad Hard CMOS Technology

Dynamic random access memory (DRAM) and flash memory technologies are nearing physical scaling limits, and are starting to require significant switching energy compared to other components of modern computing systems. Hence, interest and research in emerging memory device science has increased, and transition metal oxide resistive switches, or memristors, have been identified as one of the most promising devices. This memory is highly compatible with CMOS integration and hence, is a strong candidate for radiation hard memory. Furthermore, the analog behavior of a memristive memory cell mimics that of the human neuron, suggesting that it has the potential to enable neuromorphic computing. This presentation will discuss our multifaceted effort recently undertaken to fabricate devices with consistent attributes and understand the specific phenomena responsible for bipolar resistance switching in tantalum oxide films (TaO_x) memristors. This includes experimental investigations using in situ high resolution transmission electron microscopy (TEM) in conjunction with electron energy loss spectroscopy (EELS), time domain thermoreflectance (TDTR), and interactions of ions with the switching films. Finally, the physical models of resistive switching in different regimes derived from these experiments will be presented.

Beyond Moore's Law Through 3D-IC Fabrication

Bruce Burckel, R&D S&E, Optical Engineering, Applied Photonic Microsystems

Since the invention of the clean room, Sandia National Laboratories has made many contributions to the semiconductor industry in general, and the application of integrated circuits to national security missions, specifically. The "Beyond Moore's Law Through 3D-Integrated Circuit Fabrication" LDRD aims to follow in these footsteps. Using a patented fabrication technique developed at Sandia National Laboratories, membrane projection lithography (MPL), the goal of the program is to create the first ever device-level 3D integrated circuits and explore the merits of these devices to potentially increase performance while making the circuits more difficult to analyze. A secondary goal of the program is to leverage the capability to fabricate micron-scale 3-dimensional structures necessary to create the 3D-ICs by creating 3D-micron scale structures for hybrid CMOS-electromagnetic and CMOS-bio applications. This presentation will outline our research approach and present our progress toward generalizing MPL into a generic micronscale 3D fabrication technique as well as recent successes in creating both electromagnetic and biorelated structures.

Nanoscale and Microscale Enabled Performance

Applications of Microwave Frequency Nano-Optomechanical Systems: Oscillators, Circuits, and Sensors

Matt Eichenfield, R&D S&E, Electronics Engineering, MEMS Technologies

Here we will present our development efforts on a Nano-Optomechanical Massive MEMS Accelerometer (NOMMA), a milligram-scale MEMS proof mass integrated with optomechanical displacement sensors. The NOMMA has the potential for very high performance with extremely low Size Weight and Power (SWaP) and cost. Initial analysis of the NOMMA shows promise of a small, rugged, low power accelerometer in a relatively small package (~0.25 in3) which includes the integration of the optical source and detector. We are simultaneously utilizing deep reactive ion etching (DRIE) technology and state-of-the-art surface micromachining to realize the necessary millimeter and nanometer features in the same device. This architecture enables more than an order of magnitude greater sensitivity of any other known MEMS accelerometer, accomplished by separating the thin films needed for the optical transduction from the much larger bulk silicon inertial sensing structure yielding a robust and manufacturable sensor. In addition, this new sensor architecture enables vertical integration with the laser and photo detector allowing full optical signal chain integrated at the chip level, dramatically reducing the footprint of the sensor.

Fabrication and Characterization of a Single Hole Transistor in p-type GaAs/AlGaAs Heterostructures

Lisa A. Tracy, R&D S&E Physics, Quantum Phenomena

One of the leading candidates for a solid-state quantum bit is the spin of a single electron confined in a semiconductor. Coherent control of individual electron spins has already been demonstrated in quantum dots in high-mobility 2D electron systems in GaAs/AlGaAs heterostructures. The major source of decoherence in such experiments is the coupling between electron spins and nuclear spins in the host GaAs semiconductor. It has been proposed that hole spins in GaAs would be better suited for such experiments due to a lesser coupling between hole and nuclear spins. To date, experiments on single spins in semiconductor quantum dots have primarily focused on electron spins, mainly due to the difficulty of fabricating electrically stable nanostructures (such as quantum dots) in p-type GaAs/AlGaAs heterostructures. We recently demonstrated the world's first p-type double quantum dot in a GaAs/AlGaAs heterostructure. Using charge sensing, we have shown the ability to completely empty the dot of holes and control the charge occupation in the few-hole regime. The device design allows for control over the coupling between dots over a wide range, from formation of a large single dot to two well-isolated quantum dots. Similar devices should allow us to pursue more advanced experiments focusing on manipulation of single hole spins in GaAs quantum dots.

Wednesday, February 11, 2015 Presentations

Operational Review

MESAFab Operations and Production Overview

Dale Hetherington and Alan Mitchell, Managers, MESA Fab Operations

We present an overview of the MESAFab operations and production activities at Sandia's Silicon and Microfab facilities. This talk will describe the concurrent R&D and production work, highlighting the successes in 2014 and the opportunities moving forward in 2015. An update on the Sandia Silicon Fab Revitalization (SSiFR) is also given.

MESA's Path to Production Readiness

Kaila Raby, Manager, NW ASIC Product Realization

The presentation "MESA's Path to Production Readiness" will talk to MESA's Nuclear Weapons (NW) mission for supporting the current NW modernization programs. The talk will focus on the activities, since the last EAB, which have occurred to prepare for production, including MESA's Trust posture, Electronic Production Control Systems, Capacity Modeling, and lessons learned from completion of W761 components production.

CMOS8: Sandia's Next-Generation Strategic Rad-Hard CMOS Technology

Paul Dodd, R&D S&E, Electronics Engineering, Adv MicroElec & Rad Effects

The Sandia Silicon Fab Revitalization (SSiFR) project will lead to a recapitalized silicon microelectronics facility at Sandia based on 8" wafers. As an additional benefit, the toolset will be capable of producing 180-nm CMOS electronics, a two-generation jump from Sandia's current 0.35-µm CMOS7 strategic radiation-hardened technology. In this talk, we will describe the development of a new 180-nm strategic radiation-hardened CMOS technology (CMOS8) with dramatic improvements in density, speed, and power consumption. Potential customer applications, proposed approaches for radiation hardening, and recent progress will be reviewed. As the first new rad-hard CMOS technology development at Sandia in more than a decade, CMOS8 offers challenges and opportunities for a renewed understanding of the science and engineering of radiation effects in advanced technologies.