MEMS Commercialization: Bridging the Gap from Prototype to Production

Prakash Krishnan: Director of Marketing

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Expanding Si Platform

Driven by The Vision of a Sustainable Society & Smarter Planet

Computation • Communication

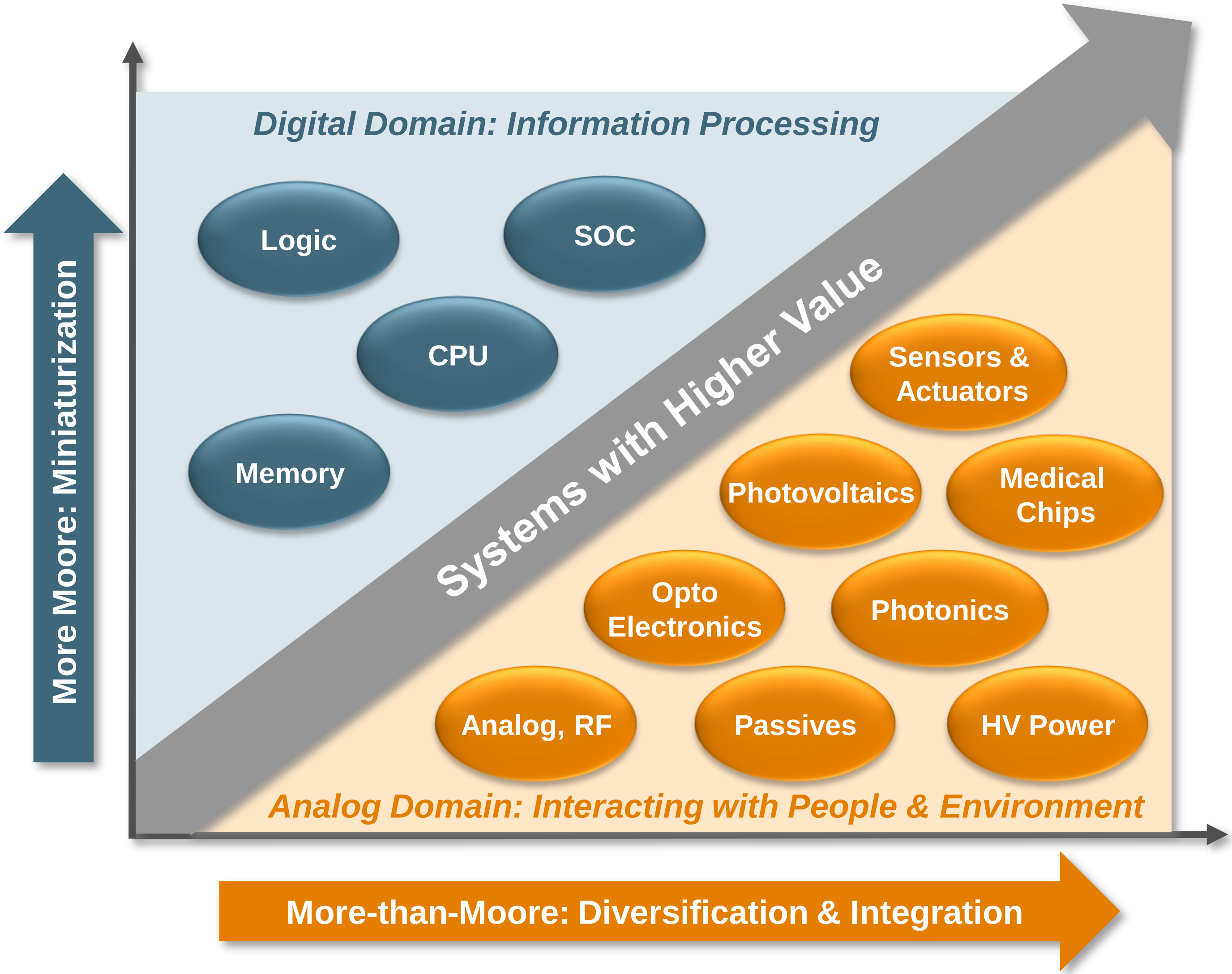
Sensing • Actuating

Bioelectronics • Life Sciences

Clean Energy • Smart Energy

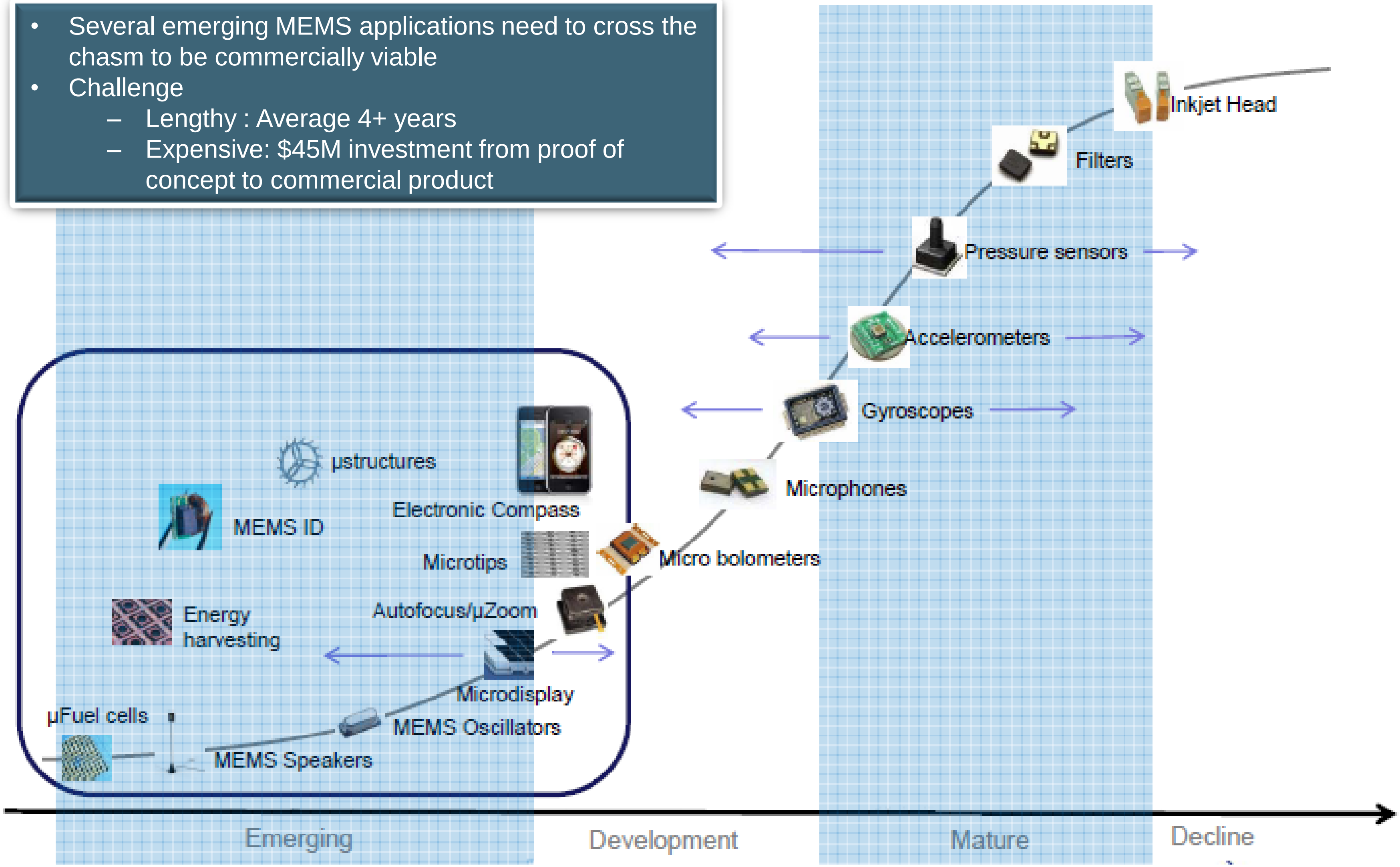
New Era of Si Scaling

System Integration



Emerging MEMS
Fuel for Future MEMS growth

- Several emerging MEMS applications need to cross the chasm to be commercially viable
- Challenge
  - Lengthy : Average 4+ years
  - Expensive: $45M investment from proof of concept to commercial product



Courtesy: Yole Developpement

Why Lengthy & Expensive?

SVTC.

- Unique products, Application specific
  - MEMS Law: One product, One Process, One Package still active
  - Applications ranging from Medical to Consumer to Defense
- Several barriers to Market adoption
  - Narrow market window
  - Replace established incumbent technologies
- Limited economies of scale
  - Low volume, niche applications
  - No driving force for standardization
- Limited budgets and resources
  - Many new products developed by Start-up's
  - Intense competitive landscape

Need solutions covering design, wafer technology, test & packaging

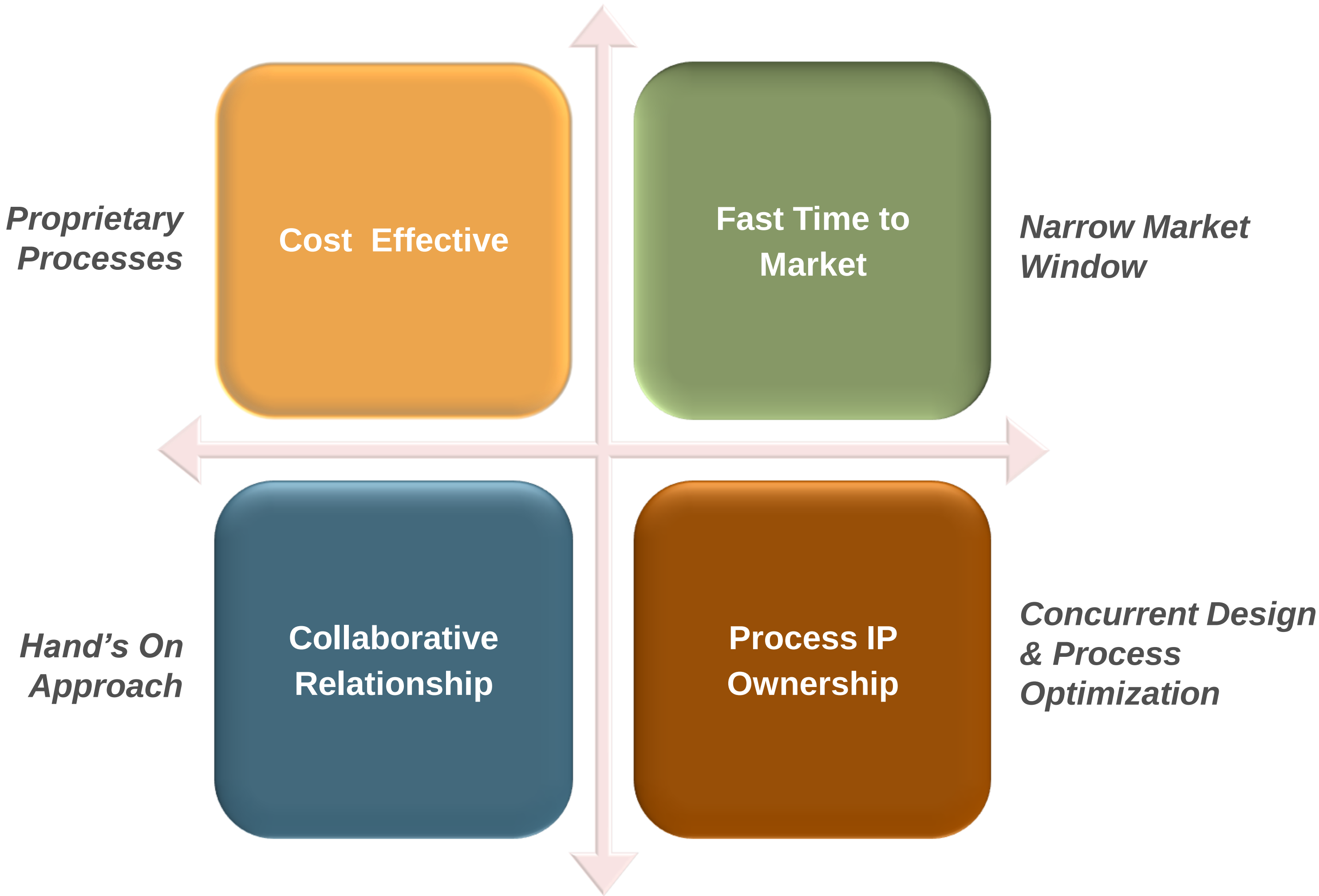
Proposed Solutions Framework

Wafer Fab Technology

Development Models	Choice of model has implications on Cost, Time to Market, IP ownership & Collaboration
Development Process	Systematic process needed to characterize and qualify for manufacturing
Standardization	Optimum standardization to create proprietary technology without compromising innovation

Development Models

Technology Development Requirements



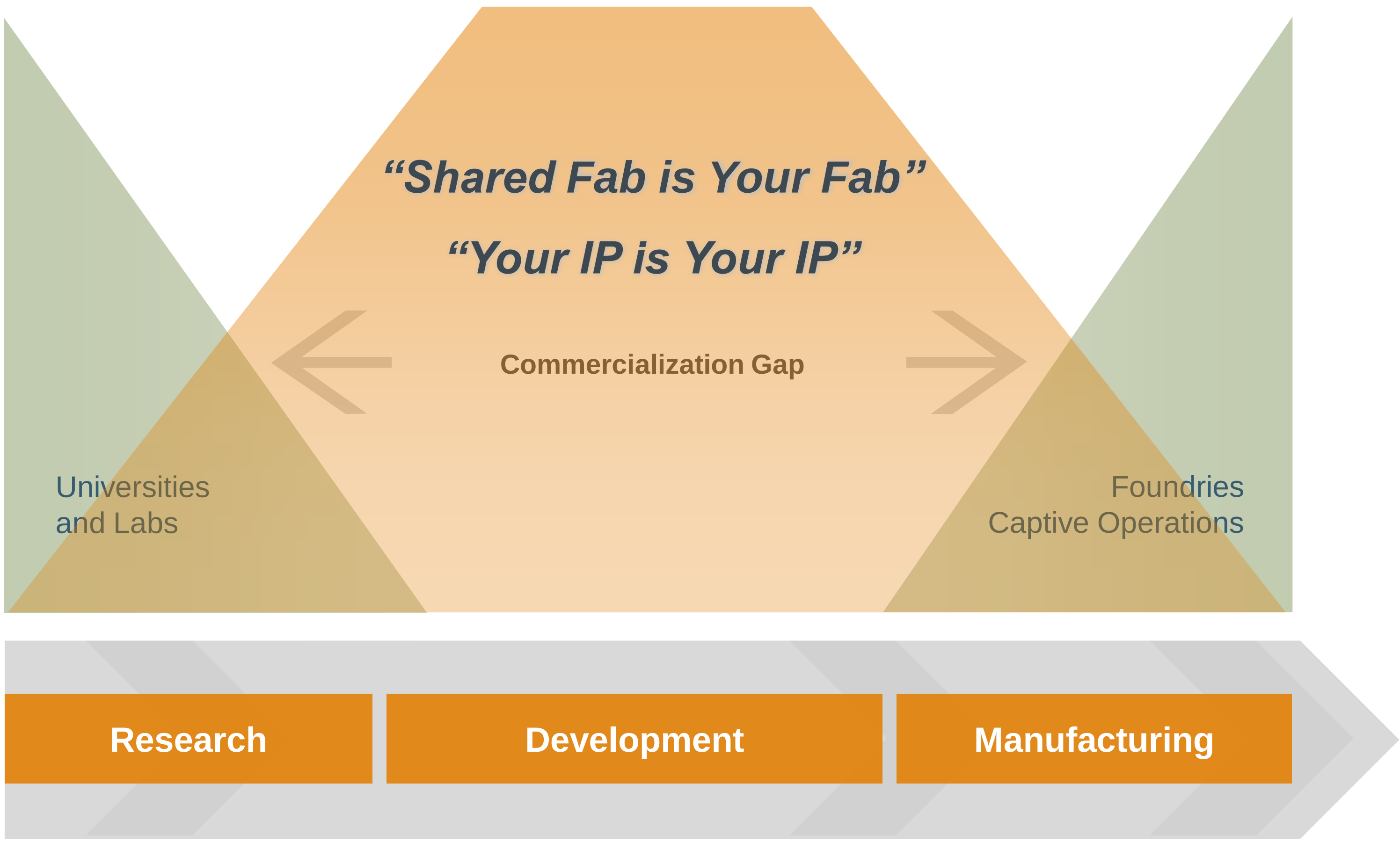
Model Options

Model	Cost	Time to Market	IP Ownership	Collaborative Relationship
University Environment	Low	Slow	Typically Shared	Research Agenda
Captive Fab	High	Fast (If Available, Limited Mfg.)	Company	Yes
Foundry	Low	Intermediate (Mfg. Priority)	Typically Shared	Selective Basis
Shared Fab (Development Focus)	Medium	Fast	Company	Yes

Shared Fab could be an optimum model as it provides a desired blend of cost, time to market & IP independence benefits

Shared Fab Model

Development Focus



Case Studies

Prototype to Production

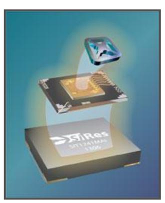
SVTC

SiTime
It's about time

Center for Integrated Systems

STANFORD UNIVERSITY

SVTC



Jazz SEMICONDUCTOR

SP
SPATIAL PHOTONICS, INC.

Demo Labs

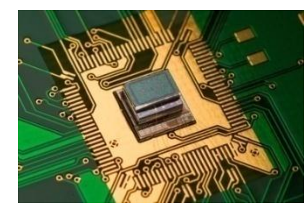
SVTC

Top Tier Volume Foundry

SILICON CLOCKS

THE UNIVERSITY OF CALIFORNIA 1868 Cal

SVTC

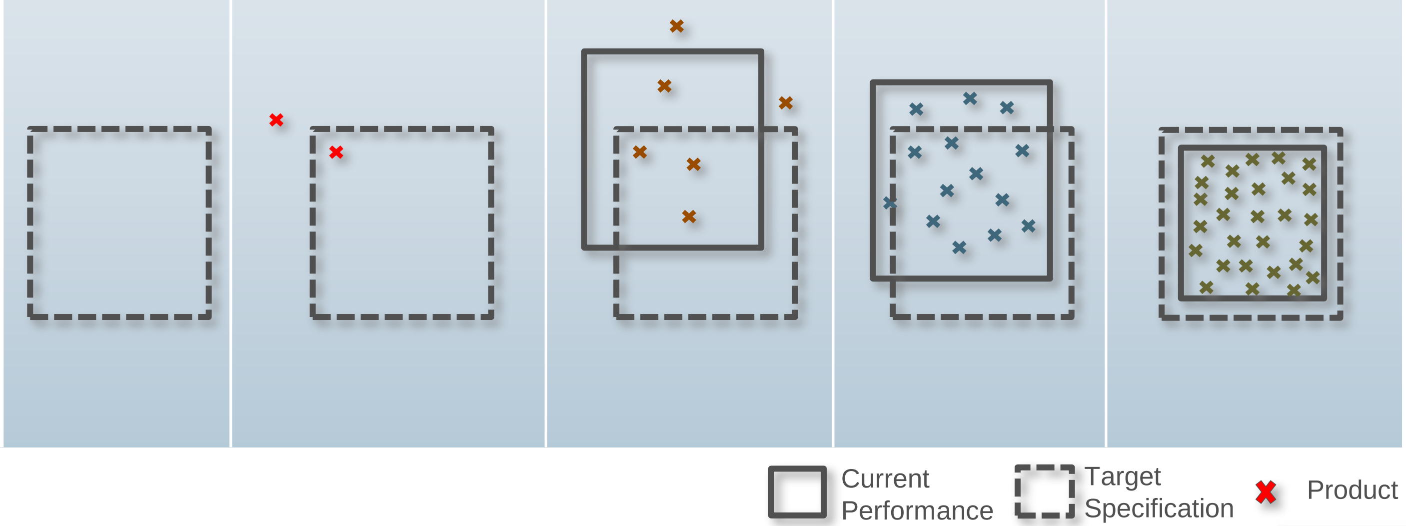


Top Tier Volume Foundry

Development Process

Technology Development Process

	Research		Development	Manufacturing	
	Ideas	Proof of Concept	Validated Process	Robust Process	Volume Process
Product Maturity	Early Definition	Partially Functional Prototypes	Fully Functional Prototypes	Qualified Product	Released Product
Process Maturity	Paper Study	Initial Integrated Flow	Validated Integrated Flow	Established Baseline	Frozen Baseline



Typical Pitfalls
Not Following Development Process

Immature, Under-Characterized Technology Leads to Unnecessary Rework Cycles & Delay of the Manufacturing Qualification

Proof of concept: Partially functional prototypes

Typical Issues: Lucky wafer syndrome, total lack of characterization for manufacturing

Validated Process: Functional prototypes

Typical Issues: Process, equipment and device windows not understood, not stable

Robust Process: Qualified Product

Typical Issues: Low Yielding Process, Many New Failure Modes to Be Discovered

Mitigation Strategy: Minimize Rework Cycle by Engaging in Technology Development Best Practices

Case Studies
Premature Manufacturing Qualification

Customer A (POC only)

- Demonstrated 12 functional memory bits at SNF
- Attempted direct transfer to HVM fab after POC
- Transfer unsuccessful – immature technology
- Utilized SVTC to characterize for manufacturing
- Achieved 1M functional memory bits
- Technology re-transferred to HVM fab
- Ramped to 15-20K wafers/month

Customer B (Validated Process only)

- Achieved 5% yield after process validation at SVTC
- Direct transfer to HVM fab after validation
- Transfer unsuccessful – achieved zero yield
- Utilized SVTC to characterize for manufacturing
- Improved yield to 60%
- Launched low volume production at SVTC
- Qualifying product for market acceptance

Premature manufacturing transfer results in rework; characterizing technology and engaging in development best practices is necessary

Standardization

Standardization Framework

Innovation & Scaling Aspects

Innovation

- + Innovative & proprietary process technologies provide "unfair" competitive advantage
- – Standardization can limit innovation & competitive advantage

Enable proprietary technologies & promote standardization at the process module level

- ➢ Maintain innovative & competitive edge with optimum amount of customization

Scaling

- + Access to 8" semiconductor infrastructure drive by demand for asset utilization
- – 8" Foundries and CMOS integration limits MEMS flexibility

Use of CMOS compatible tool set, materials and process modules are needed

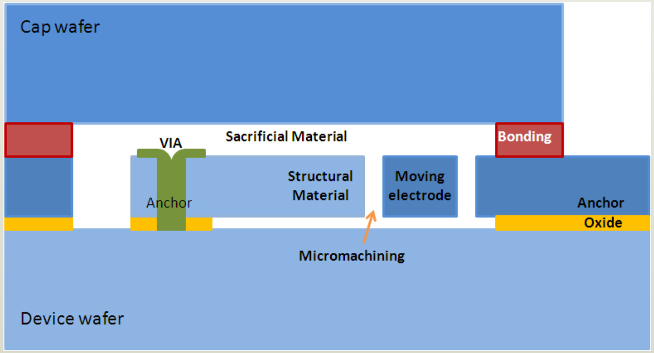
- ➢ Enables multiple foundries with lower volume, high mix portfolio and allows ease of transfer

Standardized Building Blocks

SVTC.

- Lithography
- Micromachining
- Structural Materials
- Sacrificial Materials
- Release Process
- Metallization
- Bonding
- Coatings

Process Modules



Technologies

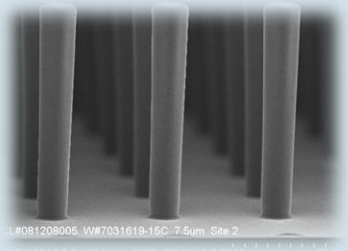
- Inertial Sensors
- Microdisplays
- Inkjet Heads
- Lab-on-a-Chip
- Pressure Sensors
- RF MEMS
- Microphones
- Oscillators
- Microbolometers
- Electro Chem
- Optics

Products

Enables the integration of innovative process technologies for various products by providing a characterized set of process modules

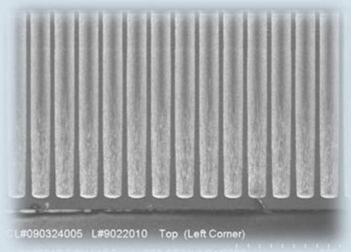
MEMS Building Blocks

Lithography



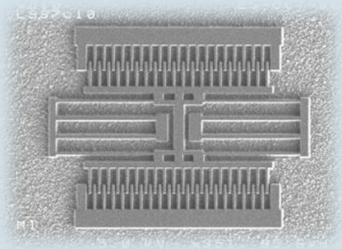
- I-line, DUV, 193nm
- 1X Proximity
- Front to Back Alignment
- Thick Resists:SU8,BCB

Micromachining



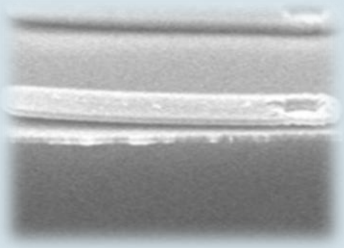
- Deep Silicon, Oxide etch
- Anisotropic: KOH
- Quartz channels & posts
- Barrel Ash

Structural Materials



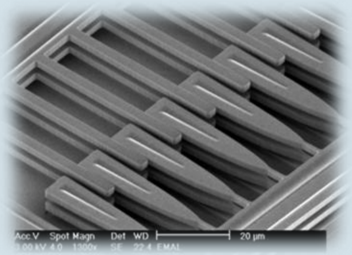
- Poly SiGe
- Poly and a-Si
- Low stress and low temp SiO_2, SiN

Metals



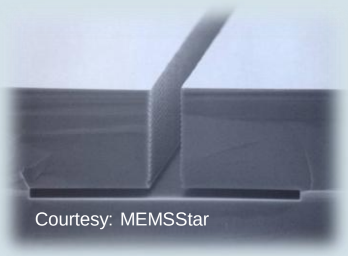
- CMOS: Ti, TiN, Ta, TaN, Al, Cu, W, Co, Si, Ni
- MEMS: Au, Ag, Sn
- Magnetic Materials

Sacrificial Materials



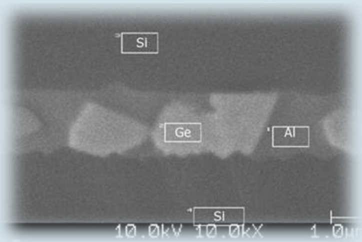
- Organic, Polyimides
- Ge
- CVD SiO_2
- a-C

Release Processes


Courtesy: MEMSStar

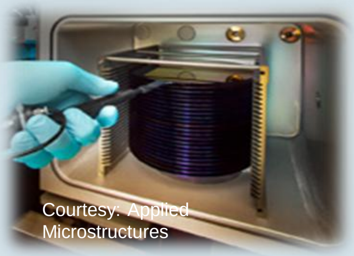
- Wet: Dilute HF, H_2O_2,, Solvent based
- Dry: O_2 Plasma
- Dry: Vapor HF, XeF_2

Bonding



- Eutectic: AlGe, *AuSn*
- Fusion: Si-Si, Si-SiO_2
- Anodic: Si-Glass, Quartz
- Temporary Bond

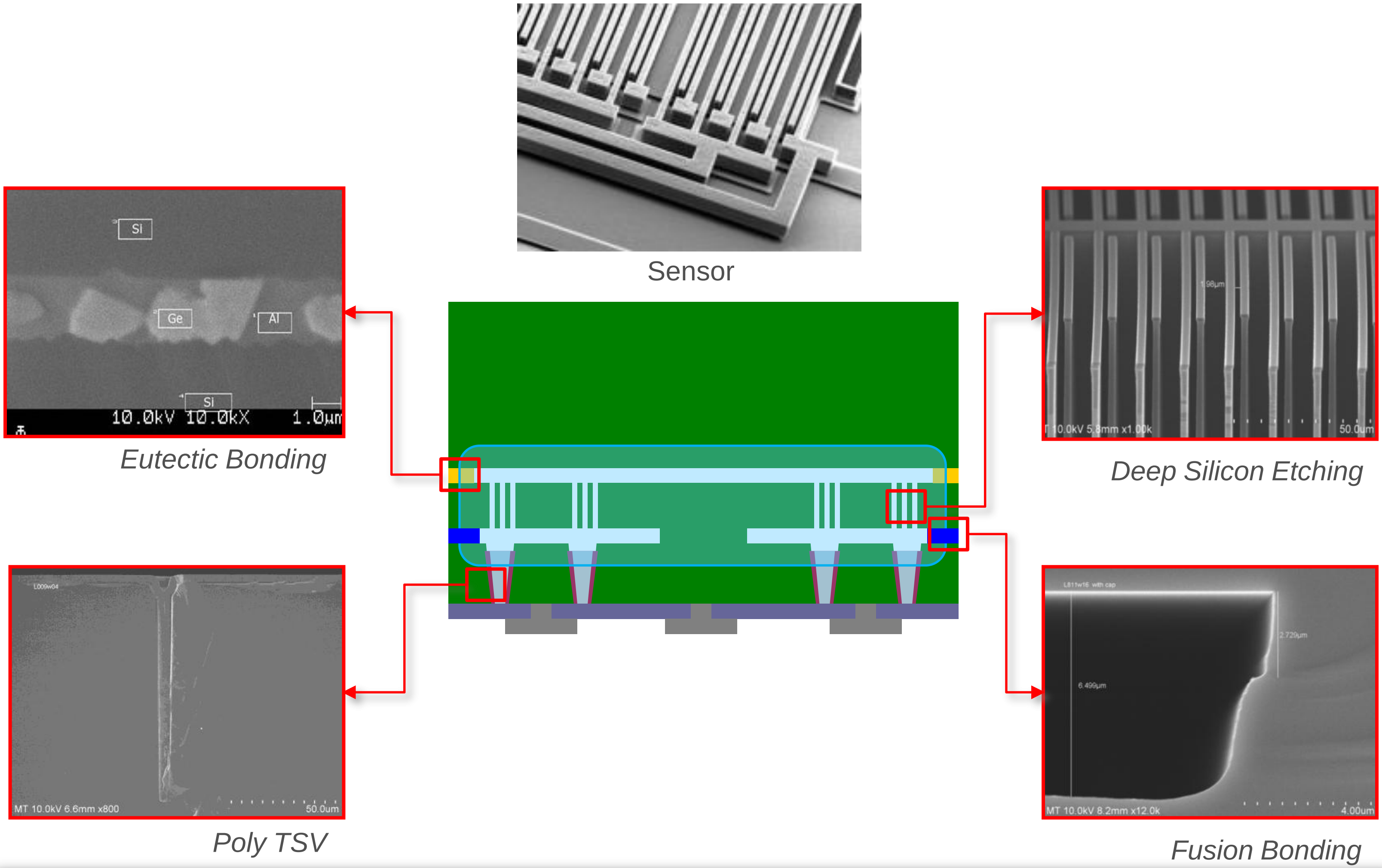
Coatings


Courtesy: Applied Microstructures

- Atomic Layer: ALD
- Organic anti-stiction
- Gettering
- Biocompatible coatings

Process Modules for Hermetic Packaging

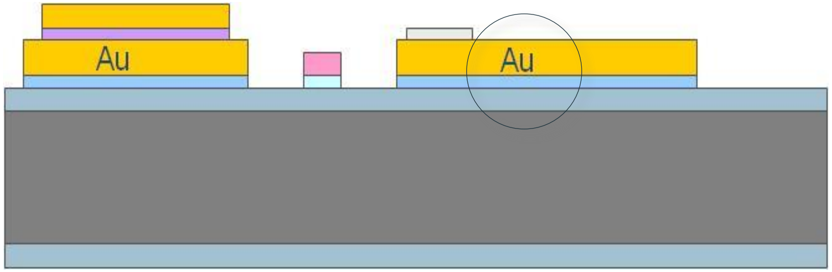
Inertial Sensor Example

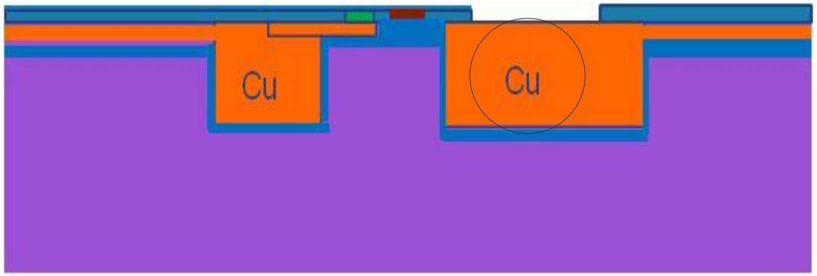


Process Modules can be reused to build other MEMS technologies and products

Use of CMOS Compatible Materials

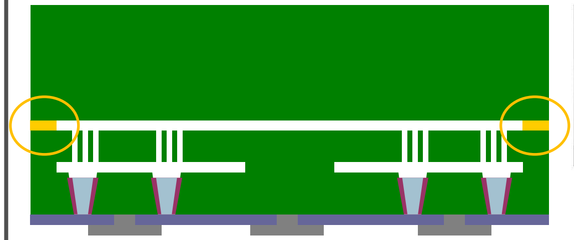
Metal interconnect



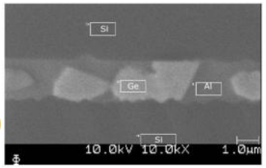


Replacing Lift Off process and Au metal with Damascene process and Cu metal

Eutectic Wafer Bonding



Hermetic seal with active sensor

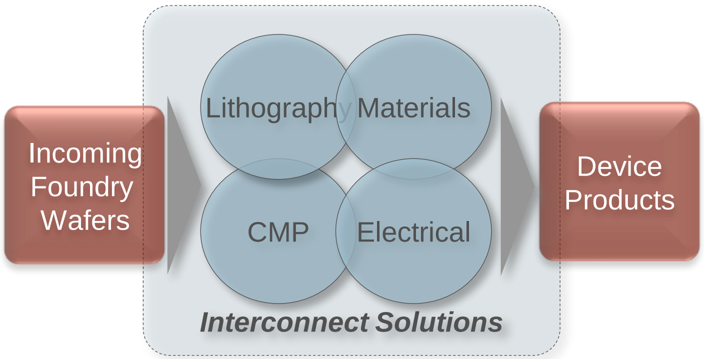


Al-Ge Metal Bond

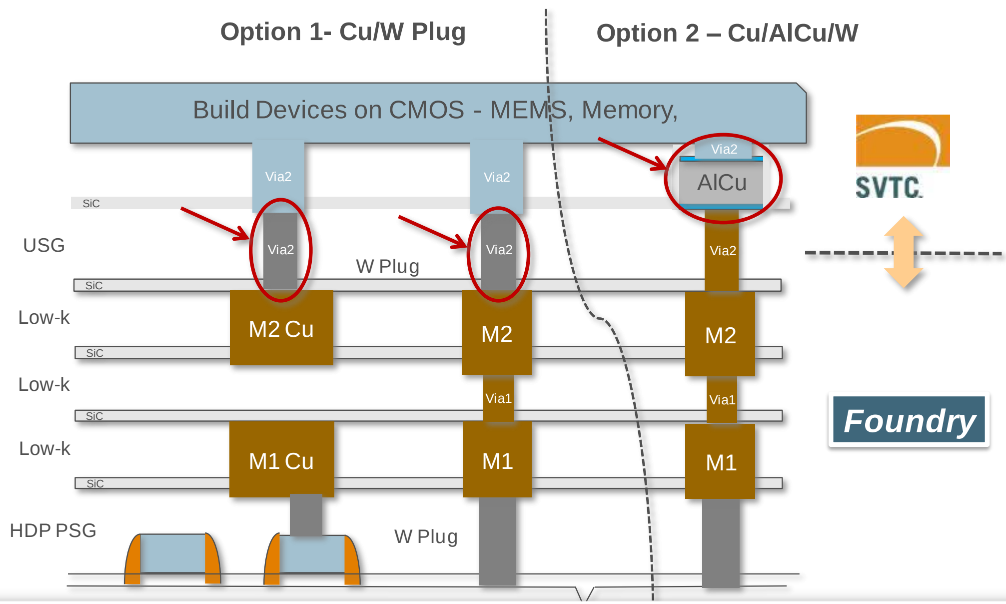
Eutectic Alloy	Au-Sn		Au-Si		Au-Ge		Al-Ge	
Temperature, C	280		363		360		419	
Element	Au	Sn	Au	Si	Au	Ge	Al	Ge
wt%	20	80	97	3	88	12	49	51
density, kg/m3	19300	7310	19300	2330	19300	5323	2700	5323
wt% /density	1.04E-03	1.09E-02	5.03E-03	1.29E-03	4.56E-03	2.25E-03	1.81E-02	9.58E-03
thickness ratio	1.00	10.56	1.00	0.26	1.00	0.49	1.00	0.53

Replacing bonding media like Au-Sn with CMOS compatible materials like Al-Ge

Integration with CMOS



Customer	CMOS Foundry	Technology at SVTC
A,B, C	A	Micro-mirrors
D	B	MEMS cantilevers
E	C	MEMS resonators
F	D	LOC



Enable Interconnect to Foundry Wafers to Integrate MEMS on CMOS Circuitry

Lessons Learned

- Challenges in MEMS Technology commercialization need to be overcome to make the associated product benefits ubiquitous

- Technology Development challenges can be bridged through a combination of:
  - **Development Business Model** that enables cost effective development & fast time to market in a collaborative, IP independent way
  - **Technology Development Business Process** that enables characterization for maturity and successful manufacturing qualification
  - **Optimum Standardization** with characterized, CMOS compatible building blocks, without compromising innovation

- SVTC has employed a unique business model and best known methods leveraged from semiconductor industry to enable successful commercialization of several emerging MEMS products

Contact Us

Melvin Hirata

Director of Business Development

melvin.hirata@svtc.com

www.svtc.com

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よろしくお願い致します。