iCAMR

International Consortium for Advanced Manufacturing Research

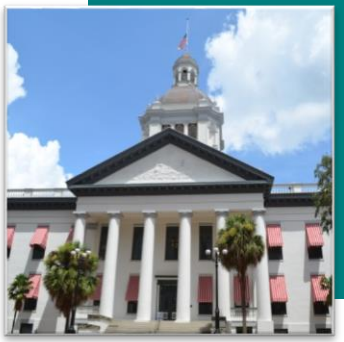
The world's first industry-led consortium (501.c.6 non-profit) for the manufacturing of advanced smart sensors and integrated devices

ICAMR: A New Era of International Collaboration

Innovation Networks & Open Innovation Programs That Bring Industry, Universities And Governments Together

Industry

- Emerging Technologies
- Manufacturing
- Commercialization



Government

- International
- State of Florida
- National research labs and agencies
- Attract joint funds

Universities

- Universities in U.S., Europe, and Asia
- Funded research
- New ideas and approaches
- Partnered research capabilities

Suppliers

- Equipment
- Materials
- Software
- Industry R&D Labs & Programs

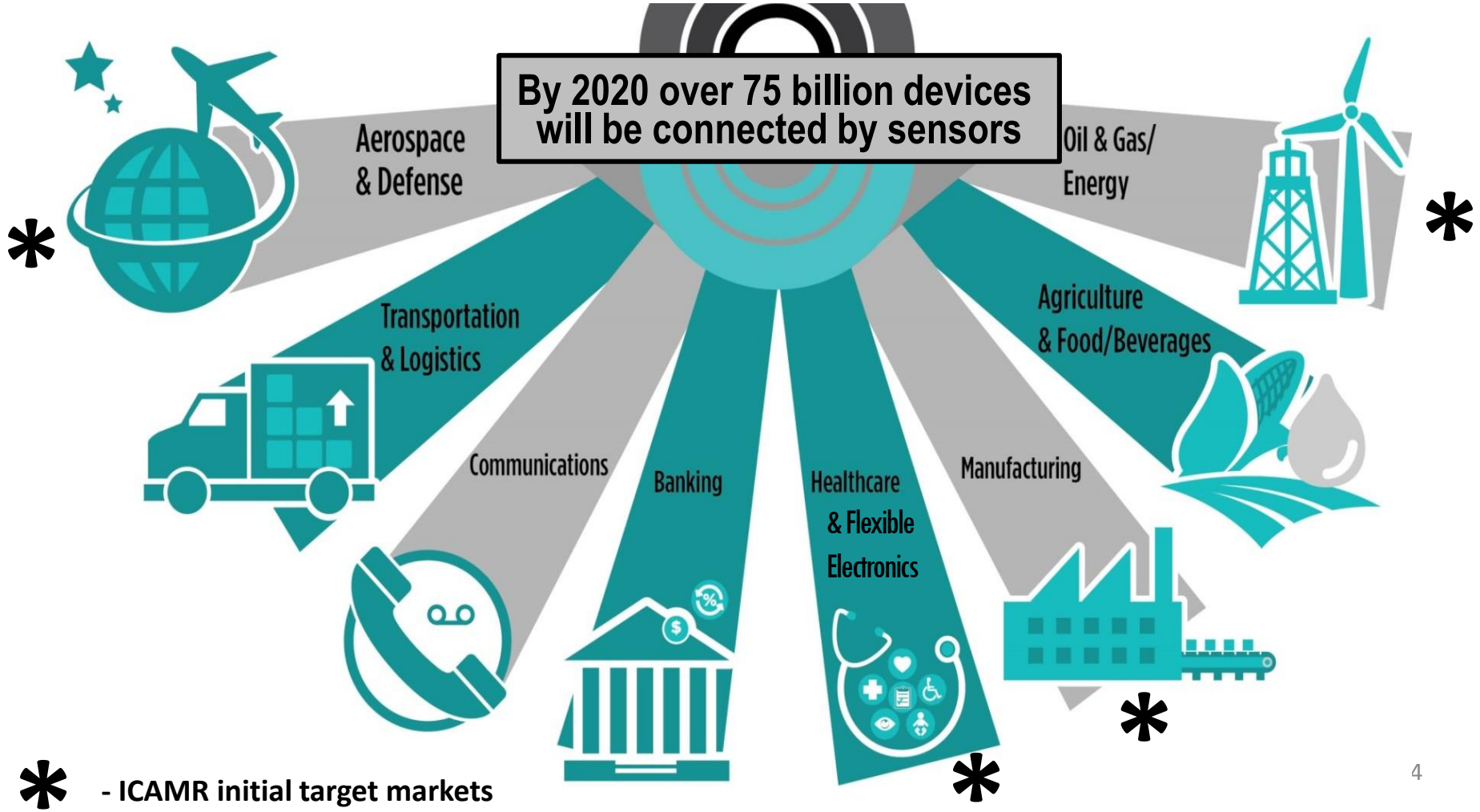
Programs

ICAMR is a 501.c.6 industry-led consortium that will provide open-innovation platforms that drive high-tech manufacturing through:

- **Manufacturing scale-up of III-V and other novel materials**
  - Faster performance at lower power, wide band gap, high voltage and frequency stability, chemical and extreme environment robustness,…
- **Development of High Volume Manufacturing process equipment for next generation production lines & "Trusted Foundries"**
- **Integration of advanced devices and systems on 200 & 300 mm Si**
  - Silicon is the ultimate integrator – can add virtually any device all on one carrier, at any technology node
- **2.5 / 3-D device integration, and advanced packaging techniques**
- **Development of new test, metrology, reliability models for next generation materials**
- **Workforce development**

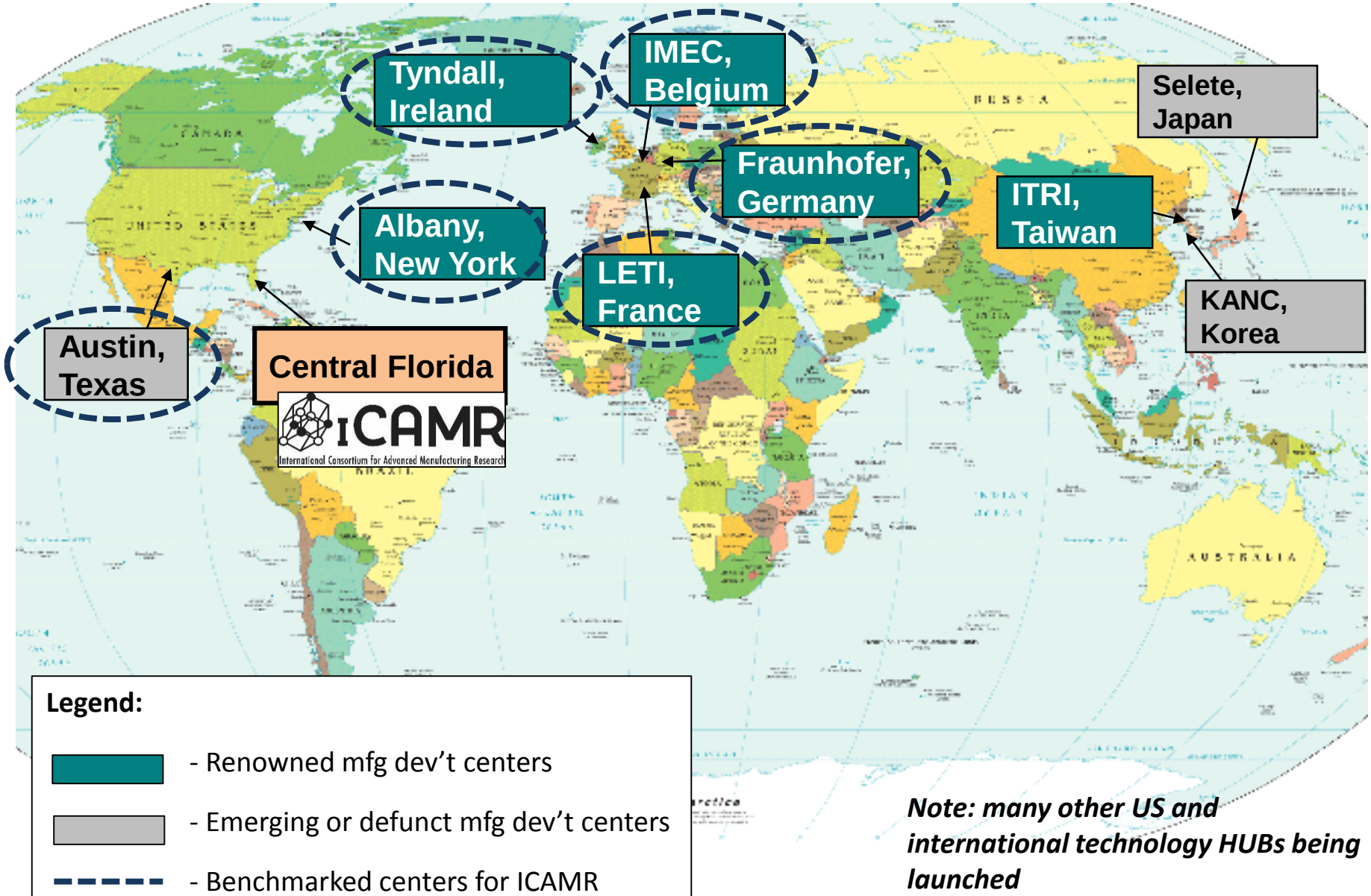
The Promise of Smart Sensors

Next disruptive market explosion will be “semiconductor-based” connected devices – led by advanced sensors and complimentary photonic devices



* - ICAMR initial target markets

Renowned Manufacturing Development Centers

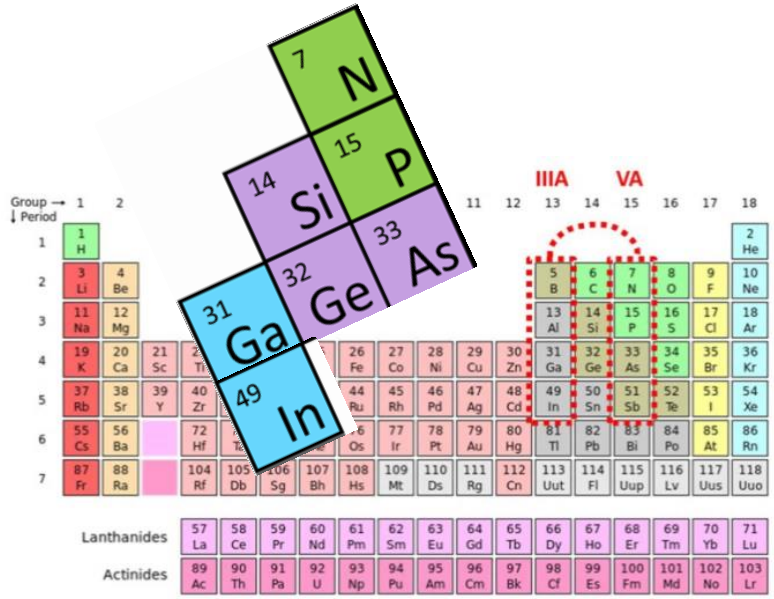


Initial Focus: Smart Device Fabrication

1.
ADVANCED MATERIALS DEVELOPMENT

III-V and other novel materials deposited on 200mm/300mm Si substrates for advanced devices:

- ***Sensors***
- ***Photonic devices***
- ***Integrated CMOS devices***

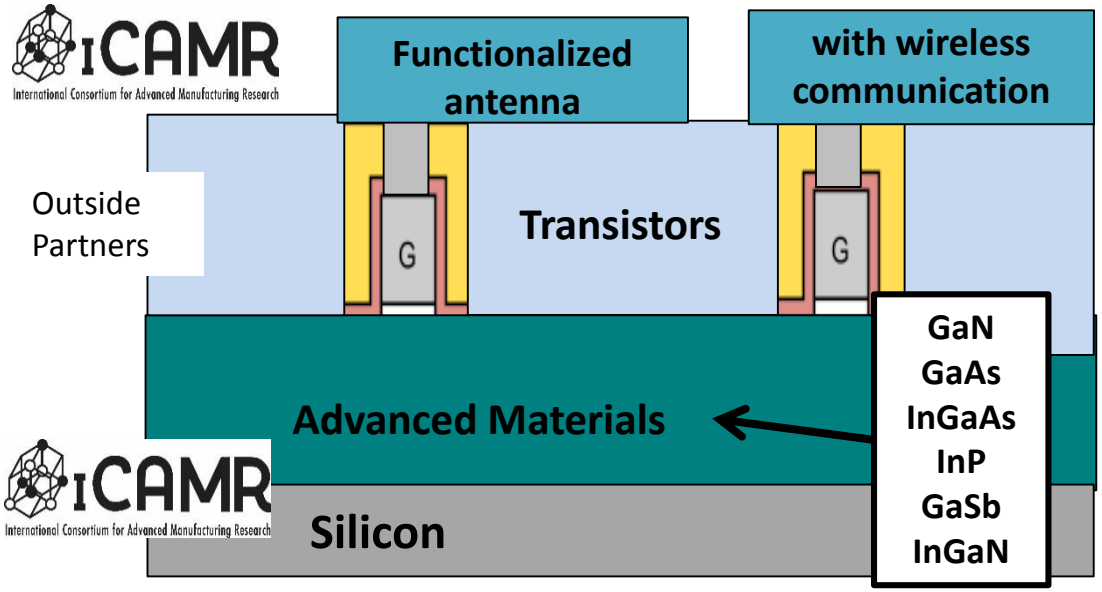


2.
DEVICE DEVELOPMENT PILOT LINES

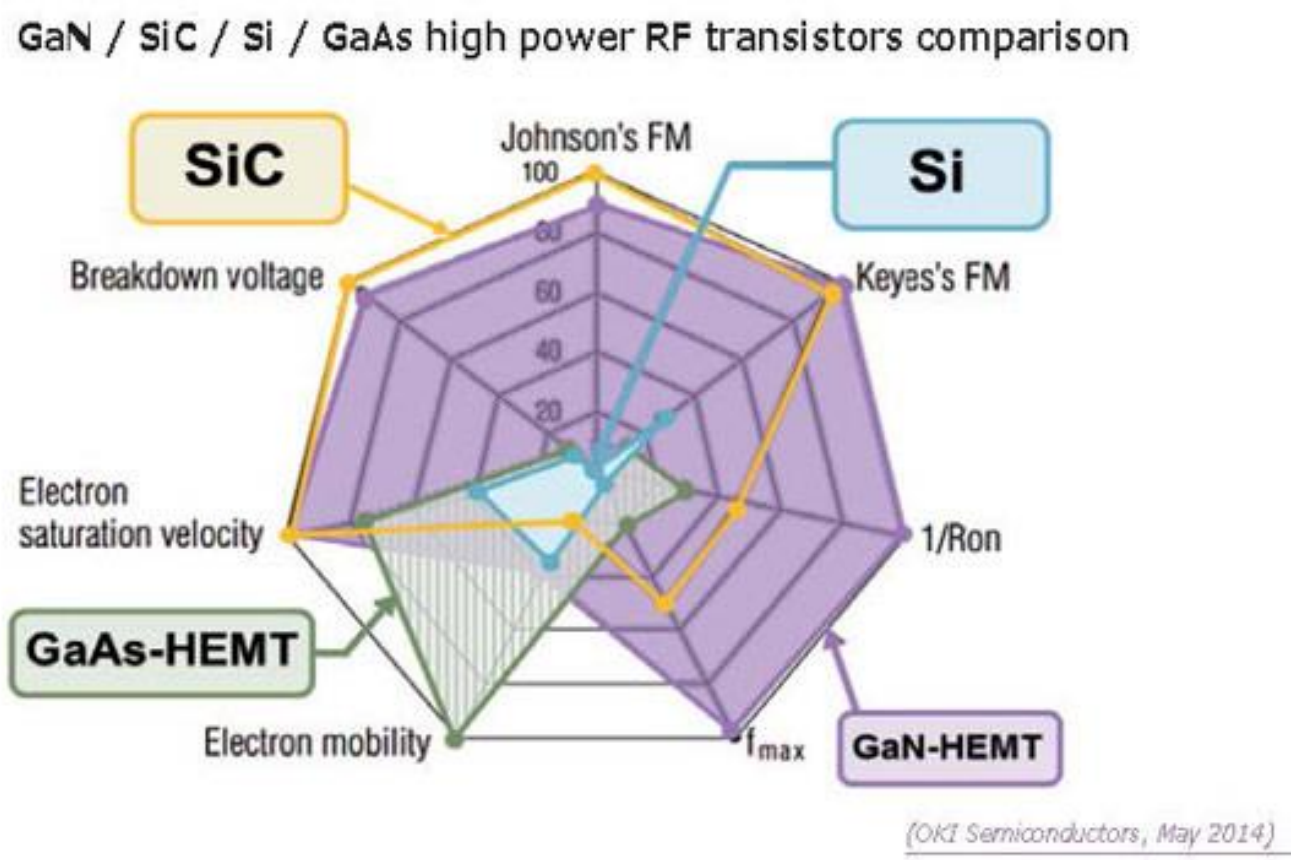
Device processing, including novel techniques for device personalization, functionalization, and CMOS integration

3.
SYSTEM INTEGRATION

Packaging, test, and systems development - including ultra-high density 2.5/3-D interposers



III-V material advantages



- ✓ Johnson's and Keyes's FM (Figure of Merritt)
  = performance of power transistors
- ✓ 1/Ron
  = close relationship to the power efficiency (lower operation costs, improved power density and size, reduced cost of ownership)

III-V scale-up W.S. during SEMICON

Key Drivers and Highest Scored Challenges

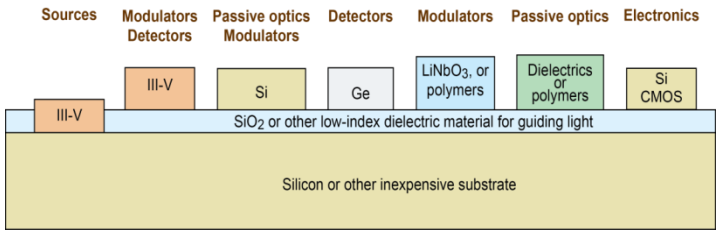
- Deposition/Growth:
  - Defects, Equipment design, Temperature, Throughput
- Metrology:
  - Hybrid methods, Depth profiling, Gas purity, HVM capability
- Contamination control:
  - Dopants, Interface defects, Wet+dry etching, Monitoring
- Process: layers integration, generated defects, HVM CoO
- ESH: permits, abatement, chamber cleaning, training
- Facilities: hazardous materials, equip. segregation, alarms, flexibility
- Device integration: device nodes, thermal, flex. subst.
- Scalability: 200mm/300mm tool sets
- Standards: new SEMI committee, design rules, roadmap
- Others: educated workforce for III-V processing

III-V Project Timeline

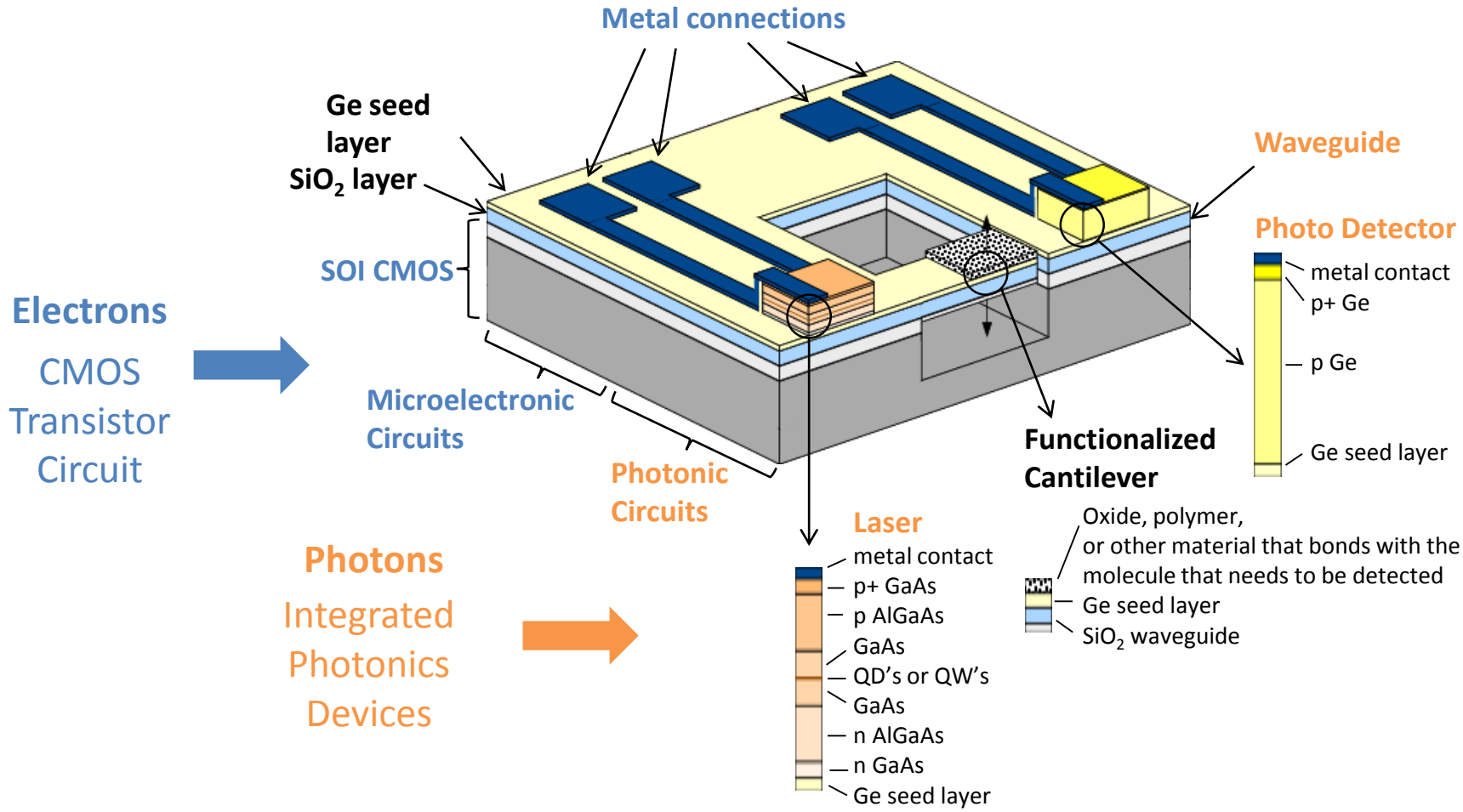
	Jan-16	Feb-16	Mar-16	Apr-16	May-16	Jun-16	Jul-16	Aug-16	Sep-16	Oct-16	Nov-16	Dec-16
Develop defect free GaN on Si (111)												
Develop defect free GaN on Si (100)												
GaN device design and optimization												
Fabricate GaN devices												
Initial device testing												
Demonstrate device performance												
Reliability testing												
Packaging												

	Jan-17	Feb-17	Mar-17	Apr-17	May-17	Jun-17	Jul-17	Aug-17	Sep-17	Oct-17	Nov-17	Dec-17
Develop defect free GaN on Si (100)												
Develop backside CMOS fabrication												
Tech Transfer to ICAMR facility												
Initial device testing												
Demonstrate device performance												
Reliability testing												
Packaging												

Example: Photonic Sensor Device

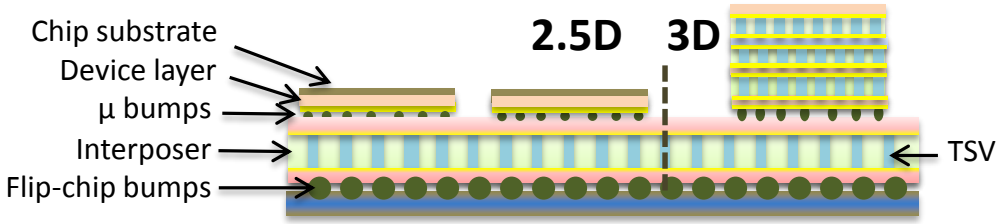


Advanced manufacturing of multimaterial photonic integrated circuits, devices, and systems, including packaging, reliability, and testing, on CMOS platforms



Device Manufacturing Development Model

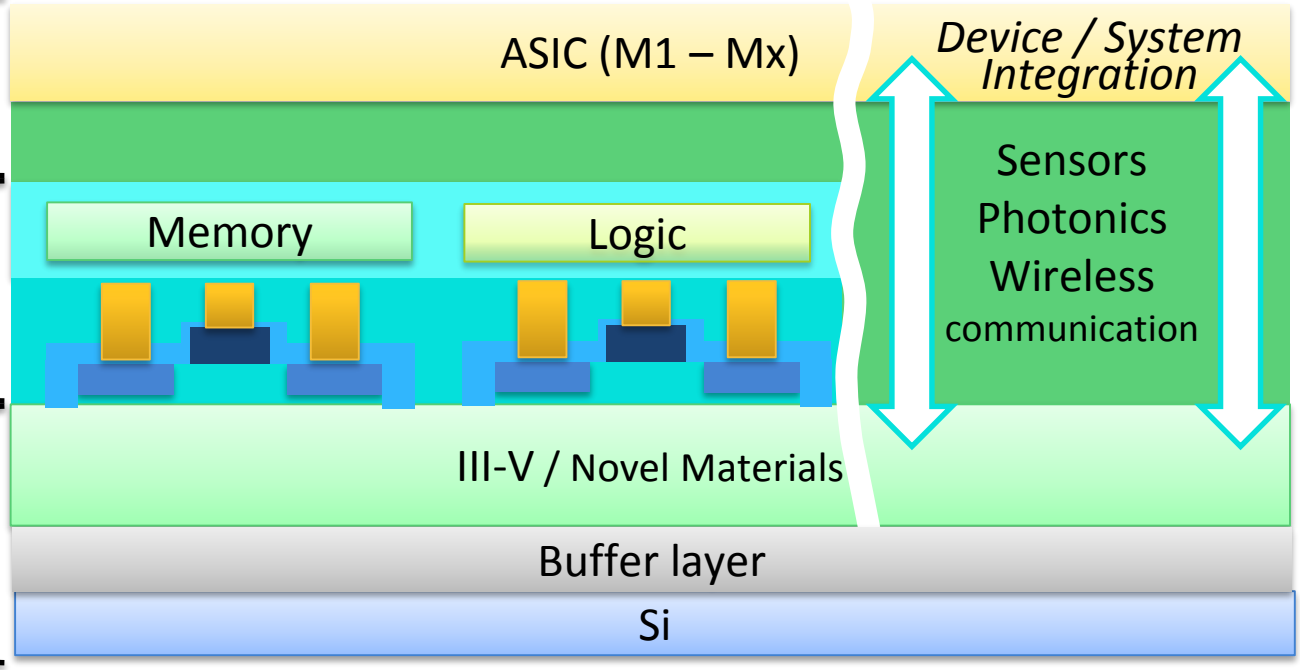
Multi-Node (<22nm) CMOS, 3-D Integration Pilot-Line



Interconnect and Personalization "Trusted Foundry"

Outsource: Transistor arrays - Specified / mixed CMOS nodes

ICAMR: III-V on Si

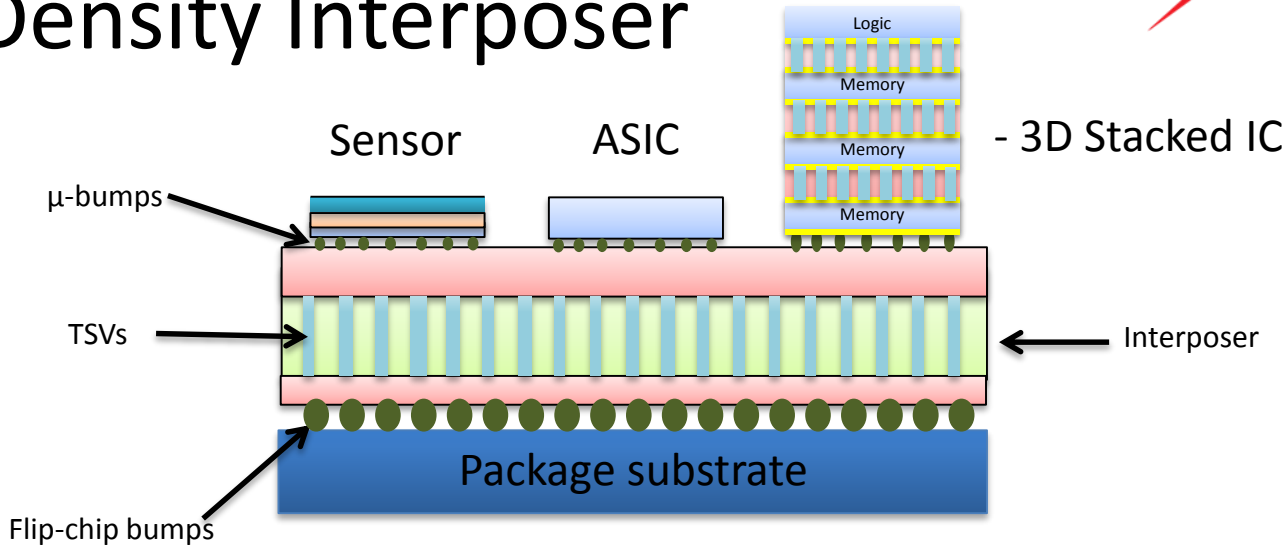


Advanced Materials Development Line – key performance attributes:

GaN, GaAs, InGaAs, InP, SiGe, Ge; others - CNT, SiC, C, Graphene, Magnetic (MOCVD/CVD/ALD dep. tools)

- **High sensitivity**
- **Low Power**
- **Harsh environments performance**

High Density Interposer



- Device scale connections (TSV, Interposer, Bumps) at 1 x 10^6 density
- Accelerate to achieve ITRS targets in the next 4 years
- Develop fabrication and assembly process for an order of magnitude beyond current state-of-the-art 2.5D/3D Integration:
  - Interposer pitch decreased from 45 to 5 µm
  - TSV pitch reduced from 180 to 8 µm
  - Depth from 100 to 50 µm
- Explore Additive Interposer Manufacturing – CNT/Dielectric Printing

ICAMR Tool Roadmap

- **Phase 0**

Engage industry and define initial technology programs. Establish partners, define ICAMR tool sets and infrastructure needs. Processing will be done at partner labs/fabs.

- **Phase I – Material Deposition – III-V on Silicon Wafer**

Purchase & Install core tool set - flexible base, HVM platform for novel III-V and other material stacks on Si

- **Phase II – Functionalization/Personalization**

Purchase & Install additional tool sets for specific device integration and support of industry driven program initiatives

- **Phase III – Packaging & Test**

Purchase and install advanced test, packaging, analytical, device libraries, and systems integration

- **Phase IV – 2.5D/3D**

Purchase & install advanced 2.5-3D Interconnects / Si Interposer equipment set

- **Phase V**

Launch US industry and DOD "Trusted Foundry" operation

Phases To Move Left Based on Industry Demand and Funding

Begin Tool Install

today 2016 2017 2018 2019 2020

Imec / ICAMR Partnership
Tool Commonalities by Phases

Equipment Type	Phase I Materials Platforms	Phase II Device integration	Phase III Packaging & Test	Phase IV 2.5-3D Interconnect	Phase V Back End
Sorter/Inspection	*	*	*	*	*
Wet Clean	*	*	*	*	*
Wet etch	*	*	*	*	*
HRXRD/XRR/XRD	*	*	*	*	*
AFM W/C-AFM CAPABILITY	*	*	*	*	*
VASE (SPECTROSCOPIC	*	*	*	*	*
3D MICROSCOPE Contour	*	*	*	*	*
SURFACE DEFECT	*	*	*	*	*
PHOTOLUMINESCENCE	*	*			*
CVD	*	*	*	*	*
MOCVD	*				*
ALD	*	*	*	*	*
TXRF		*			*
PROFILER, SURFACE ANAL		*	*	*	*
FILM THICKNESS/DEFECT		*		*	*
Litho (E-Beam)		*	*	*	*
Litho Track		*	*	*	*
PVD / Seed		*		*	*
Furnace/RTP		*	*	*	*
PR Clean/Asher		*		*	*
CMP-Metal		*		*	*
CMP-IIIV		*			*
PECVD		*			*
Etch Dielectric		*		*	*
Etch Metal		*			*
Etch Deep Si, TSV		*		*	*
Adv Packaging & Test			*	*	*
Plasma Etch			*	*	*
Flip Chip			*	*	*
Wafer Mounter			*	*	*
Wire bonder			*	*	*
Die Pick and Place			*	*	*
Plate-Etch-Strip			*	*	*
Wafer Bonding			*	*	*
Wafer Grinder			*	*	*
Laser / Saw Dicer			*	*	*
Low K Dielectric Dep Spin/CVD				*	*
Litho (adv 248 or 193nm)				*	*
Cu Plating				*	*
Ta/TaN Barrier seed				*	*
Anneal				*	*
Dry & Wet Strip				*	*
TSV depth measurement				*	*
Temp Bonder				*	*
TEOS liner				*	*
Cu Plating ** (addt'l module)				*	*
Edge trim				*	*
Grind				*	*
Dry Etch				*	*
Wet Clean				*	*
LT ox/nit pass				*	*
Taping & Detaping				*	*
Reflow				*	*
Chipbonding & test				*	*
Die to Database Inspection					*

Phase I
Phase II
Phase III
Phase IV

Federal Grant Engagement Proposals

Industry and the US Government are becoming very interested in the opportunities to leverage ICAMR's infrastructure and resources. In the very near future, ICAMR plan to pursue a variety of Federal grants:

- Institutes of Manufacturing Innovation ($70M, multi-state consortium efforts)
  - Smart Manufacturing (DOE; FOA expected Q4 2015; award in 2016)
  - Advanced Materials Processing (agency and timing TBD)
  - Open Topic (NIST; 2016)
- DOD: Device / System Foundry Initiatives (Trusted Foundry)
- NIH
  - PRISMS (pediatric sensors)
  - Healthy, Independent Living (wearable sensors for geriatric care)
  - Bioengineering Research Partnership (with National Institute on Aging)
- DOE
  - ARPAe: harsh environment sensors (wireless rotary assets)
  - Next-generation manufacturing processes
- NSF
  - Smart and Connected Health (wearable sensors/assistive technology)
  - Cyber IT Research Infrastructure Programs

For more info or to partner, please contact Andrea Wesser – andrea.wesser@ucf.edu or 407-353-3469

DOD and DOD Suppliers

Provide US based technology solutions for next generation devices, systems, and pilot-line production

- **Multiple node (<32nm) device integration of advanced materials on Si (200mm)**
  - Silicon is the ultimate integrator – can add virtually any device all on one carrier, at any technology node
- **Manufacturing scale-up of III-V materials and next generation devices**
  - Faster performance at lower power, wide band gap, high voltage and frequency stability, chemical and extreme environment robustness,…
  - Development of High Volume Manufacturing processes, equipment, supply chain
- **Provide DOD and DOD supply chain with the most advanced pilot-line in the world for Low Volume / High Mix / High Value products – "Trusted Foundry"**

  (specialized capabilities & flexibility that does not exist elsewhere)
- **Integration of high performance sensors, photonics, power electronics, RF devices, etc. on CMOS – both monolithically and 2.5/3D integration**
- **Leverage national labs/facilities and >$250M of regional investments in facility and processing infrastructure**

Imec / ICAMR Partnership
Start-up Funding Partners

Pre-Opening Start-up Funds Secured = **$168M**

Osceola County

- **$138M** from Osceola County
- Design/Build and equip 100,000 square foot center
- 20 acres plus in-kind support for power, water, and waste disposal

UCF

- **$10M** non-state and non-tuition funds to design and build center and start-up costs
- **$7M** in-kind for focused hires and resource support
- **30 year lease** of center from Osceola County at $1 per year

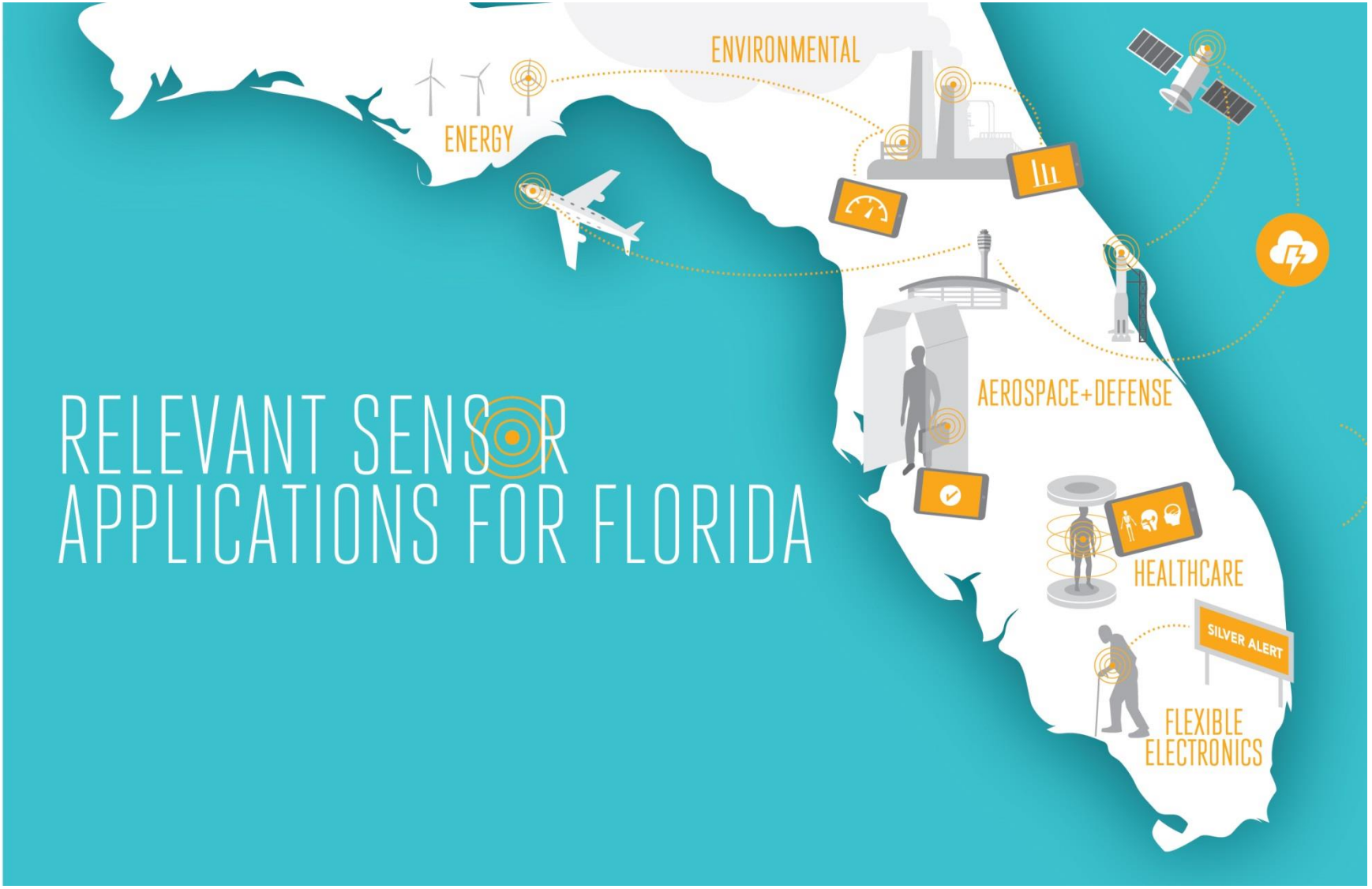
FHTCC

- **$1M** for initial operating cost
- **Up to $5M** matching funds over five years for specific research projects
- **$750K** from USF, FIU and UF

State of FL

- **$2M** State of Florida Quick Action Close Fund

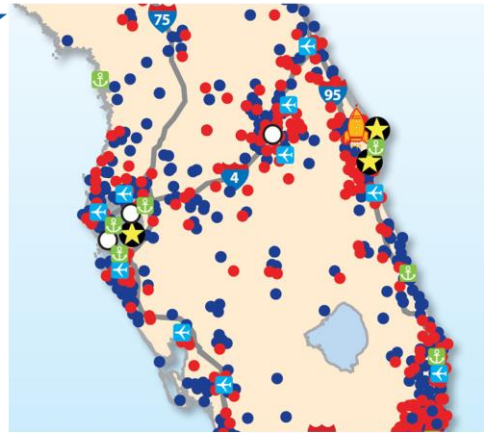
Why Florida? – Business Opportunities



Florida / Regional – Business Opportunities

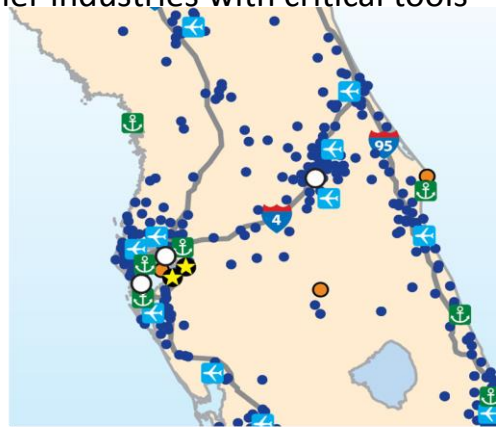
★ AVIATION / AEROSPACE

Home of Kennedy Space Center, Florida has 470+ companies ranging from aircraft and missiles to space exploration and manufacturing



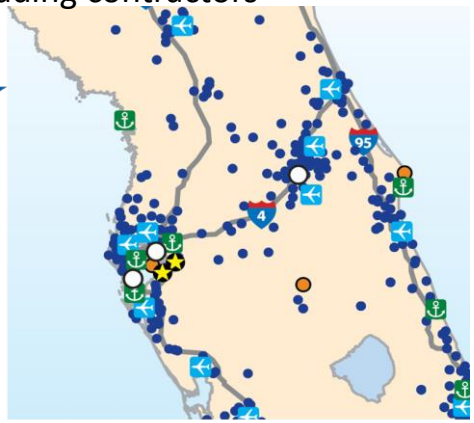
■ OPTICS & PHOTONICS

2,000+ specialists employed in some 100 companies in the region's optics and photonics sector providing defense, communications and other industries with critical tools



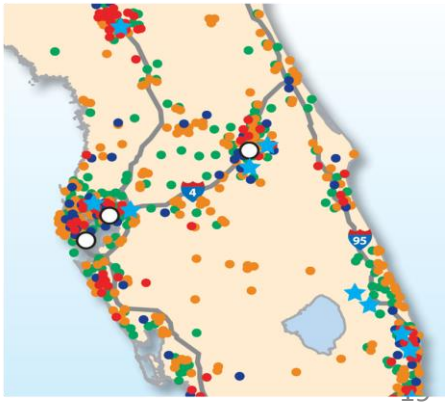
✪ DEFENSE & HOMELAND SECURITY

The region is home to 20 major military installations, 3 unified combatant commands, 2 academic security institutes and nearly all of the nation's leading contractors



✦ HEALTH LIFE SCIENCES

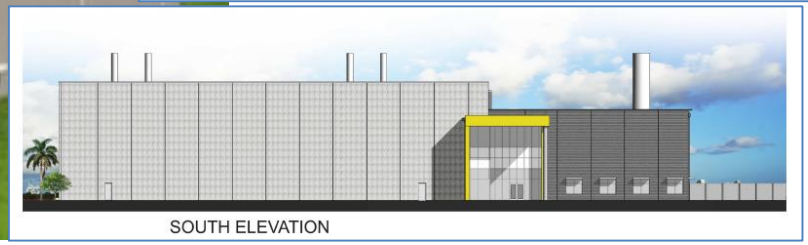
1,100+ biotech, pharma & medical devices companies and 214 hospitals; including some of the nation's most highly regarded research centers and health systems



Florida Statewide Participation

- ✓ Sensor material expertise
- ✓ Photonics expertise
- ✓ Bulk ceramics expertise for packaging
- ✓ Novel packaging expertise
- ✓ Additive manufacturing expertise

Site: Kissimmee, Florida



ICAMR – 109,000 sq ft two level state-of-the-art R&D lab/fab facility - ~$140M

- 30,000 sq ft of Class 1 – 1000 cleanroom
- 22,500 sq ft of elevated waffle slab / sub fab
- 10,000 sq ft of lab / office area (plus addition building support areas – services, loading dock,..)
- Site located on a new dedicated 350 acre research park
- All utilities (electric, water, wastewater) available to site
- Completion target is early 2017

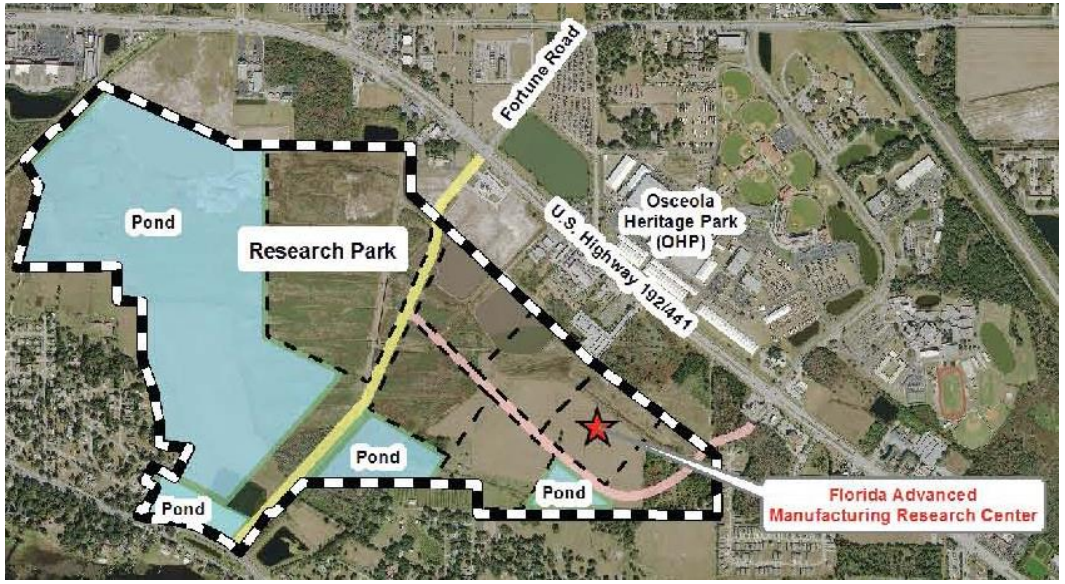
Imec / ICAMR Partnership
Facilities Design and Construction

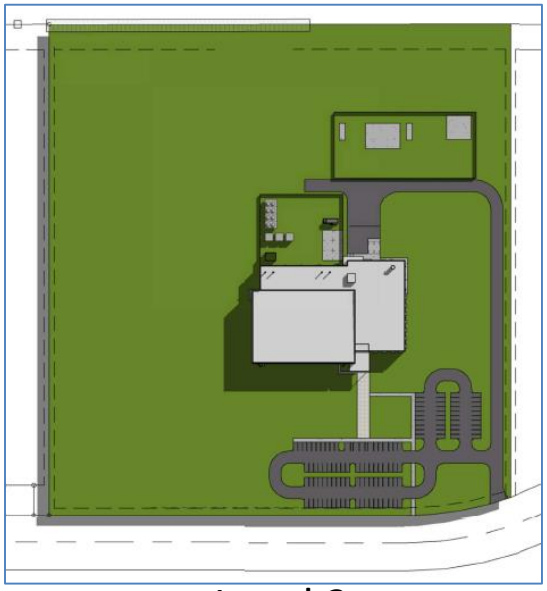
DESIGN	Duration (mos.)	Start	Finish
Programming	3	16-Mar-15	12-Jun-15
Conceptual Design	2	20-Apr-15	22-June-15
Advanced Schematic Design	1	6-July-15	10-Aug-15
Design Development	1.25	17-Aug-15	25-Aug-15
Construction Documents	5	17-Aug-15	19-Jan-16

CONSTRUCTION	Duration (mos.)	Start	Finish
Site Construction (Early Site work & Foundations)	3.5	07-Oct-15	19-Jan-16
Shell Construction	8	14-Jan-16	16-Sep-16
Shell Dry-in			16-Feb-17
Equipment Start-up and Commissioning	7	29-July-16	21-Feb-17
Building Completion "Substantial"			21-Feb-17
Initial Tool Installation	1	3-Mar-17	31-Mar-17
Building Completion "Final"			31-Mar-17

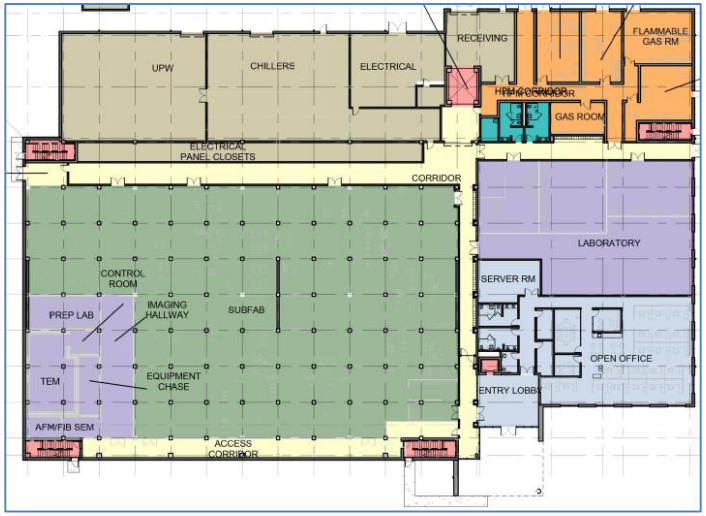
Facilities Layout

- **20 acres and 100k ft2 ICAMR lab/fab to start**
- **350 acres for high-tech campus and industry partners**





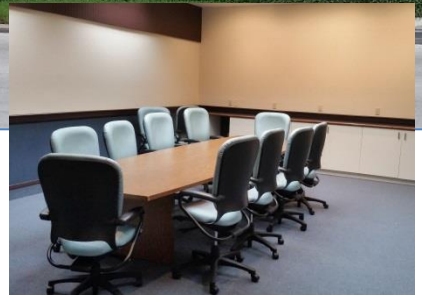
Level 1



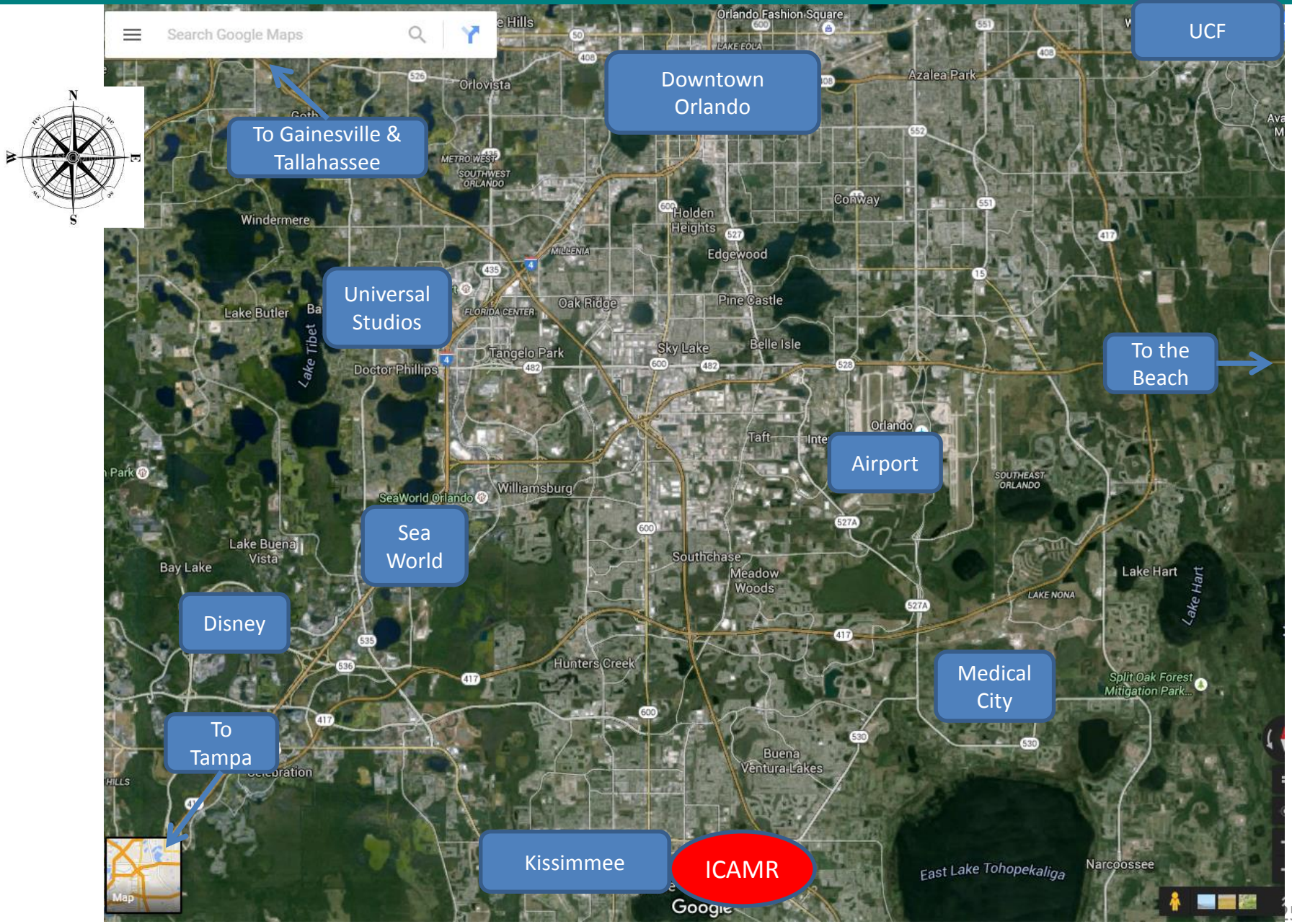
Level 2

Interim ICAMR Office

Downtown Kissimmee, FL



Site Location



Status / Next Steps

- ✓ Year 1 infrastructure and operational funding secured, >$165M
- ❖ Design phase of construction process started – defining equipment and building layout to best serve industry and emerging technologies
- ❖ Already involved in several major U.S. Federal grant submissions
  - 7 more planned for 2016!
- ❖ Securing key research institutions/processing partners
- ❖ Defining specific sensors and photonics applications / industry sectors
- ❖ Engage / recruit key US and international industry members
  - Complete eco system – device industry, equipment manufactures, supply chain, end-users,…
  - Launch initial industry-based programs by Q3, 2015 (performed at partner/member sites)
- ❖ Selecting equipment partners to develop and support next gen manufacturing tools
- ❖ Launch technology roadmapping initiatives – standards activities to follow
- ❖ Develop internships and educational/training programs
- ❖ ***Expand funding channels (state, national hubs, industry, JDPs,.)***

iCAMR

International Consortium for Advanced Manufacturing Research

CONTACT

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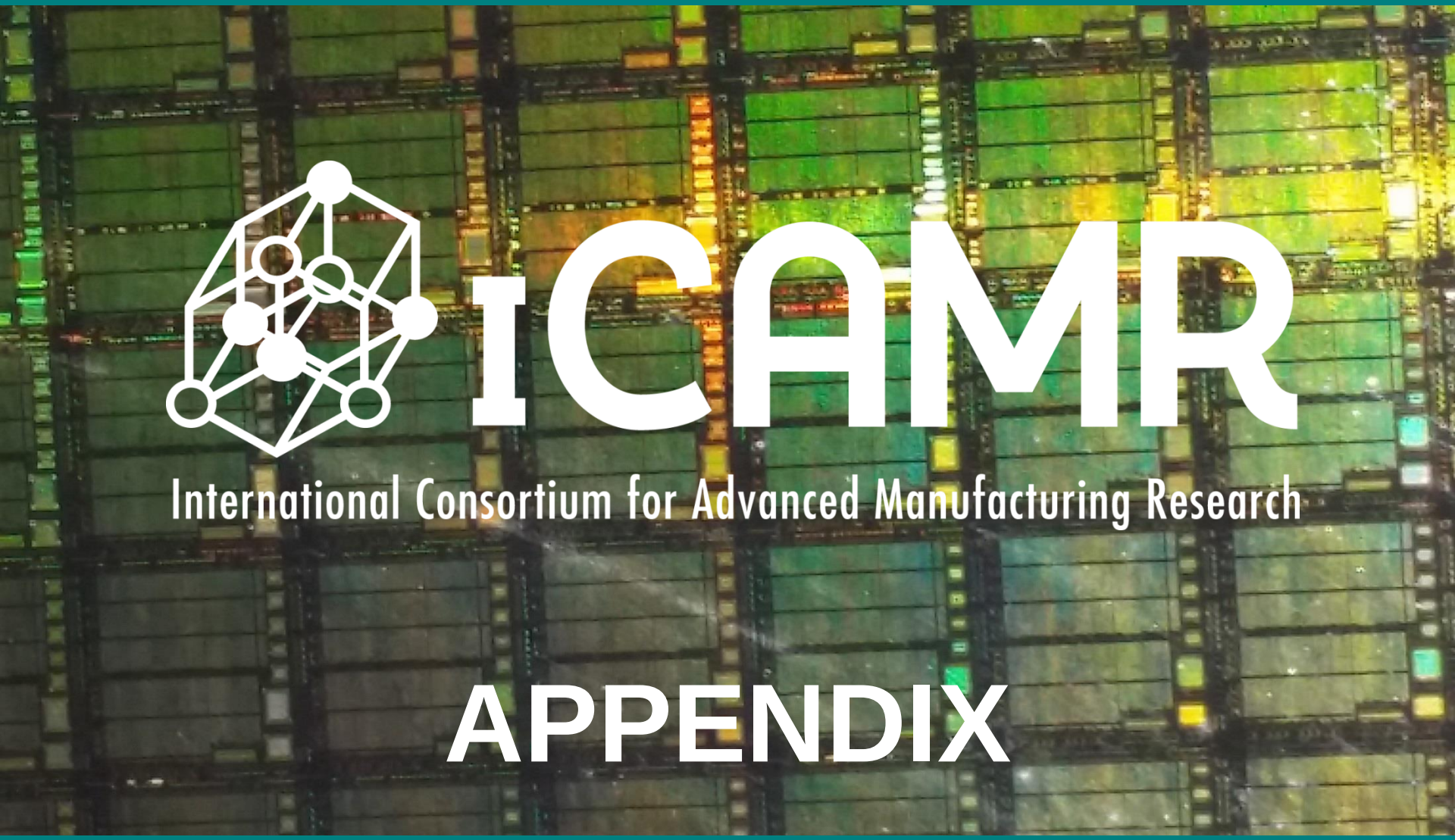
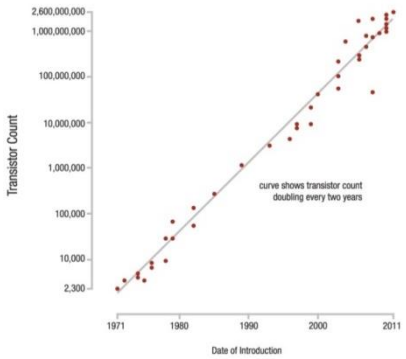

ICAMR
International Consortium for Advanced Manufacturing Research
APPENDIX

Early ICAMR Program Partners – 2015/16 Programs

Industry

Institutions

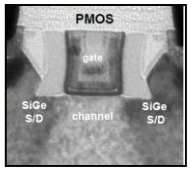
Building from Semiconductor Manufacturing Trajectory



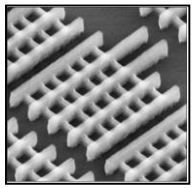
Moore's Law Drives All Solid State Manufacturing Innovation!

Manufactured Today

2nd Gen HKMG 2009

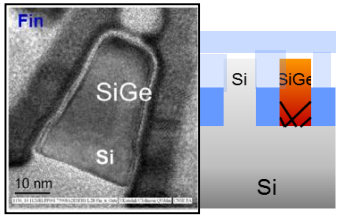


Si FinFET 2012

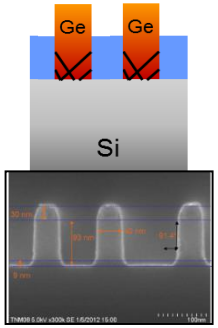


In Development

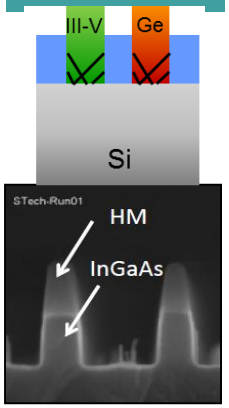
Ge pMOS; Si nMOS 2015



Ge CMOS 2017

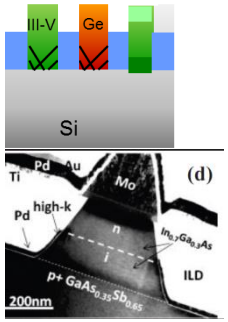


Ge pMOS; III-V nMOS 2019



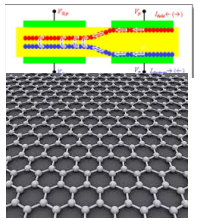
III-V TFET 2021

III-V p-i-n TFET



D. K. Mohata VLSI 2012

??? 2024



S. Banerjee 2009

ICAMR to build off III-V CMOS platforms for sensors/photonics and other advanced devices

32nm — 22nm — 14nm — 10nm — 7nm — 5nm — 3nm

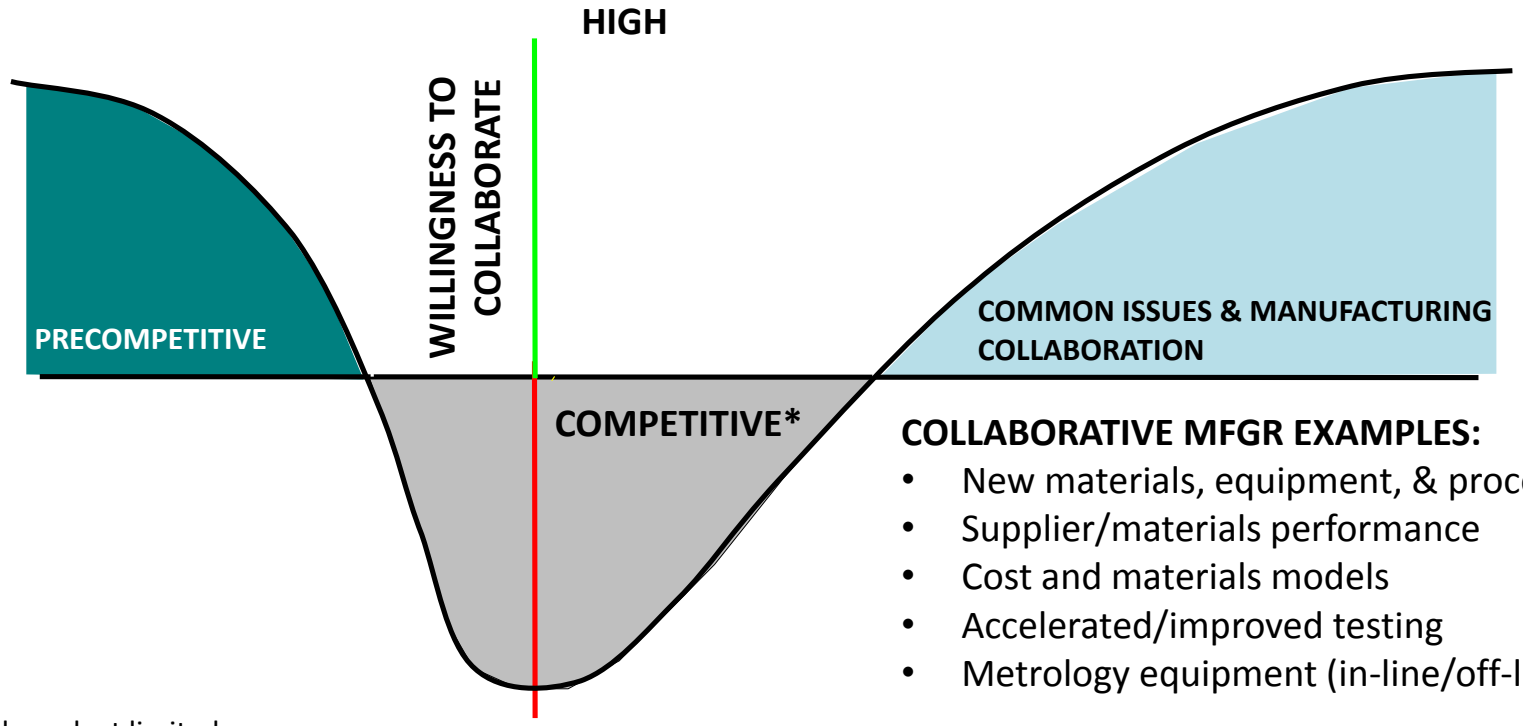
Consortium Value Proposition

The Challenge	*Collaborative Solutions*
• Industry alignment	• Create industry roadmap and standards
• Significant process, manufacturing, and technical design challenges	• Collaborative R&D, access to equipment and facilities to speed process and product development
• Lack of industry collaboration, direction, and alignment around needs/challenges	• Utilize & expand consortium model across entire value chain, develop a robust supplier industry around common needs
• Access to leading-edge capabilities	• Build / provide access to advanced manufacturing development facilities & labs
• Testing and reliability	• Establish critical test, reliability, and analytical capabilities
• Manufacturing cost	• Improve manufacturing methods to enhance productivity and reduce costs
• System integration, technology commercialization, & workforce development	• Launch specialized programs and infrastructure to support industry needs and growth
• Emerging technologies manufacturing scale-up challenges – small and large businesses	• Leverage industry-government-university capabilities and resources through the consortium to provide manufacturing scale solutions

Consortium / Collaboration Advantages

This model has been refined through years of testing:

- Multi-tiered programs and partnerships under one consortium structure
- Agility to adapt to changing needs
- Industry driven programs with high ROI – shared cost, risk, and value
- Development-friendly IP model promoting innovations across supply chain



COLLABORATIVE MFGR EXAMPLES:

- New materials, equipment, & processes
- Supplier/materials performance
- Cost and materials models
- Accelerated/improved testing
- Metrology equipment (in-line/off-line)

*-ICAMR will conduct limited proprietary programs for Members

ICAMR's Future Centers

ICAMR's infrastructure is designed to support multiple emerging technology centers and industries

Phase I

MDF for Materials, Sensors, Packaging & Testing

Advanced Devices on Si - Universal Smart Sensors:

- Sensor / Photonics Device integration and prototyping

1) Adv Materials Development:

- Support a broad range of Emerging Technologies

(BioMed, Environmental, Oil & Gas, Aerospace/Defense,…)

2) Adv Personalization, Functionalization, Test, and Packaging Development Lines

- ICAMR focused industries/apps

3) Systems/Device integration

- Supporting product dev

Advanced Energy Center

PV Programs

Next Gen PV (cSi & other)

Solar Systems & Power Elect

Smart Grid & Utility Solutions

Test & Certification (World Leader)

Energy Storage

Nanotechnology in Energy

Other renewables:

- Fuel cells
- Wind
- Marine current power

Manufacturing Competitiveness Centers

Manufacturing Hubs/Programs

- Industry/Technology-driven initiatives

Next Generation Manufacturing Pilot lines:

- Flexible Electronics
- Advanced Sys & Packaging
- Additive Manufacturing
- NEMS/MEMS/MOEMS
- Biomedical/Microfluidics

International Emerging Technologies

Emerging Tech Programs

Cyber Security

Trusted Foundries & device integrity

Healthcare Technologies

ESH

Nanotechnologies

Simulators & Models

Roadmaps & Standards

Joint University Centers

Workforce Development

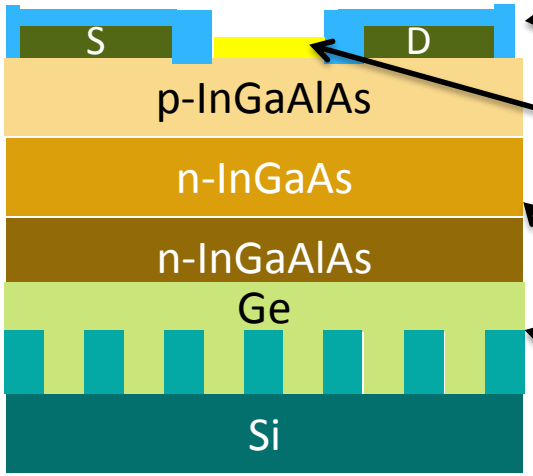
➢ ***This initiative has the potential to be a multi-billion $$$ operation!***

Manufacturing Phase Transition

Ohmic contacts
Ti, Ti/Pt, Al, W, Ta, Pd, Au
Metallization/Sputtering/
Ion implantation+annealing

Passivation layer
Si_3N_4, SiN_x, etc

Personalization / Functionalization
(oxide, polymers or antibodies)



Baseline Photonics / Sensor Device

Phase I Processing	Phase II Processing	Phase III Processing
Industry Partners – Packaging/Systems	Industry Partners – Packaging/Systems	**ICAMR – Packaging/System**
Industry Partners – Functionalization and Personalization	**ICAMR – Functionalization & Personalization**	**ICAMR**
Industry Partners to process Ohmic contacts and passivation	**ICAMR**	**ICAMR**
ICAMR to Deposit III-V Materials & Ge buffer Layer	**ICAMR**	**ICAMR**

Full Partnership Opportunities as of Q3 2016

- Manufacturing technology roadmapping and standards
- Materials characterization, integration and manufacturing protocols
- Manufacturing development, prototyping and technology transfer - commercialization
- Process and metrology equipment development
- Technology production scale-up and cost modeling
- Environmental / Safety / Health challenges, and sustainability
- Certification/test/reliability – quality
- Policies/codes/permitting
- University, national labs, and international programs
- Member company application-specific support programs
- Workforce training - educational and internship programs

Manufacturing Consortium Intellectual property model

- Consortium owns all IP created by assignees and direct hires working on collaborative programs (except assignee created patents)
- IP is licensed to all members participating in a program on a nonexclusive, royalty-free basis
- Patented inventions created by assignee:
  - Are owned by the member that is the employer of the assignee
  - Consortium members get nonexclusive, royalty-free license
- Inventions jointly created are jointly owned
- Members' patent license rights include right to make and have made their own products and sublicense to customers
- Partner and ICAMR will cooperate on publications and conferences to benefit industry
- Partner will own or have exclusive license to IP created in privately funded program – IP license for ICAMR use will be negotiated as needed

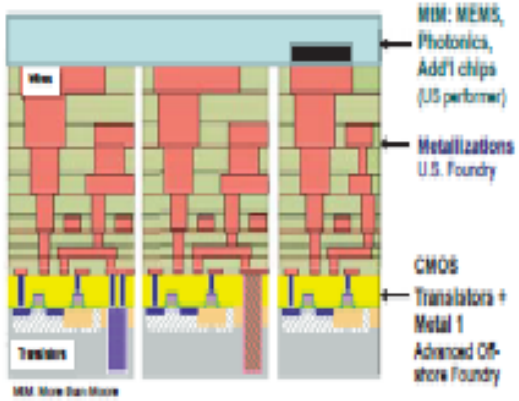
Trusted Integrated Chips (TIC)

Obtaining World-Class Performance Without Compromising Security

Program Manager: Dr. Carl McCants; E-mail: carl.mccants@darpa.gov

Split manufacturing eliminates the need to disclose the complete wiring plan for an integrated circuit outside the US

- Off-shore foundries lay down the transistor layer at the Front-End-Of-Line (FEOL) to obtain highest performance
- Chips come back to domestic foundries for metalization at the Back-End-Of-Line (BEOL) for security.
- Obfuscation techniques further protect sensitive chip designs



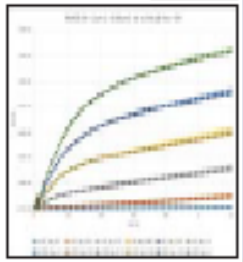
Logic families covered in TIC include: photonics, mixed-signal CMOS, analog, digital and RRAM, and sonics MEMS

Over 90% of the world's foundry capacity is controlled by non-U.S. companies with the vast majority of it located in Asia. How to use it without compromising design security?

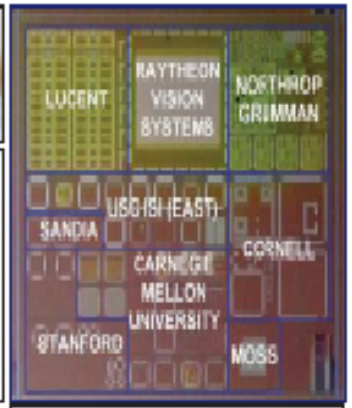
2013 Worldwide Semiconductor Foundry Production

1	TSMC	Taiwan	51.0%	7	Vanguard	Taiwan	1.4%
2	Global Foundries	Singapore, Germany	11.1%	8	Hualong Grace	China	1.4%
3	Samsung	Korea	10.3%	9	Dongbu	Korea	1.1%
4	UMC	Taiwan, Singapore	10.1%	10	Towerjazz	Israel	1.1%
5	SMIC	China	5.2%	11	IBM	USA	1.0%
6	Powerchip	Taiwan	3.1%	12	MagnaChip	Korea	1.0%

65 nm results – April 2014



No statistically significant difference in electrical performance characteristics



(ARPA multi-user test chip April 2014 fabricated jointly between Global Foundries (Singapore) and IBM (East Fishkill))

Metrics / Technology Node		CY 1 (12 mo)	CMU	Cornell	LGS/Bell Labs	RVS	Stanford
		65 nm node	65 nm node	65 nm node	65 nm node	65 nm node	65 nm node
Circuit Complexity (# of transistors)	Digital	>100K	>1M	340K	>600K	65300K	>100K
	Analog/Mixed Signal	>1K	>5K	>30K	1.8K	1310K	na
Split-Fabrication Yield		>75%	100%	100%	100%	100%	100%
Speed		>80%	102%	95%	100%	80%	100%
Power Dissipation		<125%	104%	105%	100%	105%	100%