Commercialization of Specialized Nanotechnology Fabrication in a Certified Domestic Foundry

NASA Electronic Parts and Packaging (NEPP) Program
2016 Electronics Technology Workshop

Wilbur Catabay

June 16, 2016

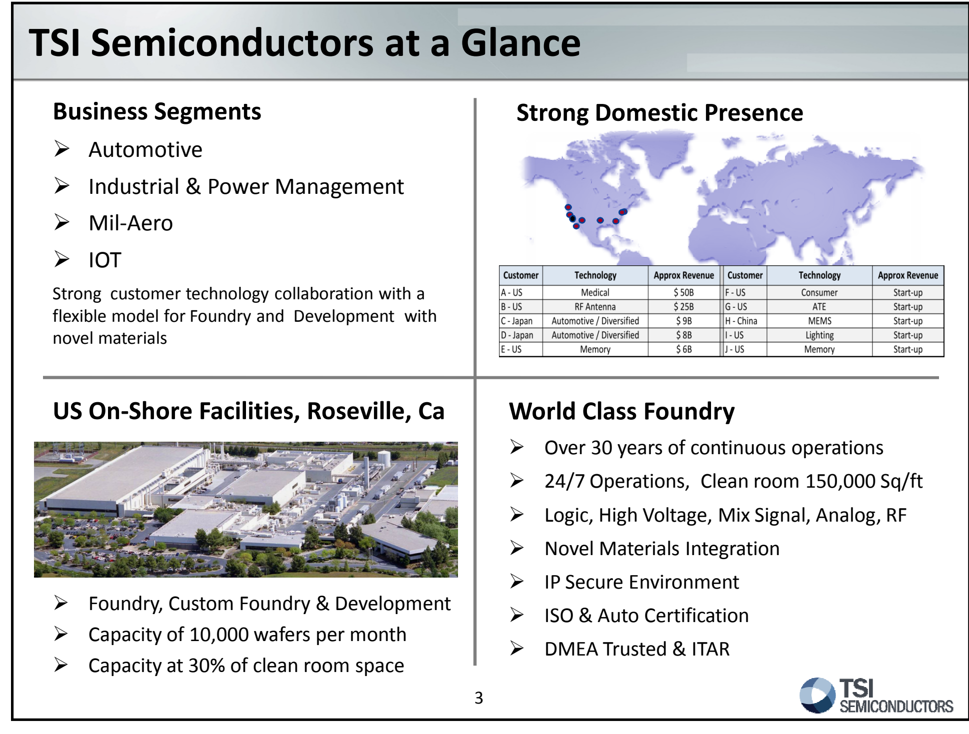
INNOVATION @ SCALE

Outline

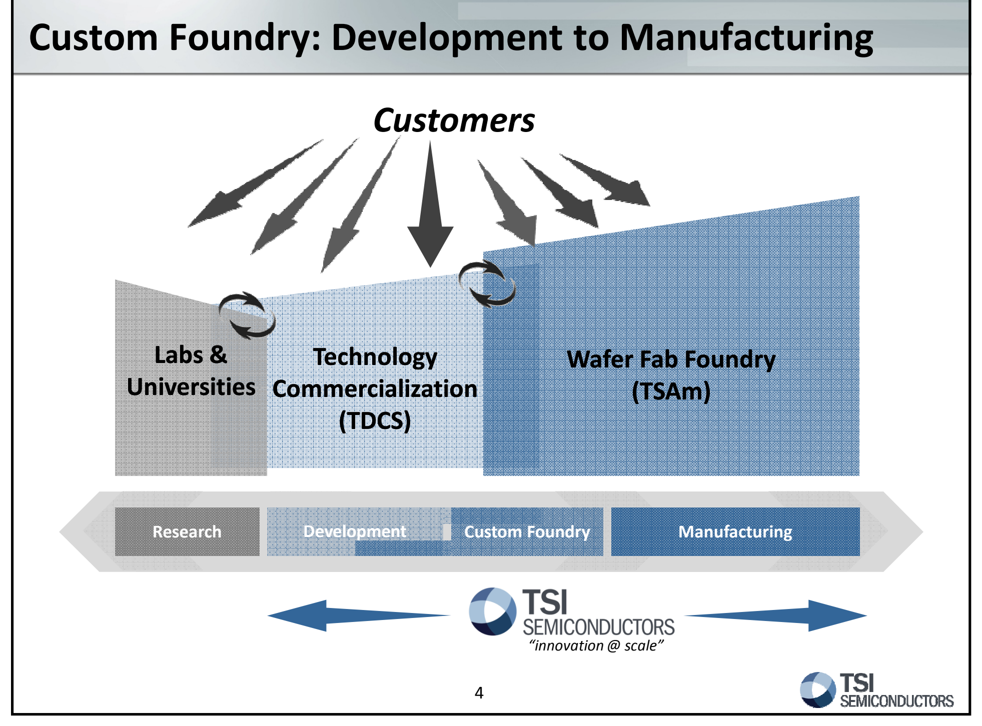
- TSI Semiconductors
  - Specialized Foundry Services
  - TDCS - **T**echnology **D**evelopment & **C**ommercialization **S**ervices
- Case Studies
  - Foundry, Customer Foundry, Development
- Leveraging Automotive Certifications for Military Standards
- Summary

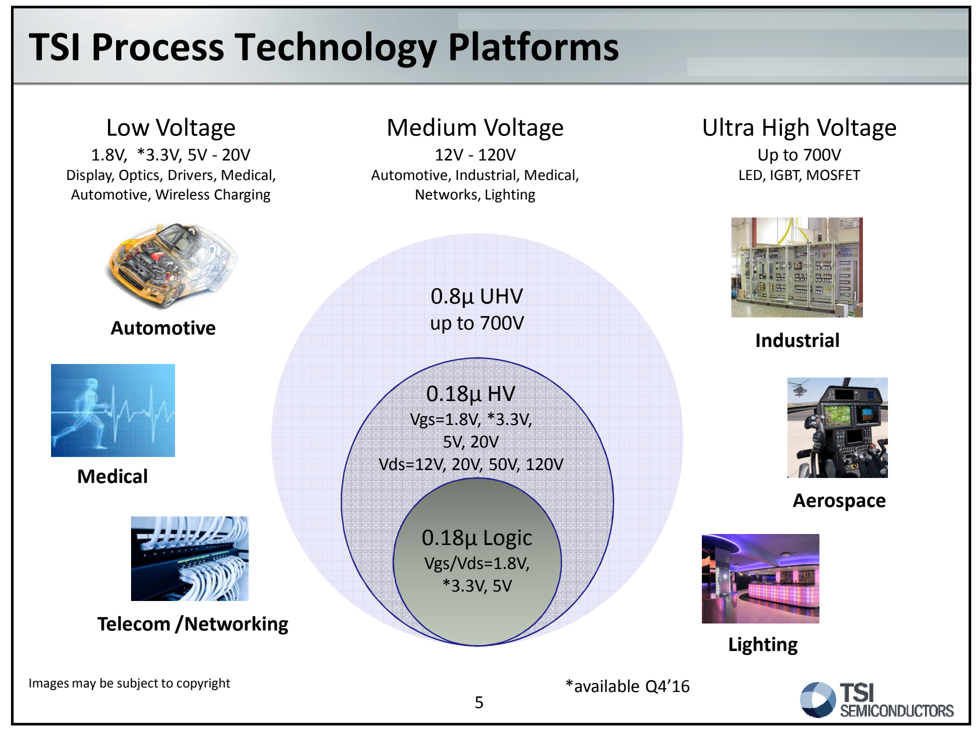
2

TSI SEMICONDUCTORS



Customer	Technology	Approx Revenue	Customer	Technology	Approx Revenue
A - US	Medical	$ 50B	F - US	Consumer	Start-up
B - US	RF Antenna	$ 25B	G - US	ATE	Start-up
C - Japan	Automotive / Diversified	$ 9B	H - China	MEMS	Start-up
D - Japan	Automotive / Diversified	$ 8B	I - US	Lighting	Start-up
E - US	Memory	$ 6B	J - US	Memory	Start-up





IBM 7HV Technology Transfer

- 0.18µ technology was transferred in 8 months
- Two customers completed silicon runs during the transfer period
- Significant number of devices from Logic, HV, Analog, RF, Mix-Signal

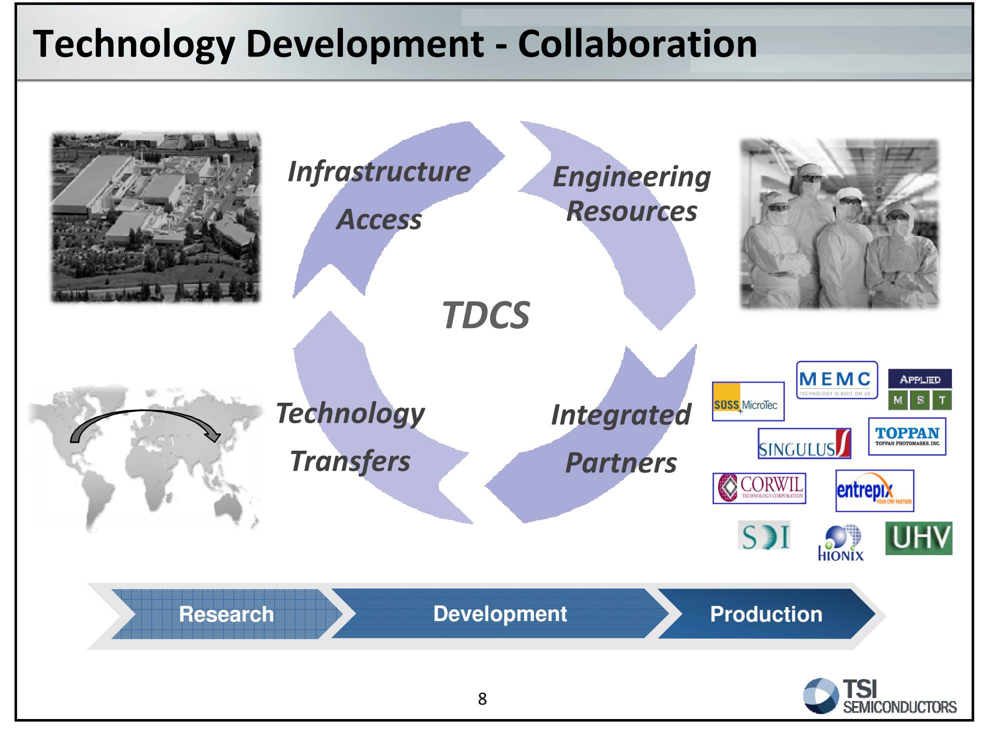
TSI Semiconductors Process Device Menu

Process	Logic CMOS		Analog/Mixed-signal/RF		High Voltage
VGS	1.8V & 5V	5V Only	1.8V & 5V	5V Only	1.8V, 5V & 20V
Triple Well Isolation	Yes	Yes	Yes	Yes	Yes
FETs	1.8V, 5V	5V Only	1.8V (RF only), 5V	5V Only	1.8V, 5V, 12V, 20V 25V, 50V, 120V
	High Vt * (2ML)	High Vt * (2ML)	High Vt * (2ML)	High Vt * (2ML)	High Vt * (2ML)
	Super high Vt * (2ML)	Super high Vt * (2ML)	Super high Vt * (2ML)	Super high Vt * (2ML)	Super high Vt * (2ML)
Resistors	N+, P+ diffusion & poly	N+, P+ diffusion & poly	N+, P+ diffusion & poly	N+, P+ diffusion & poly	N+, P+ diffusion & poly
			RR poly high R - 1.6KΩ/sq (1ML)	RR poly high R - 1.6KΩ/sq (1ML)	RR poly high R - 1.6KΩ/sq (1ML)
			RP poly precision R - 165Ω/sq (1ML)	RP poly precision R - 165Ω/sq (1ML)	RP poly precision R - 165Ω/sq (1ML)
			TaN BEOL (1ML)	TaN BEOL (1ML)	TaN BEOL (1ML)
Diodes	Schottky Barrier	Schottky Barrier	Schottky Barrier	Schottky Barrier	Schottky Barrier
Decoupling Caps and Varactors	1.8V/5V N, P caps, vars	1.8V/5V N, P caps, vars	1.8V/5V N, P caps, vars	1.8V/5V N, P caps, vars	1.8V/5V N, P caps, vars
BEOL Caps	Vertical native (VNcap)	Vertical native (VNcap)	Vertical native (VNcap)	Vertical native (VNcap)	Vertical native (VNcap) High Voltage VNcap - 120V
			Single MIM - 2.1 $fF/\mu m^2$ * (1ML) Dual MIM - 4.1 $fF/\mu m^2$ * (1ML)	Single MIM - 2.1 $fF/\mu m^2$ * (1ML) Dual MIM - 4.1 $fF/\mu m^2$ * (1ML)	Single MIM - 2.1 $fF/\mu m^2$ * (1ML) Dual MIM - 4.1 $fF/\mu m^2$ * (1ML)
BEOL Metal	6LM: M1-MT	6LM: M1-MT	7LM: M1-MT Analog Metal (AM) - 4µm	7LM: M1-MT Analog Metal (AM) - 4µm	7LM: M1-MT Analog Metal (AM) - 4µm
	M4,V4,M5,V5	M4,V4,M5,V5	M3, V3, M4,V4,M5,V5	M3, V3, M4,V4,M5,V5	M3, V3, M4,V4,M5,V5
Inductors			Analog Metal (AM) - 4µm Al	Analog Metal (AM) - 4µm Al	Analog Metal (AM) - 4µm Al
Masks (1P, 3LM)	21	16	21	16	21

Optional Devices/Layers

6

Technology Development &
Commercialization Services
(TDCS)
We create a collaborative relationship with customers to enable the fastest
and most cost effective time to market for technology and product
commercialization while enabling customer IP independence
INNOVATION @ SCALE
TSI SEMICONDUCTORS



Technology Development - Collaboration
Infrastructure Access
Engineering Resources
TDCS
Technology Transfers
Integrated Partners
SUSS MicroTec
MEMC
APPLIED MST
SINGULUS
TOPPAN
CORWIL
entrepix
HIONIX
UHV
Research
Development
Production
8
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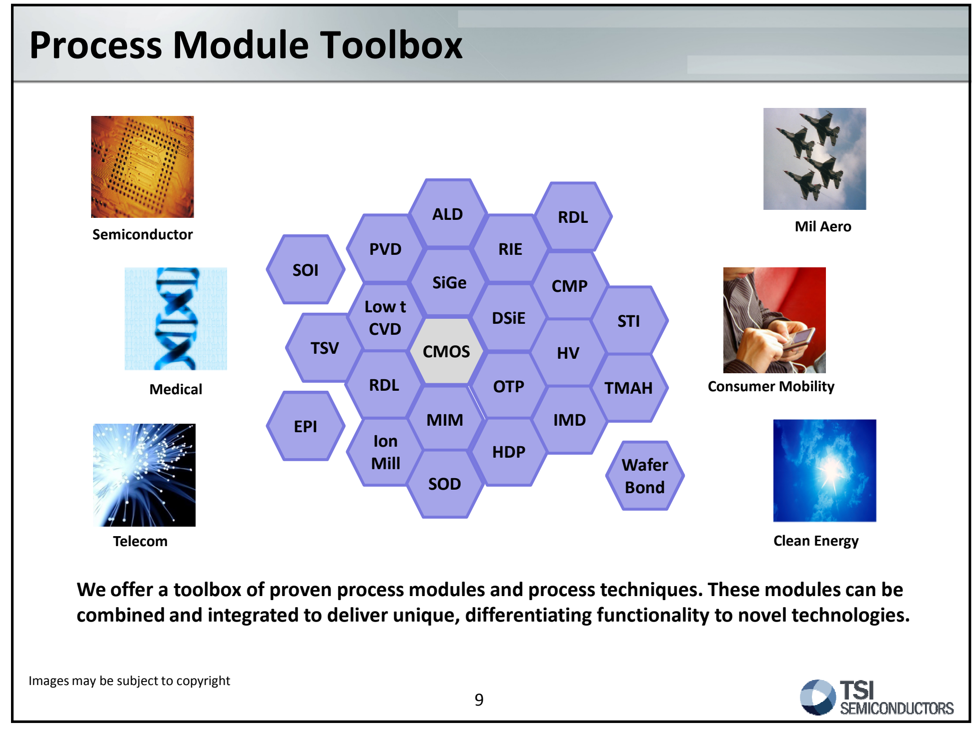
Process Module Toolbox
Semiconductor
Medical
Telecom
Mil Aero
Consumer Mobility
Clean Energy
SOI
PVD
ALD
RIE
RDL
SiGe
CMP
Low t CVD
TSV
CMOS
DSiE
STI
HV
RDL
OTP
TMAH
EPI
MIM
IMD
Ion Mill
HDP
SOD
Wafer Bond
We offer a toolbox of proven process modules and process techniques. These modules can be combined and integrated to deliver unique, differentiating functionality to novel technologies.
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9
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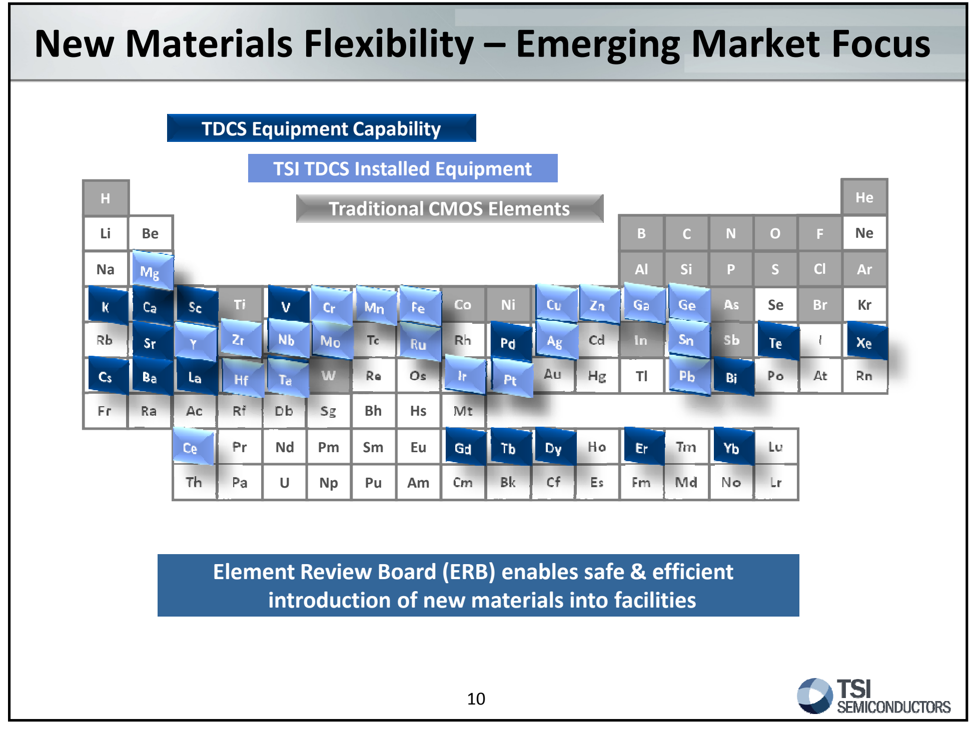
New Materials Flexibility – Emerging Market Focus
TDCS Equipment Capability
TSI TDCS Installed Equipment
Traditional CMOS Elements
Element Review Board (ERB) enables safe & efficient introduction of new materials into facilities
10
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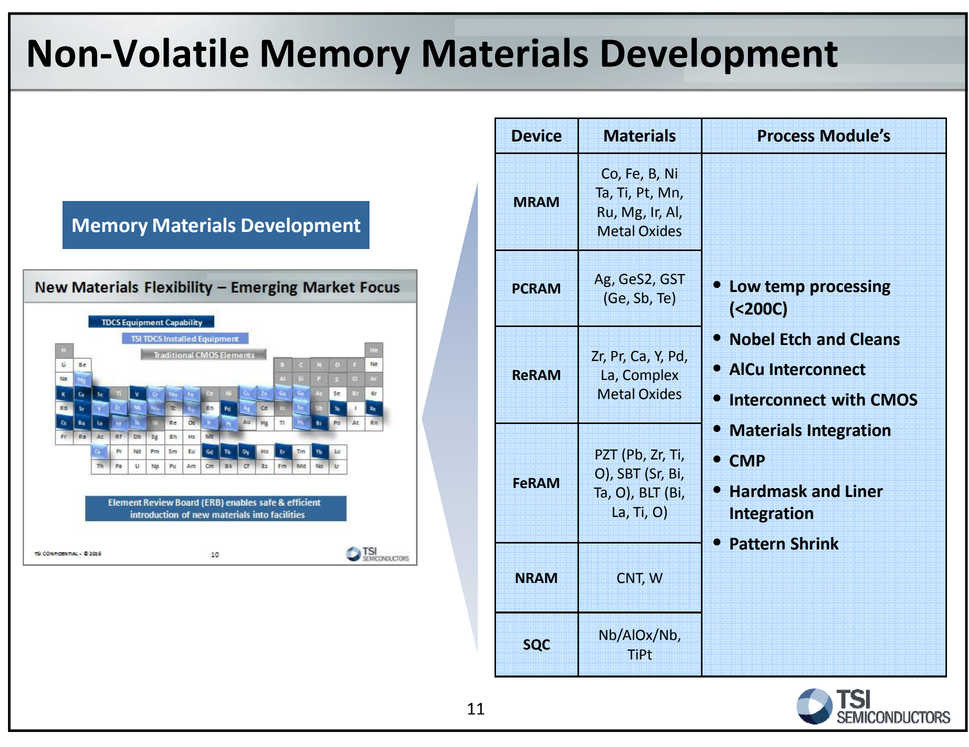
Non-Volatile Memory Materials Development
Memory Materials Development
New Materials Flexibility – Emerging Market Focus
TDCS Equipment Capability
TSI TDCS Installed Equipment
Traditional CMOS Elements
Element Review Board (ERB) enables safe & efficient introduction of new materials into facilities
Device | Materials | Process Module's
MRAM | Co, Fe, B, Ni Ta, Ti, Pt, Mn, Ru, Mg, Ir, Al, Metal Oxides
PCRAM | Ag, GeS2, GST (Ge, Sb, Te)
ReRAM | Zr, Pr, Ca, Y, Pd, La, Complex Metal Oxides
FeRAM | PZT (Pb, Zr, Ti, O), SBT (Sr, Bi, Ta, O), BLT (Bi, La, Ti, O)
NRAM | CNT, W
SQC | Nb/AlOx/Nb, TiPt
• Low temp processing (<200C)
• Nobel Etch and Cleans
• AlCu Interconnect
• Interconnect with CMOS
• Materials Integration
• CMP
• Hardmask and Liner Integration
• Pattern Shrink
11
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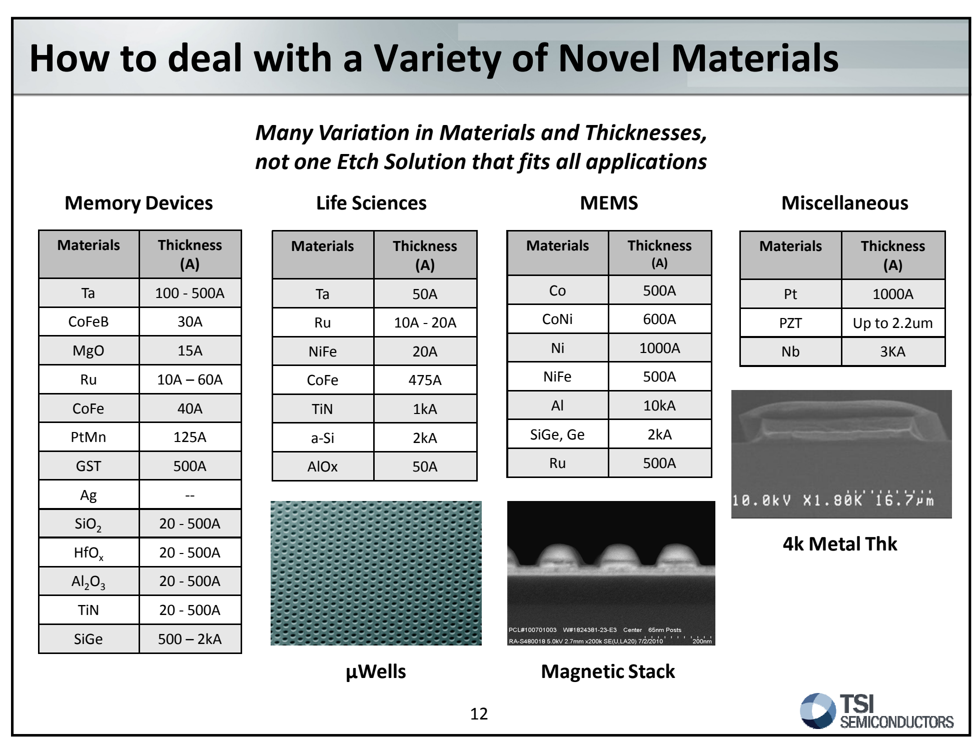
How to deal with a Variety of Novel Materials
Many Variation in Materials and Thicknesses, not one Etch Solution that fits all applications
Memory Devices
Materials | Thickness (A)
Ta | 100 - 500A
CoFeB | 30A
MgO | 15A
Ru | 10A – 60A
CoFe | 40A
PtMn | 125A
GST | 500A
Ag | --
SiO2 | 20 - 500A
HfOx | 20 - 500A
Al2O3 | 20 - 500A
TiN | 20 - 500A
SiGe | 500 – 2kA
Life Sciences
Materials | Thickness (A)
Ta | 50A
Ru | 10A - 20A
NiFe | 20A
CoFe | 475A
TiN | 1kA
a-Si | 2kA
AlOx | 50A
µWells
MEMS
Materials | Thickness (A)
Co | 500A
CoNi | 600A
Ni | 1000A
NiFe | 500A
Al | 10kA
SiGe, Ge | 2kA
Ru | 500A
Magnetic Stack
Miscellaneous
Materials | Thickness (A)
Pt | 1000A
PZT | Up to 2.2um
Nb | 3KA
10.0kV X1.80K 16.7µm
4k Metal Thk
12
TSI SEMICONDUCTORS

Etching of Novel Materials

	LAM 9600	AMAT DPS2	Tegal 6540 *	Veeco Ion Mill
Gases Available	Chamber A (60C): BCl3,Cl2, Ar, N2, O2,SF6,He,O2 Chamber B (250C): DSQ O2, H20	Chamber A (250C): BCl3,Cl2, Ar Chamber B (65C): CF4, HeO2,HBr,Cl2	HRe 2.1 (30-80C): BCl3, Cl2, CHF3, CF4, Ar, O2 HRe 4.0 (170-350C): CO, Cl2, NH3, CF4, Ar, O2	Single Chamber: Ar
Materials Etched (Examples)	Al, TiN/Al/Ti, TiW/TiAl, GST, Ru, Nb , Al2O3,	Chamber A: High-k, Al2O3, TiN, TaN, Ru, Zr, Chamber B: Metal Gate Stacks - Poly & metal alloys	HRe 2.1: Oxide, Ti, TiN, W, Ta, GST HRe 4.0: Ti, TiN, Nb, Pt, AlOx,Ta, PtMn, CoFe, MgO, Ru, Ag	Oxide, Ti, TiN, W, Ag, CoFe, Ni, Mg,

* In storage

13

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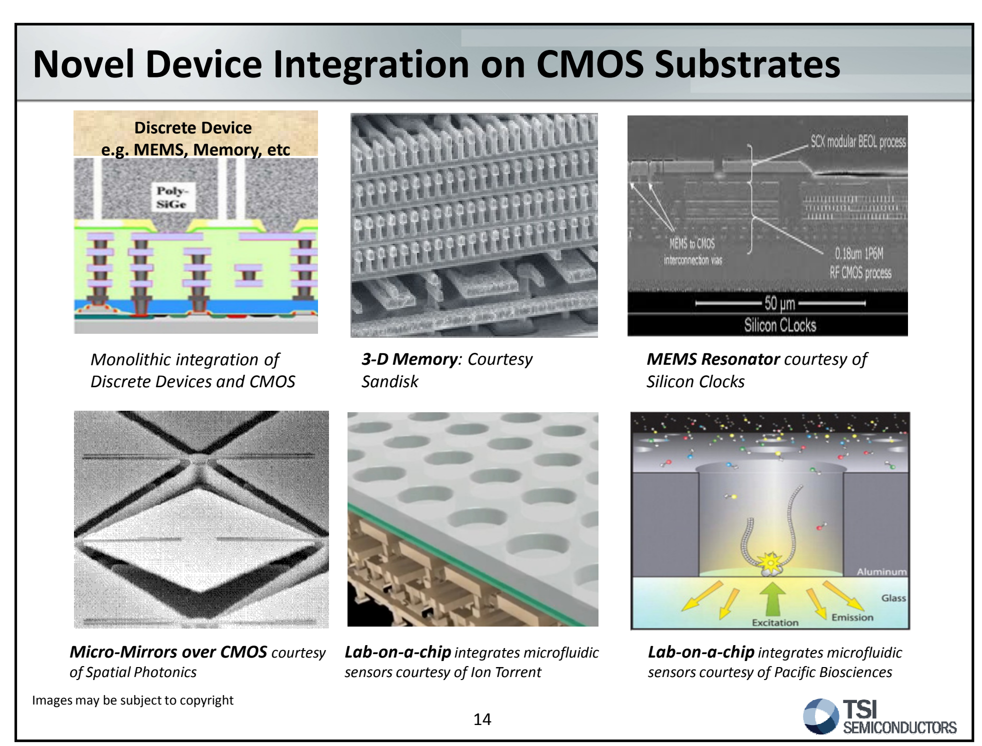


Monolithic integration of Discrete Devices and CMOS

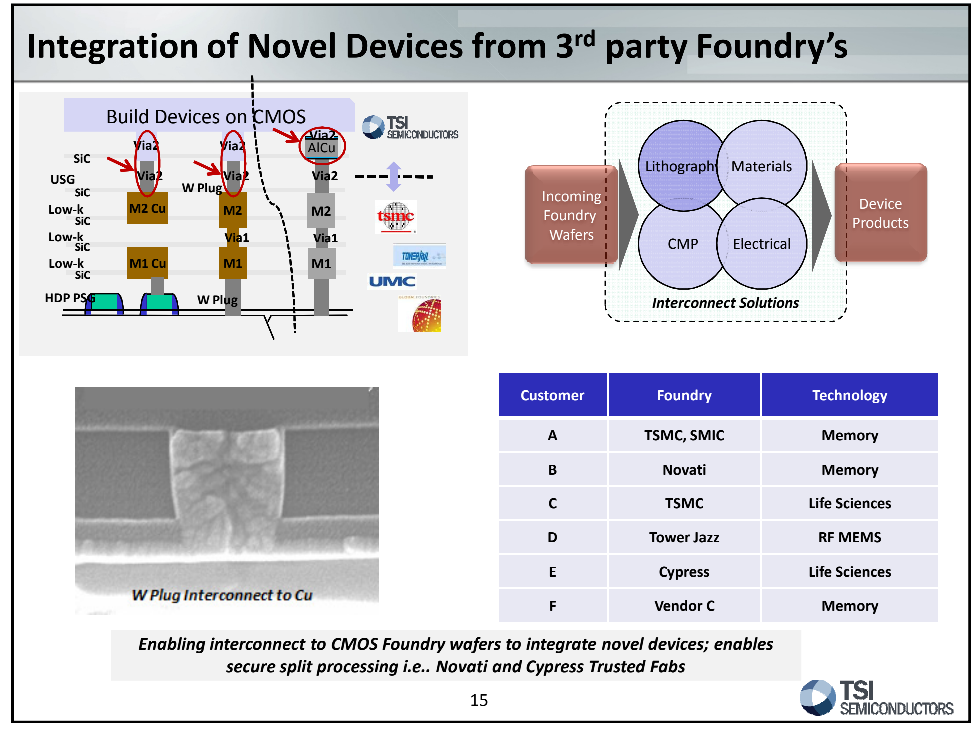
***3-D Memory**: Courtesy Sandisk*

***MEMS Resonator** courtesy of Silicon Clocks*

***Micro-Mirrors over CMOS** courtesy of Spatial Photonics*

***Lab-on-a-chip** integrates microfluidic sensors courtesy of Ion Torrent*

***Lab-on-a-chip** integrates microfluidic sensors courtesy of Pacific Biosciences*


Integration of Novel Devices from 3rd party Foundry's
Build Devices on CMOS
SiC
USG
Low-k
HDP PSG
Via2
AlCu
M2 Cu
M1 Cu
W Plug
M2
Via1
M1
Incoming Foundry Wafers
Lithography
Materials
CMP
Electrical
Interconnect Solutions
Device Products
W Plug Interconnect to Cu
Customer | Foundry | Technology
A | TSMC, SMIC | Memory
B | Novati | Memory
C | TSMC | Life Sciences
D | Tower Jazz | RF MEMS
E | Cypress | Life Sciences
F | Vendor C | Memory
Enabling interconnect to CMOS Foundry wafers to integrate novel devices; enables secure split processing i.e.. Novati and Cypress Trusted Fabs
15
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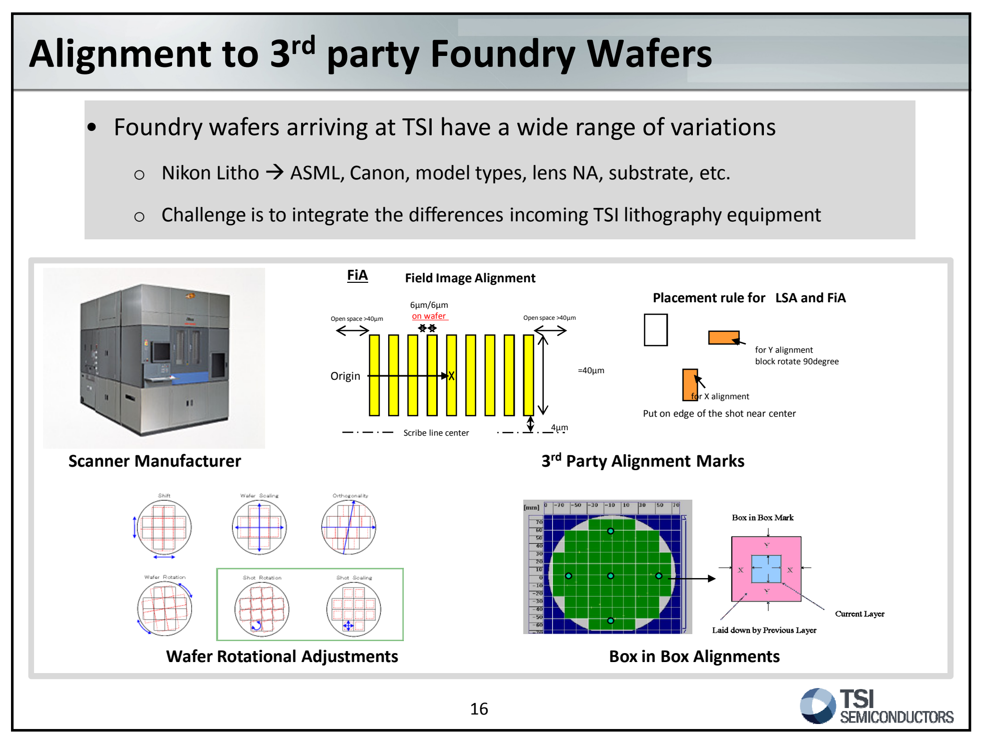
Alignment to 3rd party Foundry Wafers
Foundry wafers arriving at TSI have a wide range of variations
Nikon Litho → ASML, Canon, model types, lens NA, substrate, etc.
Challenge is to integrate the differences incoming TSI lithography equipment
Scanner Manufacturer
FiA
Field Image Alignment
6µm/6µm
on wafer
Origin
Scribe line center
Placement rule for LSA and FiA
for Y alignment block rotate 90degree
for X alignment
Put on edge of the shot near center
3rd Party Alignment Marks
Wafer Rotational Adjustments
Box in Box Mark
Current Layer
Laid down by Previous Layer
Box in Box Alignments
16
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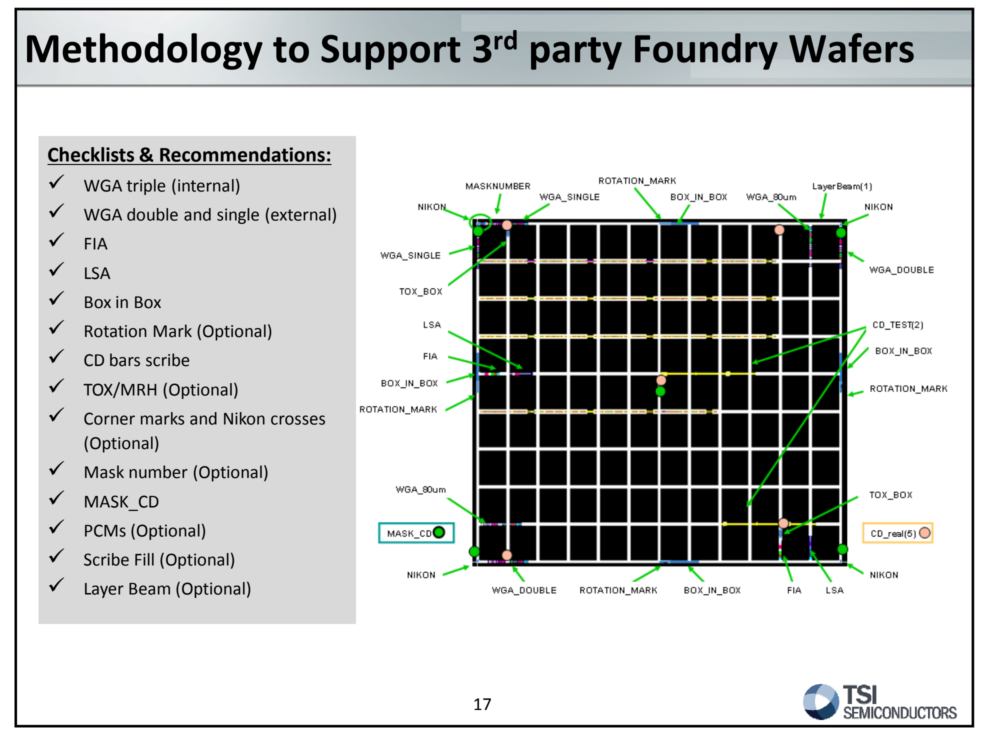
Methodology to Support 3rd party Foundry Wafers
Checklists & Recommendations:
WGA triple (internal)
WGA double and single (external)
FIA
LSA
Box in Box
Rotation Mark (Optional)
CD bars scribe
TOX/MRH (Optional)
Corner marks and Nikon crosses (Optional)
Mask number (Optional)
MASK_CD
PCMs (Optional)
Scribe Fill (Optional)
Layer Beam (Optional)
MASKNUMBER
ROTATION_MARK
WGA_SINGLE
BOX_IN_BOX
WGA_80um
LayerBeam(1)
NIKON
WGA_DOUBLE
TOX_BOX
LSA
FIA
CD_TEST(2)
MASK_CD
CD_real(5)
17
TSI SEMICONDUCTORS

Case Studies on Foundry Development Collaborations
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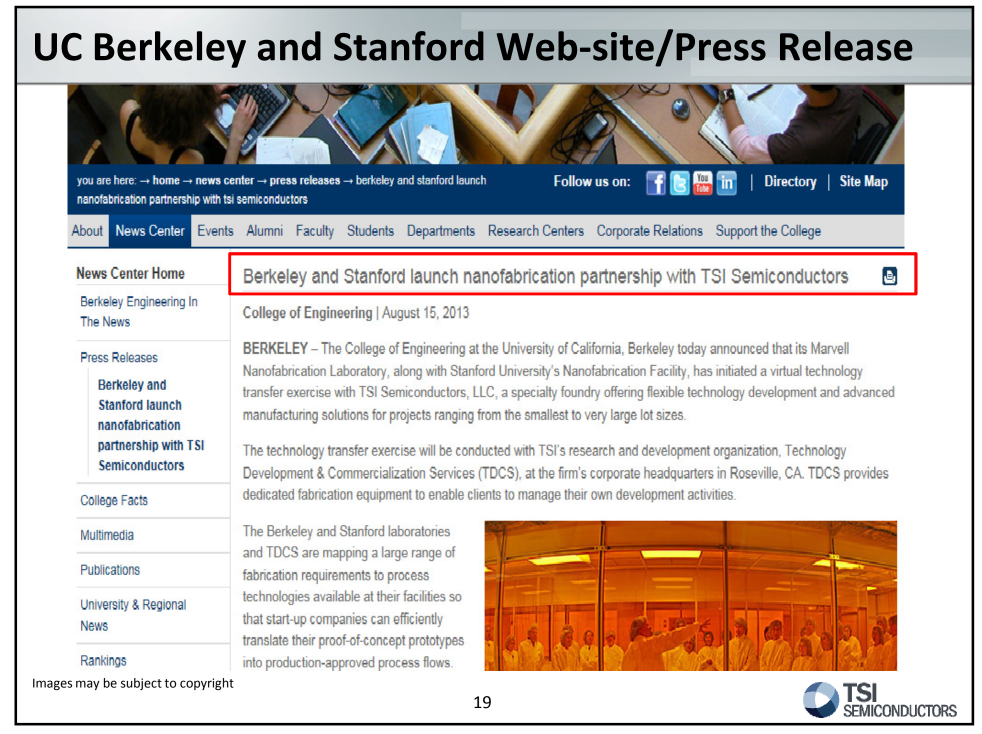
UC Berkeley and Stanford Web-site/Press Release
you are here: → home → news center → press releases → berkeley and stanford launch nanofabrication partnership with tsi semiconductors
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Berkeley and Stanford launch nanofabrication partnership with TSI Semiconductors
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Berkeley and Stanford launch nanofabrication partnership with TSI Semiconductors
College of Engineering | August 15, 2013
BERKELEY – The College of Engineering at the University of California, Berkeley today announced that its Marvell Nanofabrication Laboratory, along with Stanford University's Nanofabrication Facility, has initiated a virtual technology transfer exercise with TSI Semiconductors, LLC, a specialty foundry offering flexible technology development and advanced manufacturing solutions for projects ranging from the smallest to very large lot sizes.
The technology transfer exercise will be conducted with TSI's research and development organization, Technology Development & Commercialization Services (TDCS), at the firm's corporate headquarters in Roseville, CA. TDCS provides dedicated fabrication equipment to enable clients to manage their own development activities.
The Berkeley and Stanford laboratories and TDCS are mapping a large range of fabrication requirements to process technologies available at their facilities so that start-up companies can efficiently translate their proof-of-concept prototypes into production-approved process flows.
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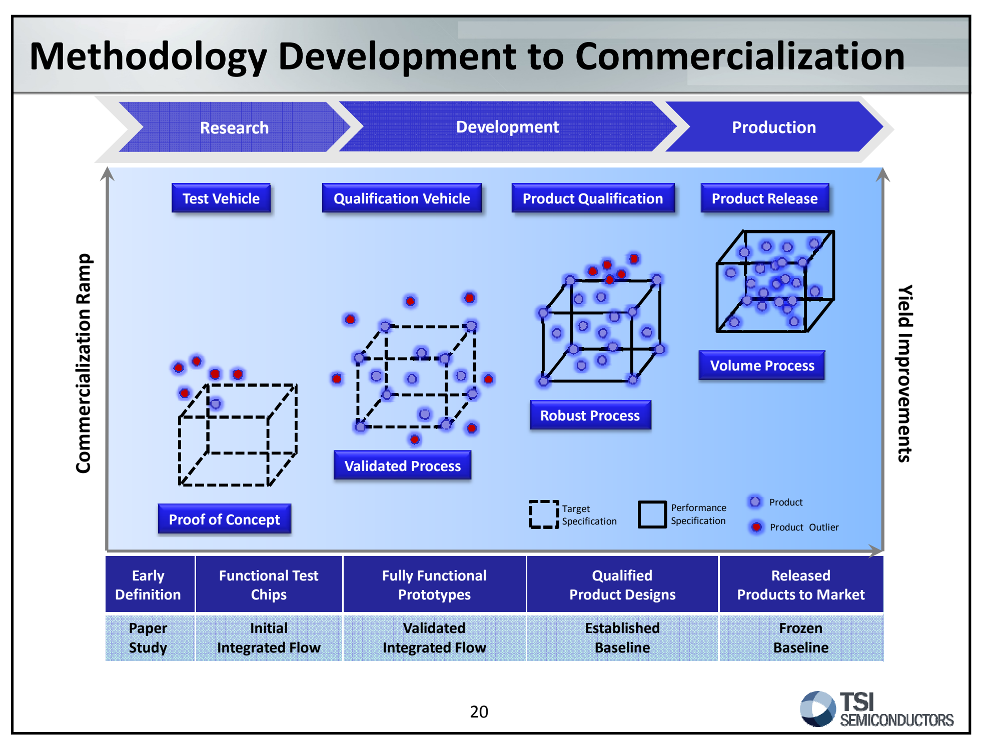
Methodology Development to Commercialization
Research
Development
Production
Commercialization Ramp
Yield Improvements
Test Vehicle
Qualification Vehicle
Product Qualification
Product Release
Volume Process
Robust Process
Validated Process
Proof of Concept
Target Specification
Performance Specification
Product
Product Outlier
Early Definition
Functional Test Chips
Fully Functional Prototypes
Qualified Product Designs
Released Products to Market
Paper Study
Initial Integrated Flow
Validated Integrated Flow
Established Baseline
Frozen Baseline
20
TSI SEMICONDUCTORS

Photonics Waveguide Technology

- **Business Model**
  - Jointly Develop leading edge Photonic MEMS Switch
  - Requires need for process innovation, commercialization in a Foundry Facility
- **POC - University California Berkeley**
  - Integrate multi-state Photonics project with TSI
  - Small scale lab on 6 inch wafer pieces
- **Commercialization - TDCS**
  - Development and Fabrication to integrate into CMOS into 200mm Processes
  - Develop process library for commercialization
- **Production – Still in Development**
  - Completed stage 1 passive components
  - Working on development & integration for stage 2 active components

Berkeley UNIVERSITY OF CALIFORNIA

Marvell Nanofabrication Laboratory

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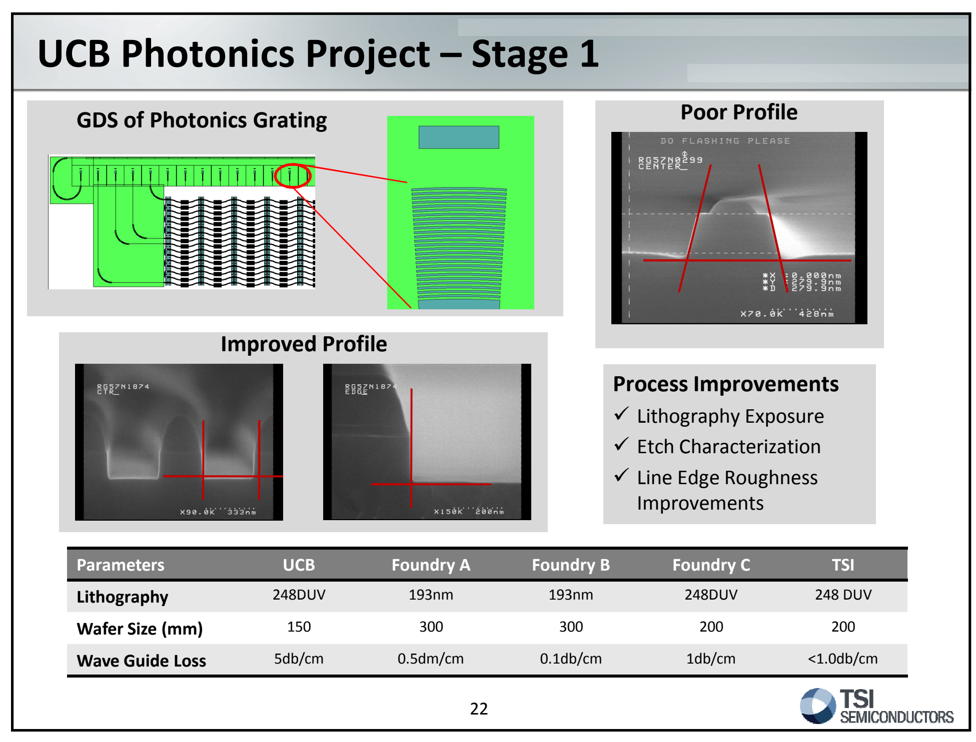

Parameters	UCB	Foundry A	Foundry B	Foundry C	TSI
Lithography	248DUV	193nm	193nm	248DUV	248 DUV
Wafer Size (mm)	150	300	300	200	200
Wave Guide Loss	5db/cm	0.5dm/cm	0.1db/cm	1db/cm	<1.0db/cm

Certification and Compliance

- TS16949:2009 – certification applies for the design & development, production, installation and servicing of automotive related products
  - This was prepared by the International Automotive Task Force (IATF) and ISO technical committee
  - Attributes for AEC-Q100 (Automotive Electronics Council)
- ISO9000 – Quality Management Systems
- ISO14001 – Environmental Management Systems
- DMEA Accreditation of Trusted Facility
- ITAR Certified in Electronics category

24

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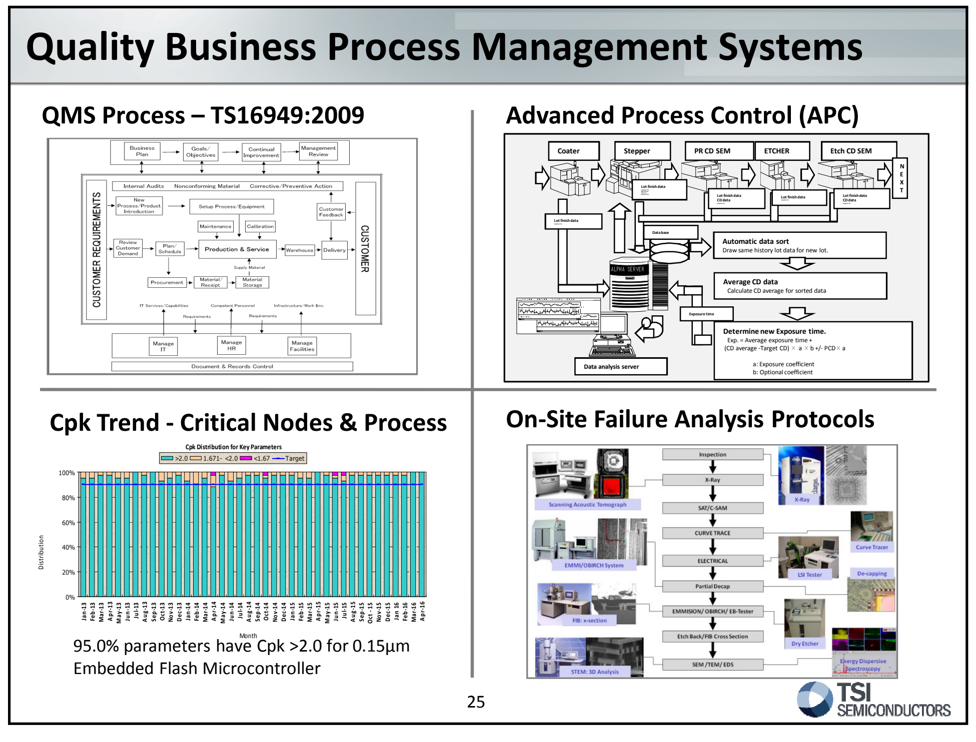

TSI Stress Test Qual for IC's – Partial Lists

Test Conditions	Type	TSI16949/AEC-Q100	Mil Guidelines
Reliability & Quality Tests (partial list)	TDDB	√	√
	Hot Carrier Injection	√	√
	Negative Bias Temp Instability	√	√
	Electromigration	√	√
	Stress Migration	√	√
	ESD	√	√
	Latch-Up	√	√
	Electrothermally Induced Gate Leakage	Customer Request	√
	Soft Error rate	√ Sort	√
	Process Avg Tests	√ Sort/FT	√
	Stat Bin/Yield Analysis	√ Sort/FT	√
	*Radiation Hardness	Customer request	√

* In progress by Design with Customer

26

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Summary

- TSI is positioned as a US-based specialty foundry with a technology platform supporting industrial, automotive, Mil-Aero and medical markets
- We are also positioned to provide a development service (TDCS) for innovative and disruptive materials development not found in typical Production Foundry Fabrications
- Customer IP is safe and secure – Trusted, ITAR Certified
- We are based in Northern CA location, close to tech eco-system
- Our services business model and collaboration enables faster and cost effective time to market for these technologies

27

Thank You

Wilbur Catabay
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TSI Semiconductors Corporation

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