MUSiC: Multi-User Silicon CarbideEXHIBIT CA National Semiconductor Research Fabrication Facility

Part 1 – Motivation and Context

Alan Mantooth



Introduction - Speaker

- □ B.S.E.E., U of A, 1985
- □ M.S.E.E., U of A, 1987
- Ph.D., Georgia Tech, 1990



□ Analogy, 1990-98 (Principal Engineer)



- U of A, Dec. 1998 (Distinguished Professor; ARA Fellow)
- Co-founded multiple startups









Office of Cybersecurity, Energy Security, and Emergency Response



Energy Efficiency & Renewable Energy













2





ARKANSAS **News item:** Semiconductor Chip Shortage

MUSiC Research Fabrication Facility

Why? Because of increasing demand by new and old products, and shortcomings in our supply chain. More and more products run on a semiconductor chip. The demand is only going to grow.



ARKANSAS The chip shortage has called attention to its critical role in our everyday life

Invented and pioneered in the United States (US), semiconductors have been an enabling technology in our way of life and the backbone of our economic prosperity and source of pride, if not symbol of American ingenuity.



Current situation also highlights that, U.S. SEMICONDUCTOR LEADERSHIP is now being Challenged by many countries Foreign control is serious trouble since Semiconductors are Critical for our National Economy and Security. Think of the impact on: High Power and Artificial Communications **Space Electronics** Intelligence Autonomous Quantum **5G** ber Security Computing vehicles **U.S. SHARE OF CHIP MANUFACTURING** FEDERAL SEMICONDUCTOR RESEARCH 2 **IS ERODING WHILE CHINA'S IS** FUNDING NOT KEEPING PACE WITH NEEDS **GROWING DUE TO GOVERNMENT INVESTMENT** .20% Share of Global Semiconductor 37% Manufacturing 1990 - 2030E .19% .15% 24% % of GDP .10% **Private R&D Spending** 10% .05% 0% .03% Federal R&D Investments .00% 1990 2000 2010 2020E 2030E 1978 1998 2008 1988 2018 U.S. ____China

At the same time *semiconductor research and innovation is expanding beyond Silicon*. Silicon Carbide is a key technology for many applications that Silicon cannot reach.

Roadmap for power SiC devices**

(Source: Power SiC: Materials, Devices and Applications 2020 report, Yole Développement, 2020)



As a result, the country that leads in advancing SiC semiconductor design and fabrication will also lead in the race to market nearly all new game-changing *economic and military* technologies.

*SiC device includes discrete diodes, transistors and modules - **Non exhaustive list of companies

ARKANSAS Will that Country be the US?

MUSiC Research Fabrication Facility

It is also *a fact* that, there are NO accessible SiC fabrication facilities in the US for researchers to prototype their ideas. Stanford guys cannot do it, MIT guys cannot do it, Caltech guys cannot do it – today only captive laboratories can do it! Every Researcher in the US has to go to a foreign country to prototype new SiC semiconductor device ideas



What's needed for US Researchers to Lead?

MUSiC Research Fabrication Facility

It is also *a fact* that a recent NSF workshop held at UA with over 70 world leading SiC researchers concluded that US Researchers desperately need access to a SiC Research Fabrication Facility to maintain our innovation and leadership in New Semiconductor Technology.

What is MUSiC?

UNIVERSITY OF

The short answer is MUSiC Takes Materials + ideas to prototype future SiC integrated circuits and power devices



ARKANSAS US Response: NSF and DOD Support Chooses UA

MUSiC Research Fabrication Facility

It is *also true* that as a result of recent proposals and peer review, NSF and ARL decided on a National SiC Research Fabrication Facility and the UA is the place do it



Congress has two Huge \$\$\$ Bipartisan Bills to aid the semiconductor industry to maintain US Leadership

ARKANSAS Why Choose the University of Arkansas?

MUSiC Research Fabrication Facility

Arkansas has successfully built a strong, multi-disciplinary program in advanced power electronics as evidenced by:

- ~\$10 million/yr in research expenditures
- 4 Centers of Excellence (GRAPES, POETS, SEEDS, CITES)
- 14 faculty across 4 departments (largest in the nation!)
- 110 graduate students (and growing)
- About a dozen full-time staff 91 journal and 79 conference papers in 2020 alone!
- 2 IEEE Transactions Best Paper Awards (2019, 2020)
- 3 R&D 100 Awards (2009, 2014, 2016)
- 4 NSF CAREER Award winners in 2018, 2019, 2021
- Facilities used at NANO, HiDEC, and NCREPT

Impact on Arkansas?

MUSiC Research Fabrication Facility

Imagine a National Facility that is the ONLY place in the US that researchers can bring their research ideas on SiC science and devices to prototype – a National Leader in Semiconductor Technology

✓ Would it be an attractor of Excellent Faculty?

NIVERSITY OF

- What about students? The semiconductor industry is and will continue to need students trained to bring ideas to prototypes.
- ✓ Would it increase our Federal and Industry Support?
- ✓ Would it lift the Visibility of the University of Arkansas?
- Would it produce the next generation of well-trained leaders in the semiconductor community?
- ✓ Would it attract industry to Arkansas?
- Could it produce new technology that becomes a source for start-up companies?

Impact: Increased Opportunities

MUSiC Research Fabrication Facility

Externally-funded research

UNIVERSITY OF

- IC Design: ~\$20M over the next 5 years
 - ARPAe, NASA, DoE, ONR, AFRL, ARL, Draper, DARPA, Sandia, and ORNL
- Sensors: ~\$15M over the next 5 years
 - DARPA, NSF, AFRL, NASA, Siemens, Ozark IC, Caterpillar, John Deere, Wolfspeed/Cree, and DoE
- Power Device Research: ~\$7.5M over the next 5 years
 - Startups, established companies, universities
- Opto-electronics: ~\$5M over the next 5 years
 - POETS, NSF, ARL, and OzarkIC
- Advanced Integration: ~\$5M over the next 5 years
 - POETS, NSF, DoE, OzarkIC, ONR, Ford, Wolfspeed/Cree, Siemens, and ARL
- Economic development
 - Growth and support of UA ARTP companies (Wolfspeed, OzarkIC, Canoo, ...)
 - Potential start of new companies in cyber and power electronics
- Collaborations
 - Expansion of existing and start of new collaborations that factor into the externally-funded research formulae
- * Growth in stature of program
 - To be the best, we have to keep moving, growing, producing

MUSiC: <u>Multi-User Silicon</u> Carbide A National Semiconductor Research Fabrication Facility

Part 2 – What's Coming Next?

ARKANSAS.

We HAVE the Team

- 1. Juan Balda, power systems and power electronics, magnetics
- 2. Zhong Chen, devices and fabrication
- 3. Jia Di, asynchronous digital IC design, cybersecurity, hardware security
- 4. Jeff Dix, analog & mixed-signal IC design, neural networks
- 5. Chris Farnell, embedded systems, cybersecurity
- 6. David Huitink, thermal management, packaging, and reliability
- 7. Qinghua Li, cybersecurity
- 8. Alan Mantooth, semiconductor device modeling, CAD, packaging, and power & analog IC design, cybersecurity
- 9. Roy McCann, power systems, motor drives, storage, cybersecurity, and controls
- 10. Yarui Peng, design automation tools
- 11. Greg Salamo, materials and devices, nitrides
- 12. Jingxian Wu, cybersecurity and communications
- 13. Morgan Ware, wide bandgap devices, capacitors
- 14. Yue Zhao, motors, machines and drives
- 15. TBH, power electronic packaging and conversion



Other Faculty Beneficiaries

- □ Fisher Yu, EE, SiGeSn semiconductors
- □ Henry Meng, ME, Atomic Layer Deposition & Batteries
- Hugh Churchill, Physics
- Space & Planetary Sciences faculty
- Materials Science & Engineering faculty
- Physics faculty
- Chemistry faculty
- Chemical Engineering faculty

UNIVERSITY OF

1

Analog Devices

We Have the Support (partial)

MUSiC Research	Fabrication	Facility
----------------	-------------	----------

2.	Caterpillar
3.	Centrotherm
4.	CoolCAD
5.	Cree
6.	Draper Labs
7.	Eaton
8.	General Electric
9.	Microchip
10.	National Security Campus (NNS
11.	Ozark Integrated Circuits
12.	Rockwell Automation

- Siemens 13.
- **Texas Instruments** 14.
- **United SiC** 15.
- **XFAB** 16.
- **ETH Zurich** 17.
- George Mason U. 18.
- **Howard University** 19.
- Illinois Institute of Technology 20.

22.	Ohio State U.
23.	Stanford University
24.	Stony Brook University
25.	SUNY Poly

KTH Stockholm

Texas Tech 26.

21.

- U. of Alabama 27.
- **U. of California, Berkeley** 28.
- U. of Colorado, Boulder 29.
- **A) 30**. U. of Illinois, Chicago
 - U. of Illinois, Urbana-Champaign 31.
- **U. of Maryland** 32.
 - **U. of Michigan** 33.
- U. of Nebraska 34.
- **U. of South Carolina** 35.
- **U. of Tennessee** 36.
- U. of Texas, Austin 37.
- **U. of Wisconsin, Milwaukee** 38.
- Virginia Tech 39.
- ARL 40.

- **ARPAe** 41.
- Fraunhofer IISB 42.
- ONR 43.
- DARPA 44.
- **DOE Vehicle Technologies Office** 45.
- **NASA Ames** 46.
- **NASA Glenn** 47.
- NSF 48.
- **Oak Ridge National Laboratory** 49.
- Sandia National Laboratory 50.



- I. The first financial path is for UA to support this effort to ensure it occurs
 - A. UA funding (phase the approach)
 - **B.** Donations
 - C. Individual grants like DURIP, MRI
- **II.** The second financial pathway is less certain
 - A. NSF Mid-Scale Research Infrastructure Grant (\$6 20 million range) -> our needs total ~\$8 million + ongoing
 - **B.** Congressional plus-up via Army Research Lab



- I. The first financial path is for UA to support this effort to ensure it occurs
 - A. UA funding (phase the approach)
 - B. Donations -> \$2M from TI and XFAB
 - C. Individual grants like DURIP, MRI -> ~\$1M award in 2020
- **II.** The second financial pathway is less certain
 - A. NSF Mid-Scale Research Infrastructure Grant (\$6 20 million range) -> notice of award for \$17.8M
 - B. Congressional plus-up via Army Research Lab -> notice of award for \$6M (\$5.4M to UA); \$5.5M in FY22 request

ARKANSAS We have begun addressing the Needs

MUSiC Research Fabrication Facility

Capital equipment (new, refurbed, upgraded)

- ✓ \$17.8M in NSF funding coming (2021)
- ✓ \$4.4M in ARL directed funding + \$1M in research (2021)
- ✓ ~\$830k in NSF Major Research Instrumentation (Chen 2020)
- ✓ \$250k/\$1M in ARL competed funding refurb only (2019-2022)
- ✓ Donations from TI and XFAB = ~\$2M
- ✓ Total = \$25.3M in equipment & staff + \$1.75M in research funding

Staff to operate and maintain the fab line (4 + postdocs)

- ✓ 3 full-time staff in NSF budget (5 years) -> Just hired Fab Manager from XFAB
- ✓ 1 full-time staff in ARL budget (1 year at a time)
- ✓ 1 post-doc in NSF budget (5 years)
- ✓ 1 post-doc in ARL budget (1 year at a time)



UA MUSiC FAB Site Planning



ARKANSAS XFAB Early Input on MUSiC Facility

MUSiC Research Fabrication Facility

MUSiC FAB Layout



Much cleaner than a medical operating room! ~23,000 sq. ft.



Financials

MUSiC Research Fabrication Facility

If staff time, service contracts, maintenance, and supplies are included, then

Expenses Expenses

- Cost to operate fab is ~\$2M/year
- Estimate does not include power

Revenue

- \$562,500 revenue per run (\$2500/mm² with 225 mm² available)
- 4 fab runs per year are required to break even; 6 is considered maximum
- Research grants ~\$3M/year easily => F&A \$500k
- Services, unique/rare equipment (epi !!), and captive runs ? (equipment mfg, universities, National labs, companies)

ARKANSAS.

Summary & Conclusions

- Recognized Power Electronics program with international credibility and collaborations (Europe, Asia, S. America)
- Substantial funds have been raised to outfit the infrastructure & begin performing the research & staff the operation
- Timing is excellent in so many ways (convergence)
- Industry needs the talent that will emerge (gray industries, offshored fab lines) -> ASA
- US is seeking to grow manufacturing in semiconductor technologies (opportunities will abound)
- MUSiC fills a gap in the manufacturing ecosystem for low-volume prototyping desired by even the largest organizations (e.g.: Rohm, UTRC, TI, Toyota, Caterpillar, John Deere, Boeing, etc.) -> XFAB
- Strategic alliances coupled with UA activity ensure capacity and usage
- Must act NOW for temporary <u>and</u> long-term solutions; opportunity does not remain available indefinitely



MUSiC Research Fabrication Facility

Back up slides

Just Look at *some* our Current Supporters/Collaborators

MUSiC Research Fabrication Facility



UNIVERSITY OF