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

TSI SEMICONDUCTORS

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

TSI SEMICONDUCTORS

TSI Semiconductors at a Glance

Business Segments

- Automotive
- Industrial & Power Management
- Mil-Aero
- IOT

Strong customer technology collaboration with a flexible model for Foundry and Development with novel materials

Strong Domestic Presence

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

US On-Shore Facilities, Roseville, Ca

- Foundry, Custom Foundry & Development
- Capacity of 10,000 wafers per month
- Capacity at 30% of clean room space

World Class Foundry

- Over 30 years of continuous operations
- 24/7 Operations, Clean room 150,000 Sq/ft
- Logic, High Voltage, Mix Signal, Analog, RF
- Novel Materials Integration
- IP Secure Environment
- ISO & Auto Certification
- DMEA Trusted & ITAR

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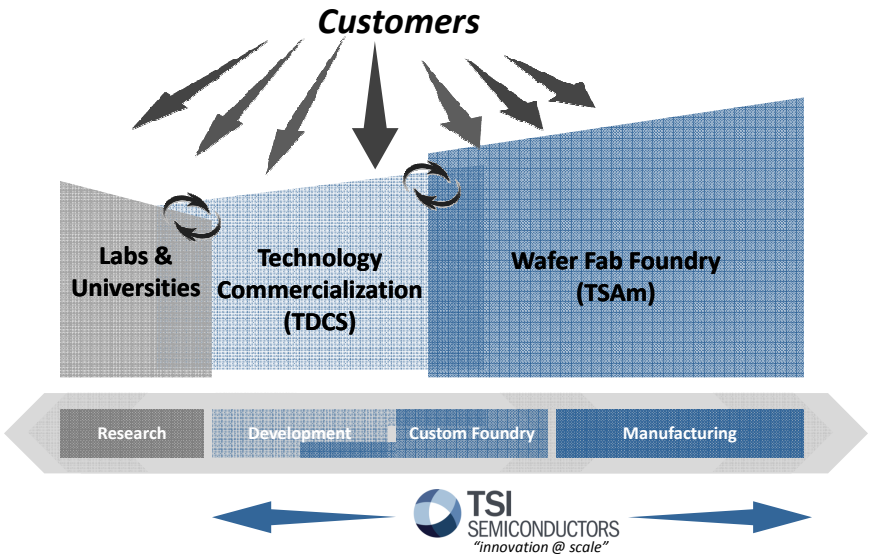
Custom Foundry: Development to Manufacturing



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TSI Process Technology Platforms

Low Voltage
1.8V, *3.3V, 5V - 20V
Display, Optics, Drivers, Medical, Automotive, Wireless Charging

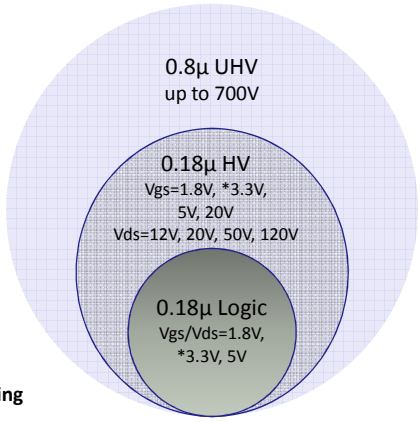
Medium Voltage
12V - 120V
Automotive, Industrial, Medical, Networks, Lighting

Ultra High Voltage
Up to 700V
LED, IGBT, MOSFET

Automotive

Medical

Telecom /Networking



Industrial

Aerospace

Lighting

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*available Q4'16

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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/µm² * (1ML)	Single MIM - 2.1 fF/µm² * (1ML)	Single MIM - 2.1 fF/µm² * (1ML)
			Dual MIM - 4.1 fF/µm² * (1ML)	Dual MIM - 4.1 fF/µm² * (1ML)	Dual MIM - 4.1 fF/µm² * (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

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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

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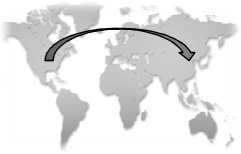
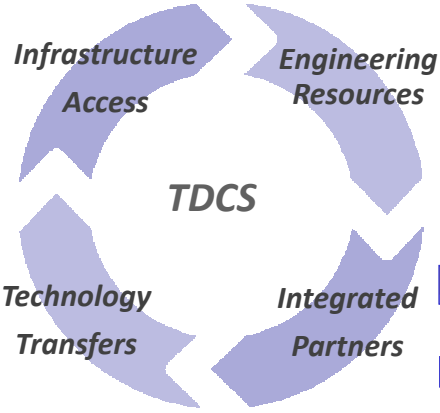
Technology Development - Collaboration





SOSS MicroTec, MEMC, Applied MST, SINGULUS, TOPPAN, CORWIL, entrepix, SDI, HIONIX, UHV

Research → Development → Production

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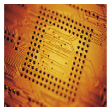
Process Module Toolbox


Semiconductor

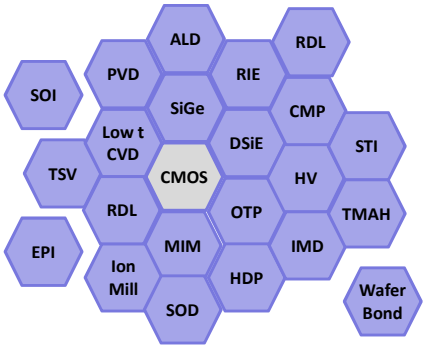

Medical


Telecom


Mil Aero


Consumer Mobility


Clean Energy



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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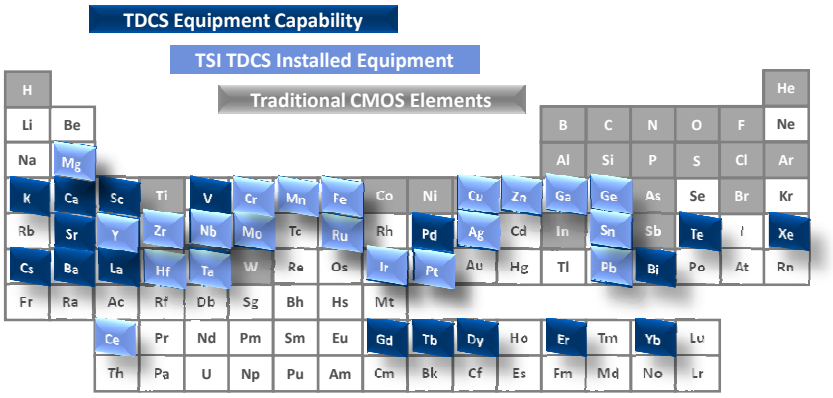
New Materials Flexibility – Emerging Market Focus



Element Review Board (ERB) enables safe & efficient introduction of new materials into facilities

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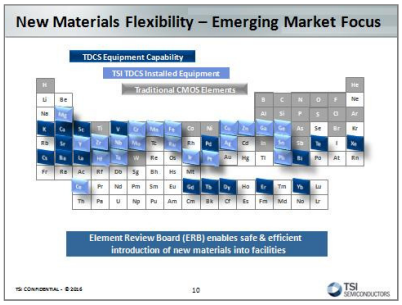
Non-Volatile Memory Materials Development

Memory Materials Development



Device	Materials	Process Module's
MRAM	Co, Fe, B, Ni Ta, Ti, Pt, Mn, Ru, Mg, Ir, Al, Metal Oxides	• Low temp processing (<200C) • Nobel Etch and Cleans • AlCu Interconnect • Interconnect with CMOS • Materials Integration • CMP • Hardmask and Liner Integration • Pattern Shrink
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	

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How to deal with a Variety of Novel Materials

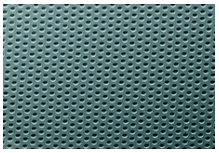
Many Variation in Materials and Thicknesses, not one Etch Solution that fits all applications

Memory Devices

Materials	Thickness (A)
Ta	100 - 500A
CoFeB	30A
MgO	15A
Ru	10A – 60A
CoFe	40A
PtMn	125A
GST	500A
Ag	--
SiO_2	20 - 500A
HfO_x	20 - 500A
Al_2O_3	20 - 500A
TiN	20 - 500A
SiGe	500 – 2kA

Life Sciences

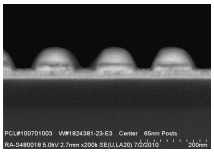
Materials	Thickness (A)
Ta	50A
Ru	10A - 20A
NiFe	20A
CoFe	475A
TiN	1kA
a-Si	2kA
AlOx	50A



µWells

MEMS

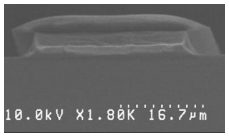
Materials	Thickness (A)
Co	500A
CoNi	600A
Ni	1000A
NiFe	500A
Al	10kA
SiGe, Ge	2kA
Ru	500A



Magnetic Stack

Miscellaneous

Materials	Thickness (A)
Pt	1000A
PZT	Up to 2.2um
Nb	3KA



4k Metal Thk

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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

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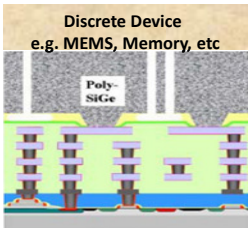
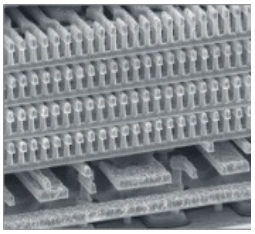
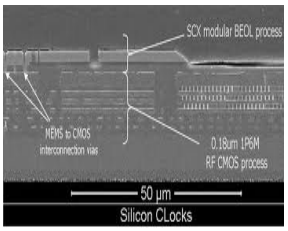
Novel Device Integration on CMOS Substrates



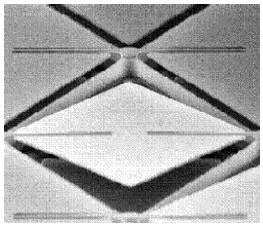
Monolithic integration of Discrete Devices and CMOS



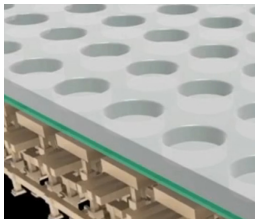
***3-D Memory**: Courtesy Sandisk*



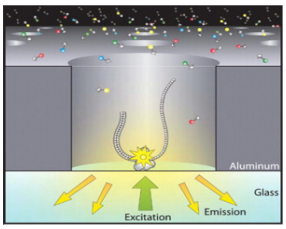
***MEMS Resonator** courtesy of Silicon Clocks*



***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*

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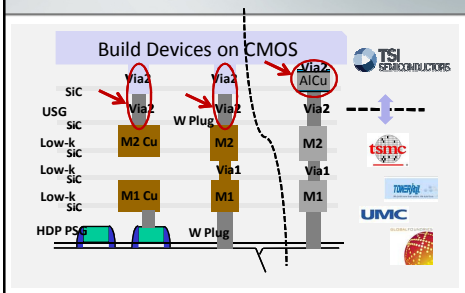
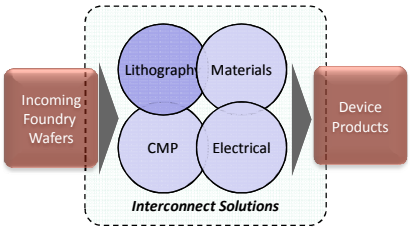
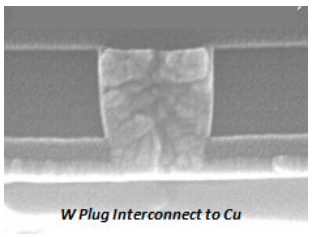
Integration of Novel Devices from 3rd party Foundry's







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

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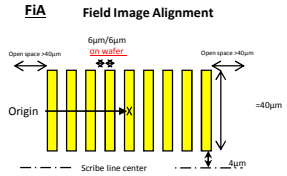
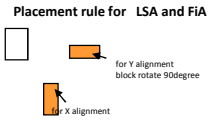
Alignment to 3rd party Foundry Wafers

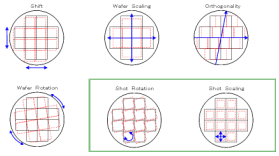
- Foundry wafers arriving at TSI have a wide range of variations
  - Nikon Litho → ASML, Canon, model types, lens NA, substrate, etc.
  - Challenge is to integrate the differences incoming TSI lithography equipment

Scanner Manufacturer

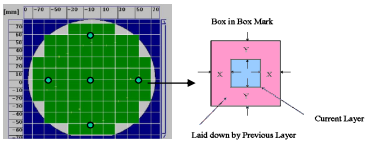




3rd Party Alignment Marks



Wafer Rotational Adjustments



Box in Box Alignments

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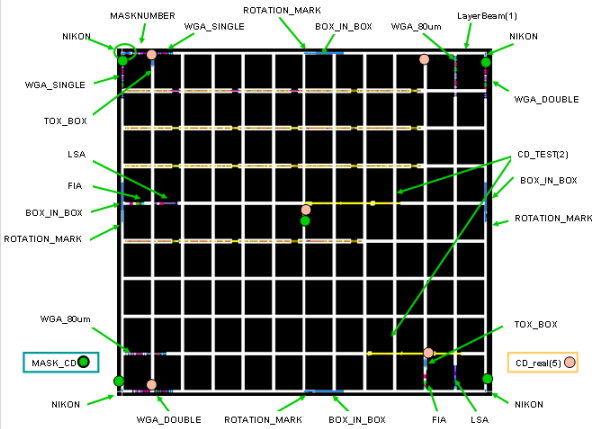
Methodology to Support 3rd party Foundry Wafers

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)



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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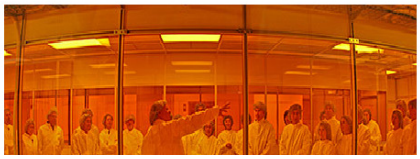
Berkeley and Stanford launch nanofabrication partnership with TSI Semiconductors

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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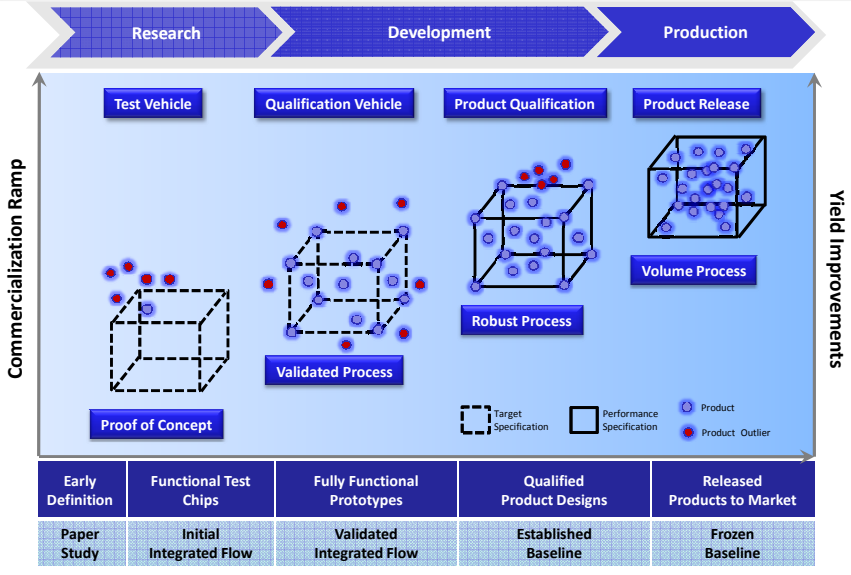
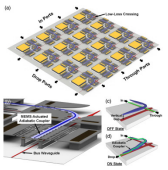
Methodology Development to Commercialization



TSI SEMICONDUCTORS

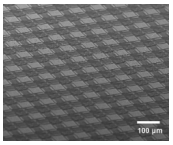
Photonics Waveguide Technology

- **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

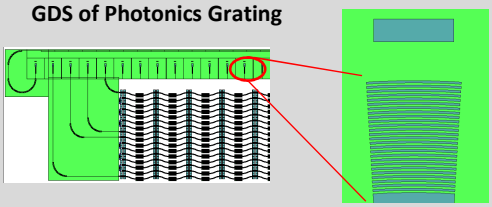
Marvell Nanofabrication Laboratory



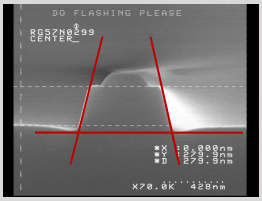
TSI SEMICONDUCTORS

UCB Photonics Project – Stage 1

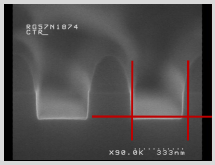
GDS of Photonics Grating

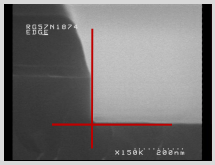


Poor Profile



Improved Profile





Process Improvements

- ✓ Lithography Exposure
- ✓ Etch Characterization
- ✓ Line Edge Roughness Improvements

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

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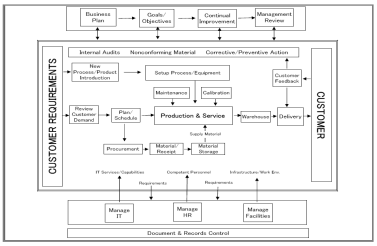
Certification and Compliance

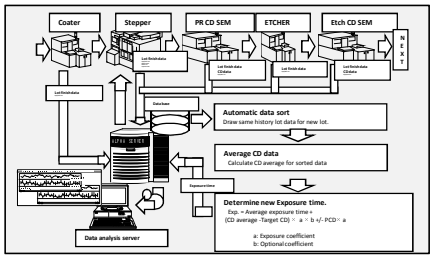
- TS16949:2009 – certification applies for the design & development, production, installation and servicing of automotive related products
  - This was prepared by the International Automotive Task Force (IATF) and ISO technical committee
  - Attributes for AEC-Q100 (Automotive Electronics Council)
-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

Quality Business Process Management Systems

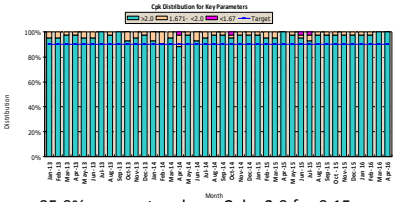
QMS Process – TS16949:2009



Advanced Process Control (APC)

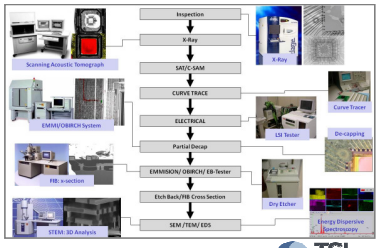


Cpk Trend - Critical Nodes & Process



95.0% parameters have Cpk >2.0 for 0.15µm Embedded Flash Microcontroller

On-Site Failure Analysis Protocols



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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

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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

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Thank You

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