SANDIA REPORT
SAND2001-1868
Unlimited Release
Printed July 2001

External Review for Sandia National Laboratories Microelectronics and Photonics Program 2000 Review

Marion W. Scott and Eva T. Wallace

Prepared by
Sandia National Laboratories
Albuquerque, New Mexico 87185 and Livermore, California 94550

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under Contract DE-AC04-94AL85000.

Issued by Sandia National Laboratories, operated for the United States Department of Energy by Sandia Corporation.

Available to DOE and DOE contractors from
U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831

Telephone: (865)576-8401
Facsimile: (865)576-5728
E-Mail: reports@adonis.osti.gov
Online ordering: http://www.doe.gov/bridge

Available to the public from
U.S. Department of Commerce
National Technical Information Service
5285 Port Royal Rd
Springfield, VA 22161

Telephone: (800)553-6847
Facsimile: (703)605-6900
E-Mail: orders@ntis.fedworld.gov
Online order: http://www.ntis.gov/ordering.htm

SAND 2001-1868
Unlimited Release
Printed July 2001

External Review for Sandia National Laboratories Microelectronics and Photonics Program 2000 Review

Marion W. Scott and Eva T. Wallace
Microsystems Science, Technology and Components
Sandia National Laboratories
P. O. Box 5800
Albuquerque, NM 87185-1425

Abstract

The US Department of Energy requires a periodic "Self Assessment" of Sandia's Microelectronics and Photonics Program. An external peer review of this program is held approximately every 18 months, and the report from the external review panel serves as the basis of our DOE "Self Assessment." The panel is comprised of leading experts in the fields of microelectronics, photonics, and microsystems from the Universities, Industry, and Other Government Agencies. The panel reviewed the Microelectronics and Photonics Program on October 2-3, 2000, and this report presents their findings.

Results of External Review for Sandia National Laboratories Microelectronics and Photonics Program (October 2000)

The US Department of Energy requires a periodic "self assessment" of Sandia's Microelectronics and Photonics Program. An external panel review of this program is held approximately every 18 months, and the report from the external review panel serves as the basis for the DOE "self assessment." This review was held on October 2-3, 2000 at Sandia National Laboratories, Albuquerque, NM. The panel was comprised of leading experts in the fields of microelectronics, photonics and microsystems from universities, industry and other Government agencies. A complete list of panel members is shown after the attached report.

The panel rated Sandia's Microelectronics and Photonics Program as "outstanding" overall. The attached report was prepared by the panel members in a format requested by Sandia to conform with the performance criteria for the DOE self assessment."

ATCH: External Review for Sandia National Laboratories Microelectronics and Photonics Program October 2000

External Review for Sandia National Laboratories
Microelectronics and Photonics Program
October 2000

I. EXECUTIVE SUMMARY

Strategic Technology and Business Issues

The committee regards the execution of the Sandia National Laboratories (Sandia) mission to be a vital strategic resource for the nation. In this review, the connection of the developing laboratory strategy regarding the new Microsystems and Engineering Sciences Applications (MESA) program, and its connection with radiation hard and Microsystems development was well articulated. Differentiated values regarding design for higher levels of surety were developed. These included the use of advanced radiation hard Silicon Insulator (SOI) devices, Microelectromechanical Systems (MEMS) and optical communication for functions essential to the long-term national security mission.

The committee's consensus review included these observations and recommendations.

Sandia needs to continue to lead technology development in radiation hard microelectronics. Resources for radiation hard parts need to be continually assessed for capability under the scenario of urgent contingencies.

The core mission of ensuring the availability of components for safe status, arming and fusing of weapons over their expected lifetime continues to be critical. A strategy to ensure availability of microelectronics systems for that mission has been developed and is being implemented. Broadened national mission elements in: 1) Non-proliferation and materials controls (nuclear detection and surveillance); 2) Energy and Critical Infrastructure (pre-emptive robustness for energy capabilities and safety for information and transportation infrastructures); 3) Emerging national security threats (anti-crime and anti-terrorist technologies) are, appropriately, gaining greater relative importance in the post cold war era.

The strategy to engage broadly, using partnership strategies with the commercial infrastructure, continues to serve Sandia and the nation well. This strategy not only provides awareness, and leading edge capabilities, but also leverages a very large resource composed of expertise in the overlapping areas of focus.

However, Sandia should maintain and develop suitable unique scientific and technical capabilities to address the challenges discussed by the panel and Sandia management.

II. ASSESSMENT PERFORMANCE MEASURES

A. Quality of Science and Engineering

The Science and Engineering objective overall was judged to be "excellent to outstanding."

Observations:

- Sandia can ensure reliability in 1E6 to 1E9 ranges.
    - Sandia faces a challenge due to simultaneous stochastic events. The quantification of reliability in that eventuality is open.
    - Definition of reliability with small numbers is an issue

Recommendations:

- Sandia should determine whether Integrated Microelectromechanical Systems (IMEMS) with Complimentary Metal Oxide Semiconductor (CMOS) is essential to MESA. If so, plan to reinstate IMEMS.

- Sandia should closely review the technical risks of the rad-hardening of the Pentium.

B. Program Performance, Management, and Planning

The objective "Program Performance, Management, and Planning" was judged to be "outstanding."

Mission: Founded upon Truman's expectation in 1949: "…to render exceptional service in the national interest.", Sandia is a "National Security Laboratory", providing capabilities in the following areas:

- Nuclear Weapons - In particular, the electronic non-nuclear components, which provide safety, security and reliability.

- Non-proliferation and Materials Controls - Nuclear detection and surveillance.

- Energy and Critical Infrastructure - Pre-emptive robustness for energy capabilities, and safety for information and transportation infrastructures.

- Emerging National Security Threats - Anti-crime and anti-terrorist technologies.

These four mission based areas represent strategic business units (SBU) for Sandia. The technology areas of Microsystems, modeling, engineering and manufacturing, as well as "surety science", provide the developmental resources to support programs in the SBU areas. In addition, the research foundations of SNL are composed of 5 laboratories: Microelectronics and Photonics, Materials and Processes, Computational Sciences, Pulsed Power and Engineering Sciences.

-Vision: Management has created a vision that provides for a value proposition based upon the strategy of "Sense, think, act and communicate."

- Examples of the strategy implementation include *sensing* with chemical and biological sensors and other microsystems, *thinking* with ASIC chip design, *acting* with MEMS, and *communicating* with Vertical Cavity Surface Emitting Lasers (VCSELs). This guiding vision is key to the integration, which includes packaging, and will take place in the future within the MESA program..

- An additional strategy is to develop and leverage the industrial and academic infrastructure to support the elements of the mission. This is to be done through partnerships.

- Finally, Sandia has created a vision of ***Integrated Microsystems*** that allows the sense, think, act and communicate functions to be integrated. This is much more than scaling integrated circuits and represents a new vision for creating an electronics capability for the 21st century.

- The Sandia internal customers are not always proficient at defining their needs. However, management processes now in place help to do this.

- Customers have shown support for the specific program MESA and the solutions proposed.

- The SBU process is widening opportunities, but a process for narrowing the scope of these opportunities is essential. There is concern over management of the complexity of the solution. Because there are many options, wise choices must be made.

- Staffing is an issue of the recent past; good programs attract good people, i.e. Sandia has an environment that can't be provided in industry.

- There was concern over "make vs. buy" decisions for components, with respect to MDL stability and availability in the commercial marketplace.
    - If Sandia makes it, revenue is generated. If made outside, Sandia loses the use of the revenue. Accordingly, make insures stability.
    - If internally made, it is unavailable to others, with the exception of government customers. There was a decision to develop analog Advanced Silicon Integrated Circuits (ASICs) elsewhere, albeit not off the shelf.
    - Regarding the use of infrastructure developed capabilities, Sandia can always analyze and say no.

Recommendations:

- For partnerships, Sandia should develop a strategy for securing venture capital that can be associated with launching spin-offs.

- Sandia should ensure security of the stockpile through a balanced approach to obtaining components through internal development, and commercial off-the-shelf buys.

- SNL needs a "Marketing Strategy" to grow "wedges" other than Nuclear Weapons, based upon chemical and biosensors, microelectronics and integrated Microsystems.
    - The assumption is that Nuclear Weapons are going away, and replacement missions are just as important to the nation.
    - Examine the needs of the medical and the environmental communities.

C. Relevance to the National Needs and Agency Mission

The objective of "Relevance to the National Needs and Agency Mission" overall was judged to be "outstanding".

The overall relevance of the programs reviewed to meet the needs of the Defense Program (DP) mission is outstanding.

Observations:

- The presentations were impressive with regard to safety, security, etc., and were considered the key drivers. However, cost reduction of the overall program through high reliability standardization was also expressed.
- Certain technology elements were defined on an as-needed basis.
- The presentations established a compelling basis for an outstanding rating.
- A process was in place for decision-making that spanned the mission, the vision, and all the way through to the deliverables.
- - Sandia recognizes that working with other agencies and collaborating groups, such as the Air Force, is important.
- "Industry best Practices" are being adopted.
    - Sandia's management vision is driven by value propositions for how technology and products can be delivered to the SBUs .
    - Inputs to value propositions are obtained from a wide spectrum of councils and committees.
    - Budget constraints demand an efficient management process.
- A clarification of the mission relevance and complexity was developed through the concept of SBUs.
- A connection between the new program MESA and the MDL was made.
- Partnerships lead to new businesses and spin-off models.
    - Awareness of external capabilities is important to define total capabilities. This is done through engagement with the external infrastructure.
- SNL is proactive in the generation of Cooperative Research and Development Agreements (CRADAs).
    - RFP/Q type responses, for example, the EUV program

Recommendation:

- Sandia should not allow partnerships to be defocusing, but rather, synergistic.

D. Performance in the operation of a major Facility

Facilities overall were judged to be "outstanding".

Observations:

- Planning for MESA is a key part.
- A more business like approach was evident since the last review.
- The recapitalization plan is working.
- Operation of the MDL was well focused, run with metrics that are well communicated.
- MDL is delivering products that the mission wants.
- It appears that MESA will be funded on time with the differentiating vision.
- MESA is a unifying program, making use of the core competencies of Sandia.
- MESA is key to the next level of capitalization and new enabling equipment.

Recommendations:

- For Sandia, 6" wafer size is acceptable for > 10years
- Be careful of the design rule gap for Sandia applications, 0.35 vs 0.18 (commercial) and the gap is getting larger. Be mindful of the implications.

III. SPECIFIC PROGRAMS REVIEWED

A. Managing Science and Technology to meet Defense Program Needs - Rick Fellerhoff

Weapon designers have recently studied Sandia's in-house S&T capabilities to evaluate readiness to support upcoming subsystem replacements. One aspect of these studies has focused on Microsystems needs, procurement and risk mitigation strategies, and cost of operations of the MDL. To extend weapon life, the W80 and W76 are scheduled for subsystem replacement. Considering other options available, Sandia's in-house design and FAB capabilities are key to success from both a technical requirement, and a cost basis. These studies provide the users of Sandia technology with valuable insight into the operations, costs, and configuration options that may not be immediately appreciated.

B. Photonic Crystals and Photonic Bandgaps - Mial E. Warren

There have been a series of recent breakthroughs in the realization of photonic crystals. The optical analogue of electronic crystals that use three-dimensional periodic variations in dielectric constant to radically alter the optical properties of materials. Sandia National Laboratories has adapted processes developed for silicon microelectromechanical systems, to fabricate three dimensional photonic lattice structures that exhibit the highest performance of any such structures to date. These structures are robust and mass-producible by conventional semiconductor processing techniques. Structures have been fabricated with "bandgaps" in the mid- and near-infrared, including the important communications band at 1.55 цm.

- **This work we reviewed to be in the world leading class –excellent.**
  - **a materials problem was solved**
  - **utilized good architecture**
  - **clarity and definition of use for waveguide and optical switch**
  - **needs an application for SBU customers, if one exists, the committee did not see it**
  - **needs engineering definition**

C. GaN Materials Science: Theory to Applications - Robert M. Biefeld

Sandia is exploring the growth and properties of AlGaInN alloys for possible use in optoelectronic, electronic and photonic applications. Since the demonstration of the growth of high quality GaN on sapphire substrates in the early 1990's, there has been a revolution in the amount of research on GaN-based materials. High quality LEDs have been rapidly brought to market, and blue lasers are not far behind. Research into the use of GaN for high power devices is also progressing rapidly. Work on GaN materials covering the fundamental, first principle modeling studies of hydrogen behavior in GaN, to actual device demonstrations will be presented. The growth of quaternary AlGaInN alloys and their demonstrated use in ultraviolet LEDs has been explored. *In-situ* stress monitoring and control during the metal-organic chemical vapor deposition of AlGaN/GaN, distributed Bragg reflectors (DBRs) to eliminate cracks and enable the demonstration of the first solid state ultraviolet vertical cavity surface emitting laser (UV-VCSEL) has been employed. GaN transistors on Si substrates using novel growth techniques to address the lattice mismatch between GaN and Si are being developed. Novel growth techniques to minimize the formation of threading dislocations in GaN grown on both sapphire and Si are also being developed. These newer techniques should enable the demonstration of higher quality devices on both Si and sapphire substrates.

This is outstanding science

- **Many potential applications, an umbrella opportunity.**
- **The originality of the dislocation-free lateral growth was unclear.**
- **The making of compounds is a value added process technology.**
- **Pursue DOE workshop(s); drive to define use.**
    - **The market for energy conserving light sources is important to DOE.**
    - **Communications applications.**
    - **Pursue applications of this technology in sensing and monitoring.**

D. Chemical and Biological Microsensors -Steve Martin

Chemical and biological microsensors are under development to address a number of the needs of Sandia's SBUs. This includes sensors for chemical and biological warfare agents that can be used in counter-proliferation and battlefield applications. It also includes chemical sensors to detect corrosive environments and degradation by-products inside nuclear weapons, enabling self-monitoring weapon systems. Our strategy has been to utilize Sandia's unique microfabrication capabilities to build small, smart sensor systems. This has led to the evolution of sensors from discrete devices to integrated sensors (including on-chip electronics) to microanalytical systems (including micromachined structures for chemical separation). This has resulted in a marked decrease in system size and an increase in functionality. Several examples of chemical and biological sensors under development will be described. In particular, recent advances in biosensor development will be highlighted.

- **Chemical and Biological sensor work is outstanding.**
- **Important to limit to mission applications.**
- **Sandia should exploit its leadership in this area to develop new markets.**
- **Sandia should maintain its differentiating edge in this area by using its core competencies.**
- **Early insertion technology should be sought for applications.**
- **Re: Bio component, recommend teaming for added success. Staffing and strategic partners (with the right competencies) are key.**

- **Sandia should seek national coordination with DARPA, possibly through SBU sponsorship.**
- **Continue to demonstrate leadership role either DOE (DTRA) for coordinating.**

E. Sandia's Radiation Hardened Microelectronics Strategy & Program- Mike Knoll

Radiation hardened microelectronics are critical to Defense systems because commercial-off-the-shelf integrated circuits (ICs) will not meet radiation requirements. Sandia's microelectronics strategy is to buy commercial parts when they meet mission needs, and to maintain in-house research, technology, and product capabilities. This allows technologies to be transferred to industrial partners for manufacturing, and as required, to supply product to systems customers using the Microelectronics Development Laboratory (MDL) facilities.

The needs of system customers drive Sandia's microelectronics capabilities. Sandia microelectronics include the Nuclear Weapons program (Stockpile Life Extension Program as well as advanced development programs), nuclear non-proliferation programs (satellite payloads), and low volume custom ICs for other government agencies. Sandia microelectronics has provided over 15 different chip types to system customers in the past 2 years, and is developing 5 different product types in FY01. To support these customer needs, Sandia' MDL is developing two different IC technology generations, which are a .5 μm CMOS bulk mixed signal technology, and a .35 μm CMOS/SOI digital technology.

This briefing described: 1) The status of the commercial radiation hardened integrated circuit (IC) industry; 2) our system customers; 3) the strategy to address our system customer's rad hard IC needs (specifically, why does Sandia have an in-house radiation hardened integrated circuit (IC) fabrication and product capability?); and 4) the rad hard IC infrastructure, CMOS technology roadmap, and current and planned product deliveries.

F. Satellite Applications (for Radiation Hardened Microelectronics) - Anthony Medina

Since 1963, Sandia National Laboratories has provided unique capabilities in space to meet nuclear treaty verification, remote monitoring, and other national needs. These programs have been sponsored primarily by the DOE and USAF, for use by the DoD and other government agencies. Sandia's ability to provide this service has been made possible by leveraging off the corporate technology base in numerous technical specialties, with one of the most dominant being Sandia's radiation hard microelectronics program. As more and more commercial companies discontinue work in the area of radiation hard microelectronics , it is imperative that Sandia maintain its full complement of radiation hard microelectronics facilities and capabilities.

Both Rad Hard programs were judged to be "excellent to outstanding".

- **SOI rad hard is key to success of Nuclear weapons program.**
- **Pentium is a good idea:**
  - **Can prove to be commercially valuable.**
  - **Review risks to show implementation in MDL.**
  - **Don't get too far behind leading edge.**
    - **(now 0.35 vs. 0.18, but will be 0.13 micron in 2 years)**
- **This program has very high visibility.**
  - **Overwhelm for success, key for MESA.**

- **Drive for early Si proof-of-concept @ 0.35micron to support timely MESA funding.**

G. Technology Partnerships at Sandia - Gilbert V. Herrera / Rich Carson

In 1989, Congress gave the DOE National Laboratories a technology transfer mission with the goal of promoting the competitiveness of U.S. industry, relative to competition from other countries. Over the past decade, this program has evolved into a "partnership" program that reflects both the globalization of U.S. industry and the value of synergy between industrial partnerships and our DOE missions. In the process, partnerships at Sandia have become a significant source of revenue, providing over $70M of FY2000 funding. This talk will briefly describe Sandia's technology partnership program, with an emphasis on how partnerships have been of value to our Microelectronics and Photonics program.

H. Microsystems and Engineering Sciences Applications (MESA) -Don Cook

Sandia's involvement in microsystems is to realize a safe, secure, reliable, certifiable and affordable stockpile. This involves creating the required facilities and equipment to design and produce diamond-stamped components for weapons.

Microsystems Engineering is the programmatic activity to get "diamond-stamped" microsystems-based solutions into the stockpile. Design, integration, qualification and production are key elements.

MESA is the major capital construction project which will put in place the facilities and equipment required to design and produce diamond-stamped microsystem-based components for nuclear weapons. The MESA project supports the Microsystems Engineering effort. The Microsystems Engineering effort integrates essential activity for the Stockpile Life Extension Process.

I. Modeling and Simulation - Sudip Dosanjh

This presentation will provide an overview of Sandia's efforts in high performance computing. Two specific projects that are relevant to Sandia's microelectronics program will be highlighted. One project is fairly mature and has developed the capability to perform large, complex chemically reacting flow simulations for chemical vapor deposition applications. A newer effort is developing a massively parallel simulation code for modeling complex circuits. In addition, future plans for supporting MESA and micromachine initiatives will be discussed.

IV. SUMMARY

The committee strongly agrees that Sandia's Microelectronics and Photonics programs are a vital strategic resource for the nation. A value driven proposition was articulated. This is a new vision for the development of an "Integrated Microsystems" capability that implements the ability to electronically "Sense, think, act and communicate". This provides a pathway for microelectronic

application that is actually ahead of today's commercial directions. It also runs parallel to, and utilizes the core capabilities based upon Moore's law of scaling. The vision is the basis for the newly described MESA program, which will drive to implement the Integrated Microsystems capabilities.

A process was in place for decision-making that spanned the mission and vision all the way through program development deliverables. "Industry best Practices" were being adopted. These included: wide-set(s) of inputs (councils, committee, etc,). A process that defined how programs were prioritized and selected against budget constraints was articulated as part of an efficient management process.

The panel reviewed individual programs such as photonic crystals, GaN science, chemical and biological sensors, radiation hard microelectronics for weapons and satellite applications and facilities operations. The presentations established a compelling basis for and outstanding rating. These programs establish a basis for the movement to MESA and what it may provide.

The committee was pleased to see the connection between the existing programs and the MESA vision with respect to the applications of the mission critical elements related to nuclear surety. Additionally, the mission was also clearly connected (through a strategic business unit model) to the emerging missions elements in nuclear non-proliferation and materials controls, energy / critical infrastructure, and emerging national security threats, anti-crime and anti-terrorist technologies. These are, appropriately, gaining greater relative importance in the post cold war era.

In summary, the Microelectronics and Photonic capabilities at Sandia provide the opportunity to deliver exceptional service to the nation in broad areas and in changing times.

The committee was presented with a hierarchical agenda that was also dynamic and allowed for considerable discussion as we proceeded. Some mid-review items such as budget process and organization roles were discussed in an ad-hoc manner to allow the committee a better overall perspective. The composition of the committee held representatives from industry, universities, and government. The committee worked as a team and contributions were well balanced.

PANEL MEMBERS

Dr. Jack C. Boudreaux
NIST/ATP
Administration Room A231
Gaithersburg, Maryland 20899

Dr. Paul Fleury, Dean
University of New Mexico
Farris Engineering Center, Room 107
Albuquerque, New Mexico 87131

Mr. Jerry Gaspar,
Rockwell Collins MS 106-76
Cedar Rapids, Iowa 52498

Dr. Ross A. Lemons
Materials Science & Technology Division
Los Alamos National Laboratory
P. O. Box 1663 MS G574
Los Alamos, New Mexico 87545

Dr. Bob Pugh
Space Electronics and Protection Branch
Air Force Reserve Laboratory
3550 Aberdeen Ave, SE
Kirtland AFB, New Mexico 87117

Dr. Rueben F. Richards, Jr,
Emcore Corporation
394 Elizabeth Avenue
Somerset New Jersey 08873

Dr. Tom Seidel, *Panel Chairman*
GENUS
1139 Karlstad Drive
Sunnyvale, California 94089

Dr. Quat Vu
Intel Corporation
3065 Bowers Avenue MS SC1-03
Santa Clara, California 95052-8119

Dr. Kensall Wise
College of EngineeringUniversity of Michigan
2401 EECS
Ann Arbor, Michigan 48109-2122

DISTRIBUTION

1	MS 9018	Central Technical Files, 8940-2
2	MS 0899	Technical Library, 4916
1	MS 0619	Review and Approval Desk, 15102
1	MS 0612	For DOE/OSTI
1		(Each) External Panel
1	MS 0513	Alton D. Romig, 1000
1	MS 0151	Tom Hunter, 9000
1	MS 0724	Robert Eagan, 6000
1	MS 1221	James Tegnelia, 15000
1	MS 1231	Roger Hagengruber, 5000
1	MS 0102	Joan Woodard, 0002
1	MS 9001	Mim John, 8000
1	MS 0457	John Stichman, 2000
1	MS1079	David Williams, 1700
1	MS 9061	Walter Bauer, 8704
1	MS 1165	Bill Guyton, 15300
1	MS 1140	Sam Varnado, 6500
1	MS 0970	Jerry Allen, 5700
1	MS 0511	Rick Fellerhof, 1020
1	MS 0603	Mial Warren, 1743
1	MS 0601	Bob Biefeld, 1126
1	MS 0892	Steve Martin, 1764
1	MS 1071	Mike Knoll, 1730
1	MS 0971	Anthony Medina, 5730
1	MS 0157	Gil Herrera, 1310
1	MS 0323	Don Cook, 1900
1	MS 0316	Sudip Dosanjh, 9233
1	MS 1425	Marion Scott, 1707
1	MS1077	Eva Wallace, 1701
1	MS 1077	Tom Zipperian 1740
1	KAO 0184	Heather Trumball, DOE
1	KAO 1396	Larry Adcock, DOE/AL-LPD
1	KAO 1396	Steve Thompson, DOE/AL-LPD
1	Robert A. Jones DP-152, Office of Research and Testing U.S. Department of Energy, Headquarters 9901 Germantown Road Germantown, MD 20874-1290	
1	Ted Luera DOE DP-131 1000 Independence Ave. Washington, DC 20585	