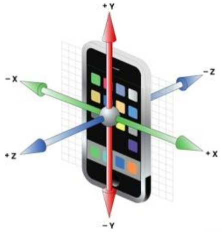
MEMS Integrated Design for Inertial Sensors (MIDIS™)



Yole Development Webcast
June 27th, 2013

Luc Ouellet, Eng.
Vice President, Technology Development
Teledyne DALSA Semiconductor

Yole Développement C2MI CMC MICROSYSTEMS

TELEDYNE DALSA
Everywhereyoulook™

Content

- Teledyne DALSA Semiconductor Inc. (TDSI)
- TDSI's MEMS Expertise
- TDSI's Inertial Sensors Expertise
- Introduction to MIDIS™
    - Low Cost Solution
    - Standard Technology Platform
    - High Performance Platform
    - Gyroscopes - Maximum Q-factor
    - Accelerometers - Optimal Damping
    - Cross Section of Typical MIDIS™
    - Equipment Set to Manufacture MIDIS™
    - Wafer-Level Integration of MIDIS™ to CMOS
    - Possible Future Integrations in MIDIS™
- Design Access to MIDIS™

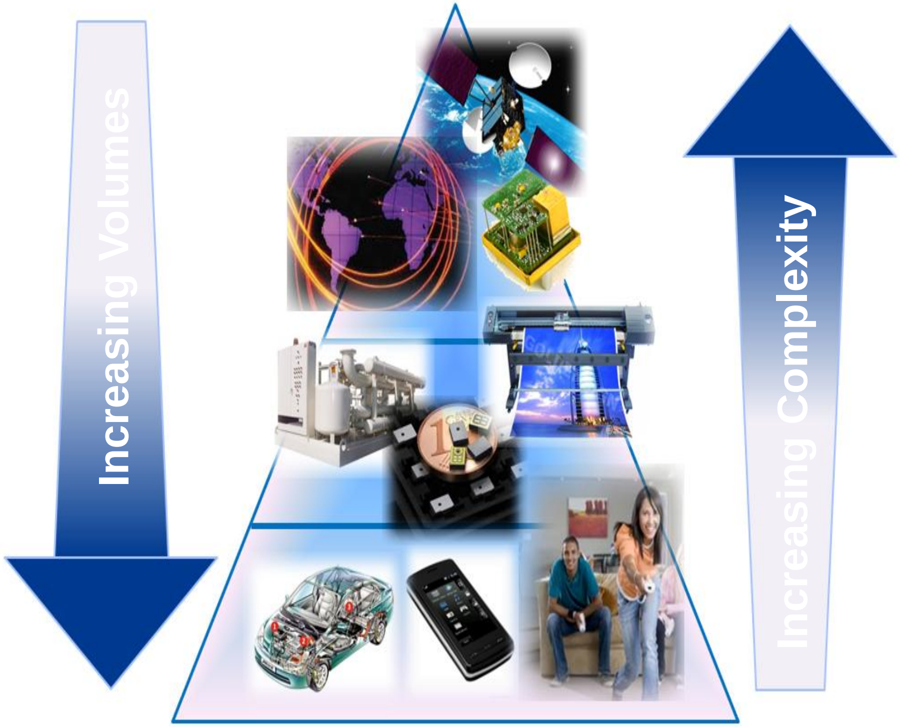
TELEDYNE DALSA
Everywhereyoulook™

Teledyne DALSA Semiconductor Inc. (TDSI)

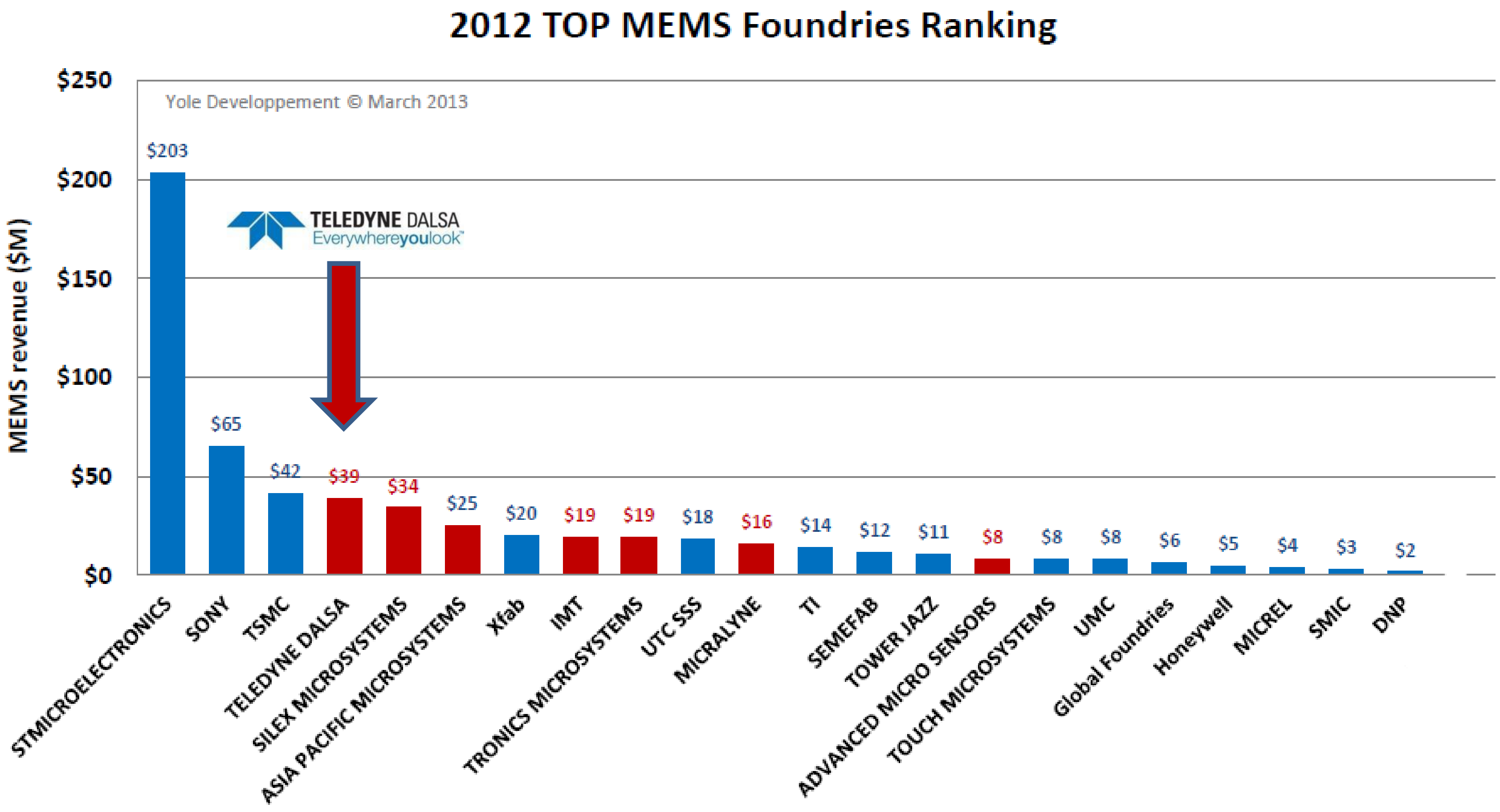
- Providing World Class Foundry Service for more than 30 years
  - Originally Mixed Signal CMOS
  - 15 years on MEMS and CCD products
    - ✓ Technology Leader in these Markets
  - Pure Play Foundry Model for MEMS
    - ✓ Wide Technology Portfolio
    - ✓ 150 & 200mm Wafers
    - ✓ Low & High Volume
  - World Class Quality Systems
    - ✓ TS16949 & ISO14001 Registered
    - ✓ Qualified Automotive Supplier
    - ✓ Audited by Major Auto Makers
    - ✓ Reliability Testing & Monitoring
    - ✓ Failure Analysis Service

Teledyne DALSA Semiconductor Inc. (TDSI)

- Providing World Class Foundry Service for more than 30 years
  - High Volume Products:
    - ✓ Cell Phones
    - ✓ Laptops
    - ✓ Gaming
    - ✓ Automotive
    - ✓ …
  - Low Volume Complex Products:
    - ✓ Military
    - ✓ Medical
    - ✓ Scientific
    - ✓ Industrial
    - ✓ …



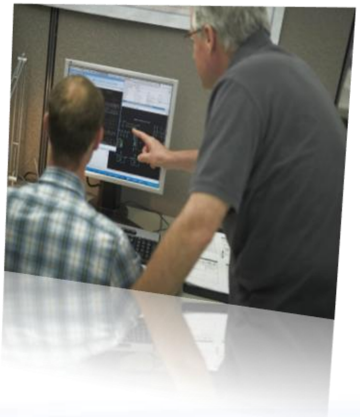
TDSI's MEMS Expertise

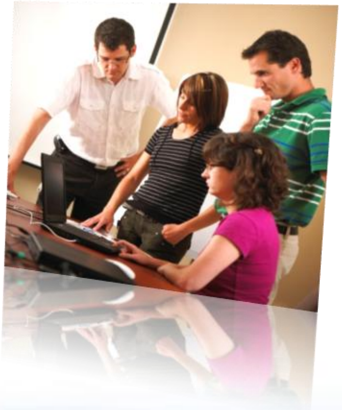


In red: pure play open MEMS foundries

TDSI’s MEMS Expertise

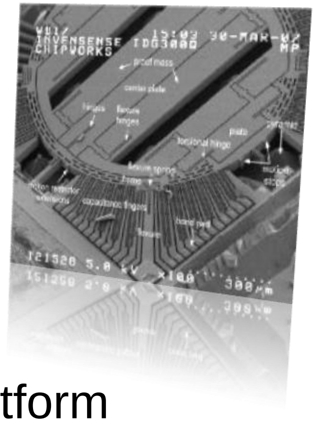
- Inkjet Heads
- Pressure Sensors
- Microphones
- **Accelerometers**
- **Gyroscopes**
- Microbolometers
- Microdisplays
- Projection Systems
- Optical MEMS
- Microfluidics
- RF MEMS
- Oscillators
- Micro Speakers





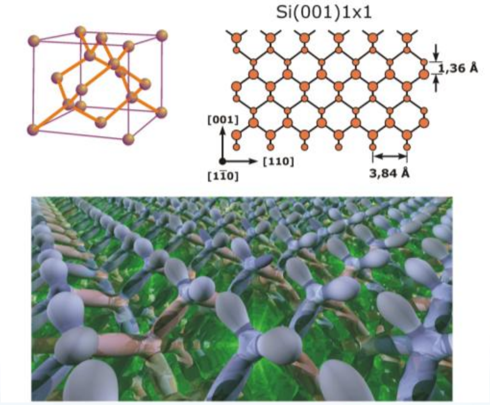
TDSI’s Inertial Sensors Expertise

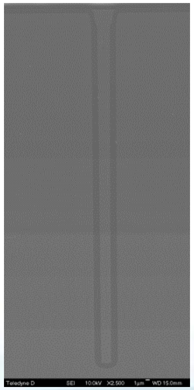
- Involved in Inertial Sensors Since 2002
- Development & Mass Production:
  - Gyroscopes
  - Accelerometers
  - Has Served Multiple Customers, Including Invensense
  - Several Markets:
    - ✓ Gaming
    - ✓ Image Stabilization of Cameras
    - ✓ Portable Devices
    - ✓ Automotive
  - More than 100M Units Shipped
  - Experience to Develop a Standard Platform

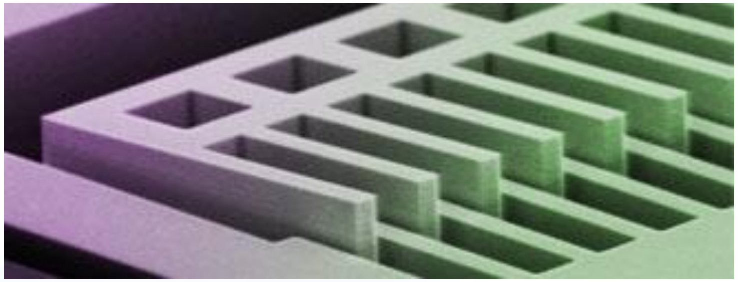


Introduction to MIDIS™

- Low Cost Solution:
  - Smaller Die Size - Aggressive Lithography Features
  - Smaller Die Size - Though-Silicon Via (TSV)
  - Single Die - 6-Axis Combos (3-Axis Gyroscopes & 3-Axis Accelerometers)
  - SOI Eliminated - SSP & DSP Wafers Only
  - Getter Eliminated - DWB Maintains Good Q-factor
  - Au-based Seal Eliminated – Hermetic DWB
  - Epitaxial Silicon Eliminated – Standard Silicon
  - Possible Wafer-Level CMOS ASIC Integration (200mm Wafers)







Introduction to MIDIS™

- Standard Technology Platform:
  - MIDIS™ is Available to All Teledyne DALSA Customers
  - MIDIS™ Reduces Time-to-Market - A Proven Process
  - MIDIS™ Reduces Development Cost - A Proven Process
  - MIDIS™ is Supported by a Process Design Kit (PDK)
  - MIDIS™ is Already Used in Canada, USA, Japan, Korea & China

Introduction to MIDIS™

- ➢ High Performance Platform
  - ❖ Gyroscopes:
    - ✓ Hermetically Sealed at ~10 mTorr (~1.5 Pa)
    - ✓ Q-factor > 50,000 (Design Dependent)
  - ❖ Accelerometers:
    - ✓ Hermetically Sealed at ~150 Torr (~20 kPa)
    - ✓ Efficient Damping (Design Dependent)
  - ❖ Antechamber Concept
    - ✓ No Gas Contamination of Gyroscopes Cavity from Exposed CMOS
    - ✓ Hermetic Bond Without Thermal Limitation (CMOS Bonded after)

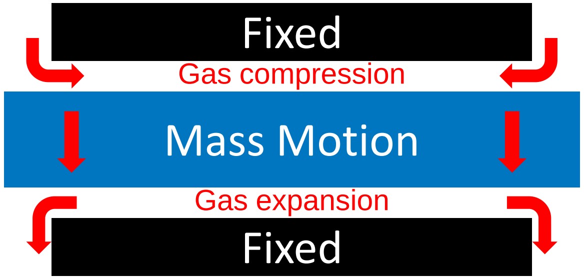
Introduction to MIDIS™

- Gyroscopes - Maximum Q-factor
  - ❖ Maximum Q-factor is required for gyroscopes. Q-factor is reduced by some independent energy loss mechanisms:

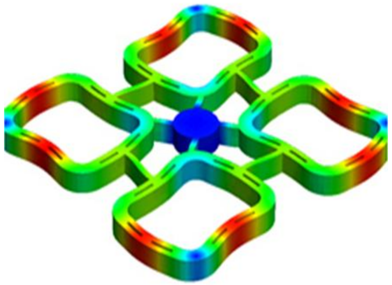
$$\frac{1}{Q_{Total}} = \frac{1}{Q_1} + \frac{1}{Q_2} + \cdots + \frac{1}{Q_n}$$

of which:

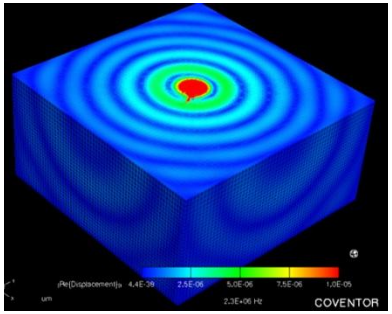
- ✓ <u>Air damping</u>; i.e. Kn - Knudsen number (Mean-free-path to MEMS gap ratio)
- ✓ <u>Thermo-elastic damping</u>; i.e. Zener’s coupling of elastic deformation and T° fields
- ✓ <u>Anchor loss</u>; i.e. non-elastic longitudinal & transverse pressure waves in anchors
- ✓ <u>Material loss</u>; i.e point defects, dislocations, grain boundaries, non-elastic …



Air damping



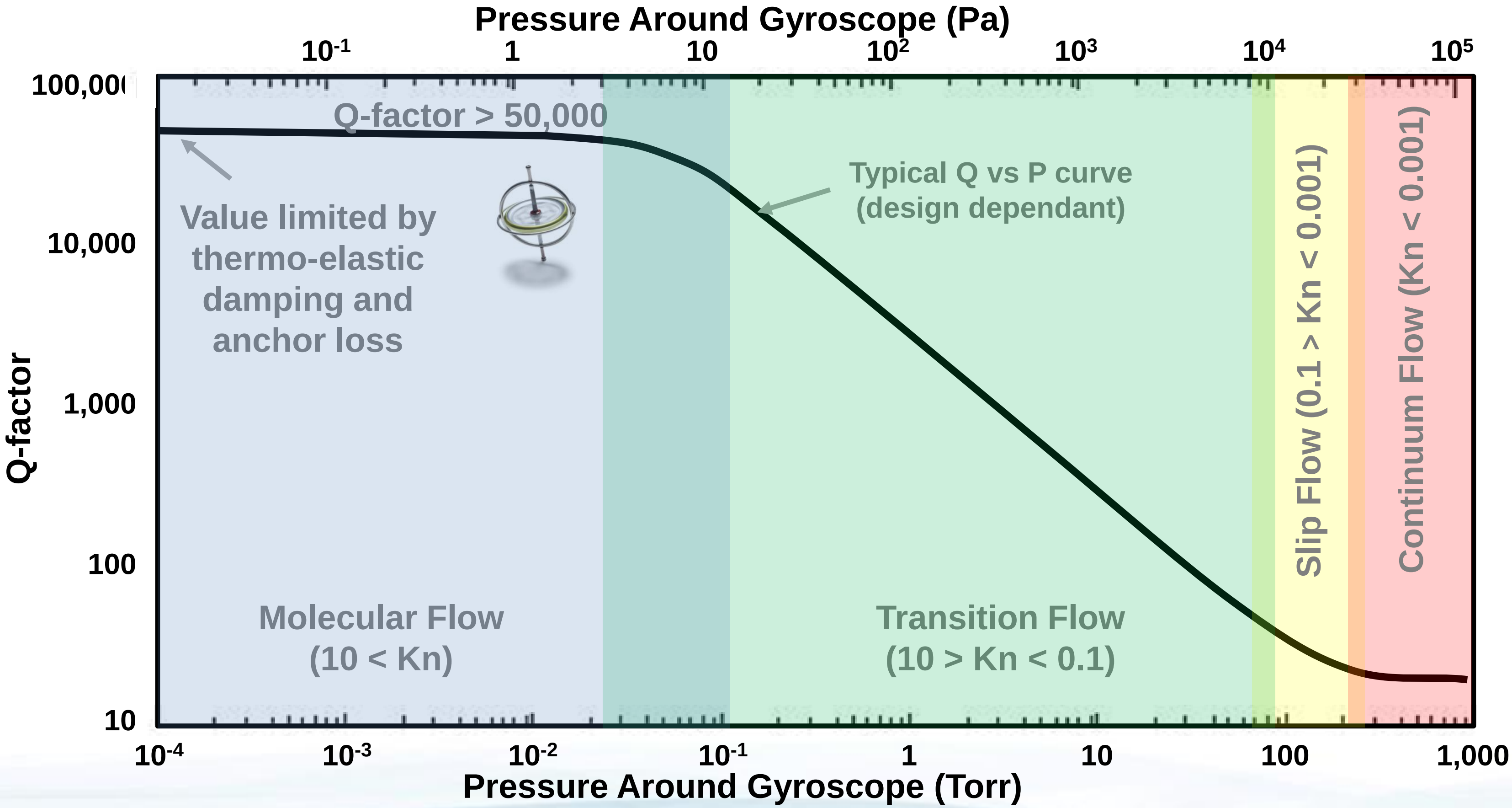
CoventorWare Thermo-elastic damping



CoventorWare Anchor loss

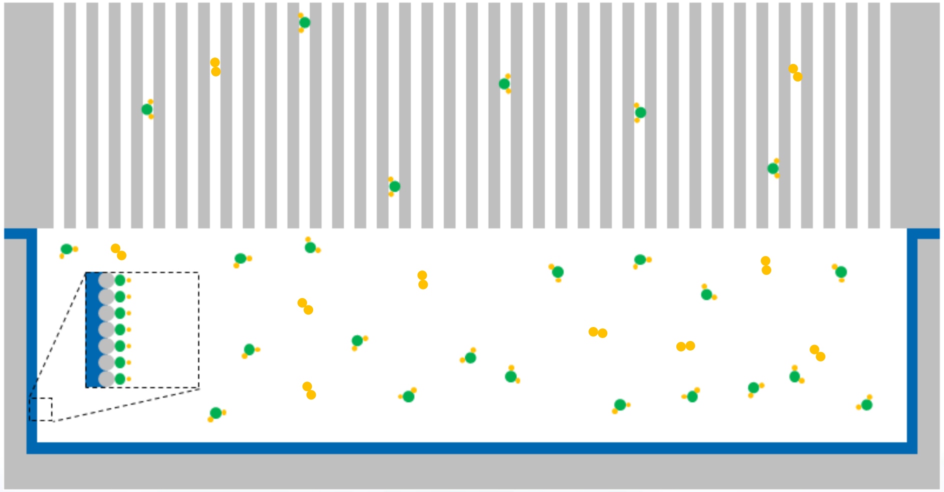
Introduction to MIDIS™

- Gyroscopes - Maximum Q-factor
  - Air damping typically determine the global Q-factor of gyroscopes



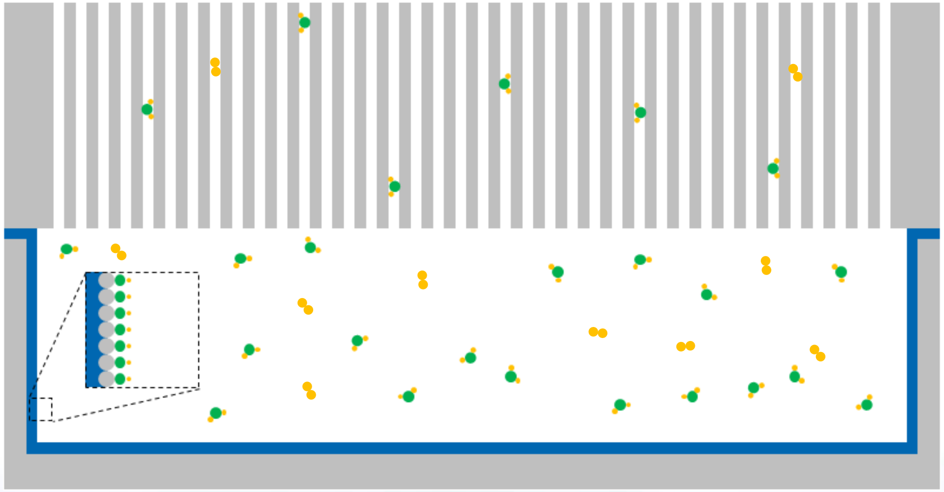
Introduction to MIDIS™

- Gyroscopes - Maximum Q-factor
  - <u>Air damping</u> can increase very rapidly:
    - ✓ Due to internal walls' source of gas
      - **Avoid exposure of gyros to porous materials (PECVD SiN, TEOS, PSG)**
      - **Getters are NOT efficient for organic residues, Ar (PVD), He (Air)**
    - ✓ Micro-cavity volume is very small - 0.0025mm^3 (0.5x0.5x0.01mm)
    - ✓ Only 8E^{+8} molecules at 10mTorr (1.3Pa) not to increase by 10X over 5 years !
    - ✓ Total leak-up rate equivalent **to 45 molecules/second** (7.5E^{-13} atm*cc/s)



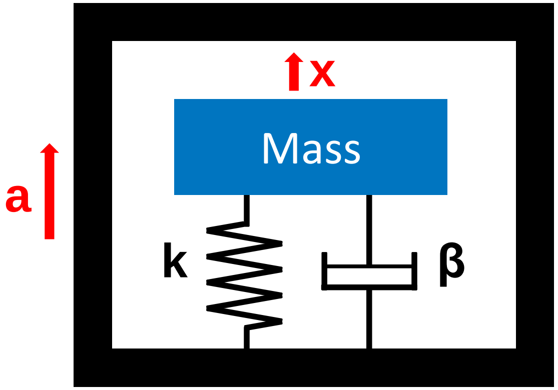
Introduction to MIDIS™

- Gyroscopes - Maximum Q-factor
  - <u>Air damping</u> in a hermetically sealed micro-cavity can increase very rapidly:
    - ✓ Total leak-up rate equivalent **to 45 molecules/second** (7.5E^{-13} atm*cc/s)
      - Mil-Std 883H - 1E^{-9} atm*cc/s (61,500 molecules/second)
      - Mil-Std 750 - 1E^{-8} atm*cc/s (615,000 molecules/second)
      - Mil-Std 202G - 1E^{-8} atm*cc/s (615,000 molecules/second)
      - JEDEC JESD22 - 1E^{-9} atm*cc/s (61,500 molecules/second)
    - ✓ Kn increases, Q-factor of gyroscopes degrades



Introduction to MIDIS™

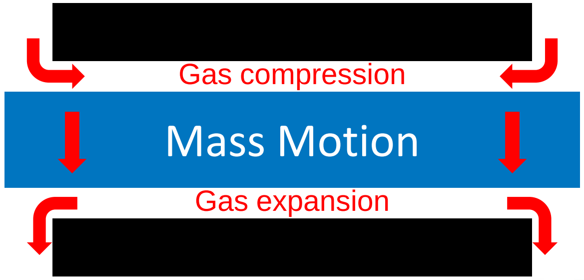
- Accelerometers - Optimal damping
  - Optimal air damping is required for accelerometers:



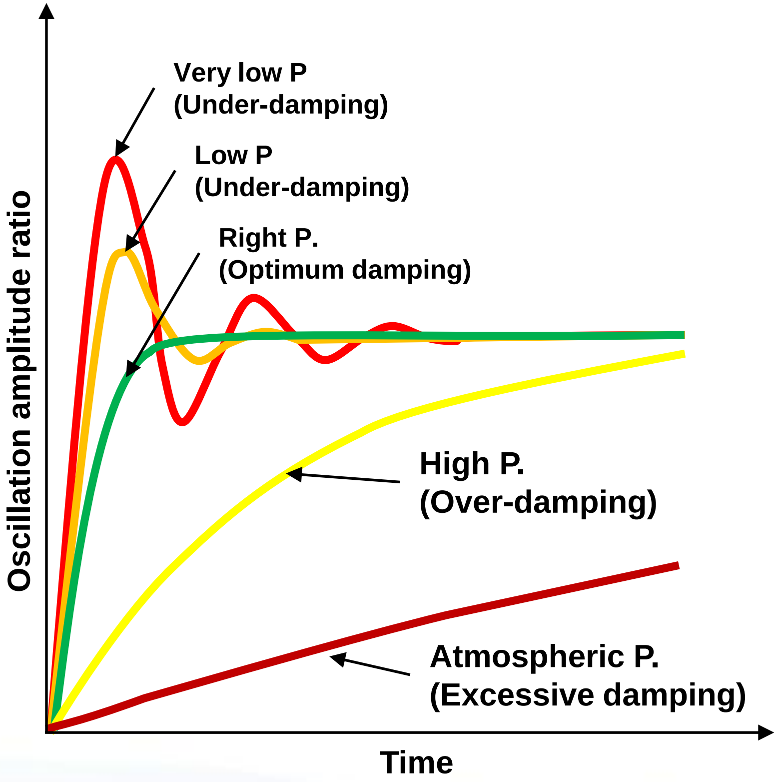
$$m\ddot{x} + \beta\dot{x} + kx = ma$$

$$\omega_o = \sqrt{\frac{k}{m}}$$

$$\xi = \frac{\beta}{\sqrt{4mk}}$$



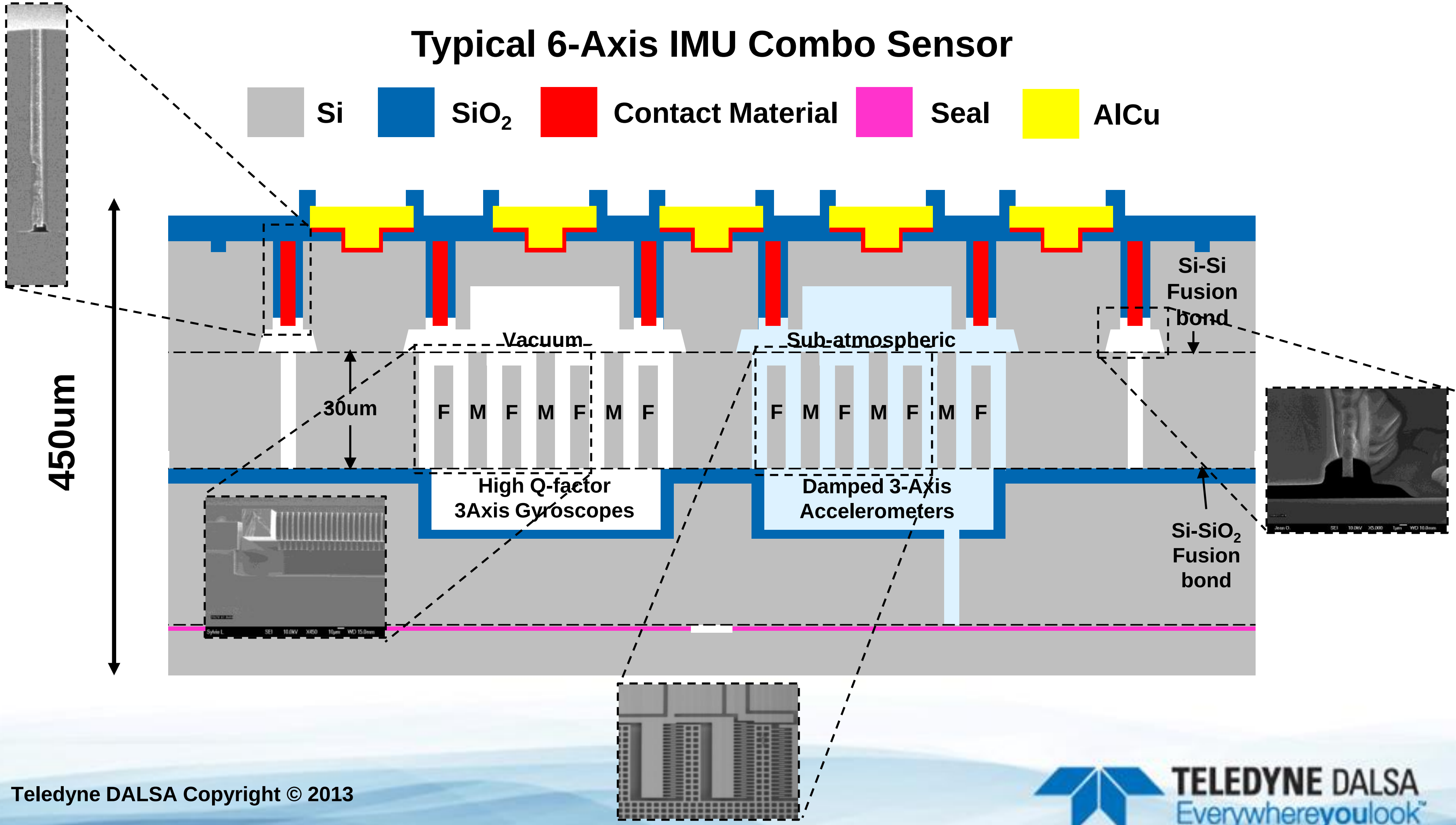
Air damping



Introduction to MIDIS™

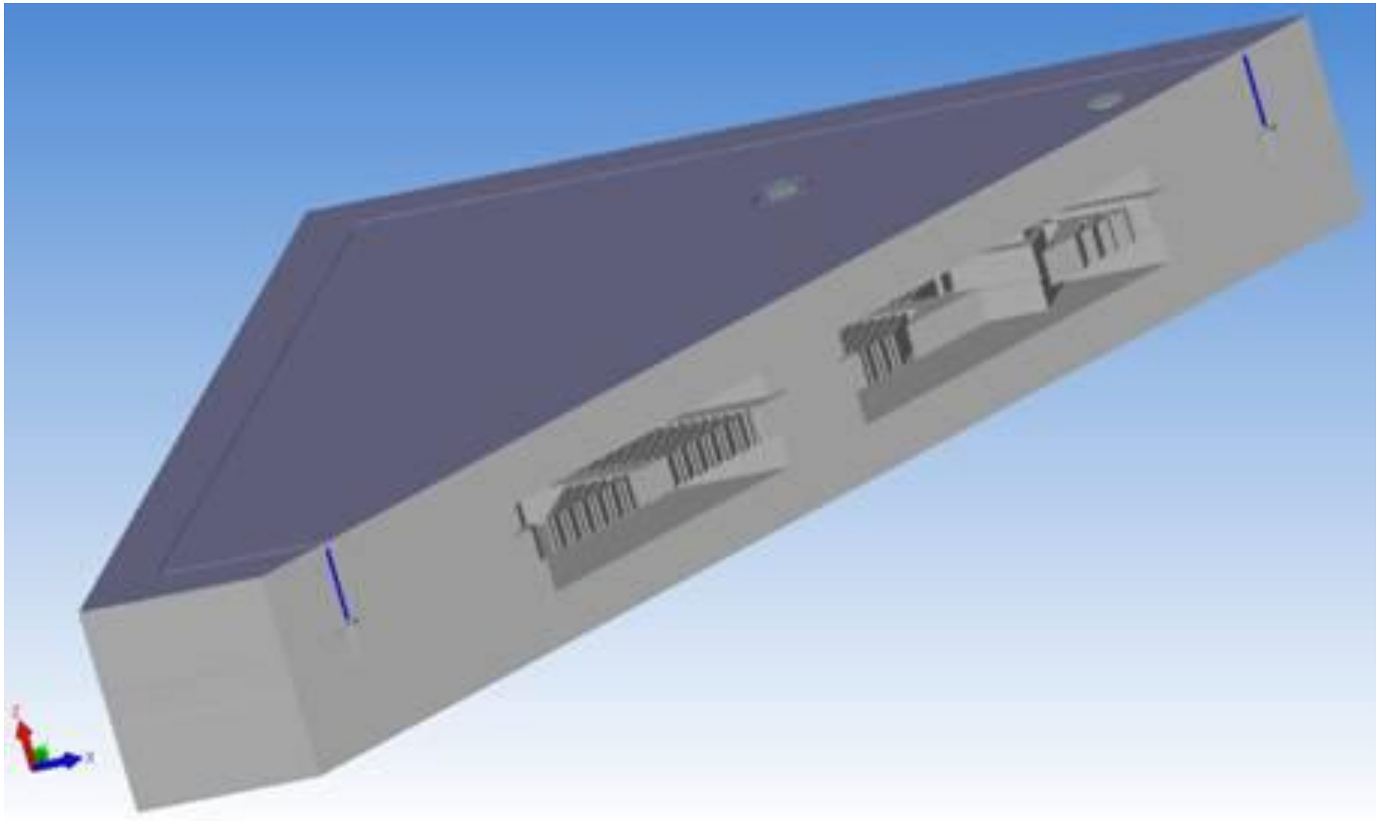
- Cross Section of Typical MIDIS™

Typical 6-Axis IMU Combo Sensor



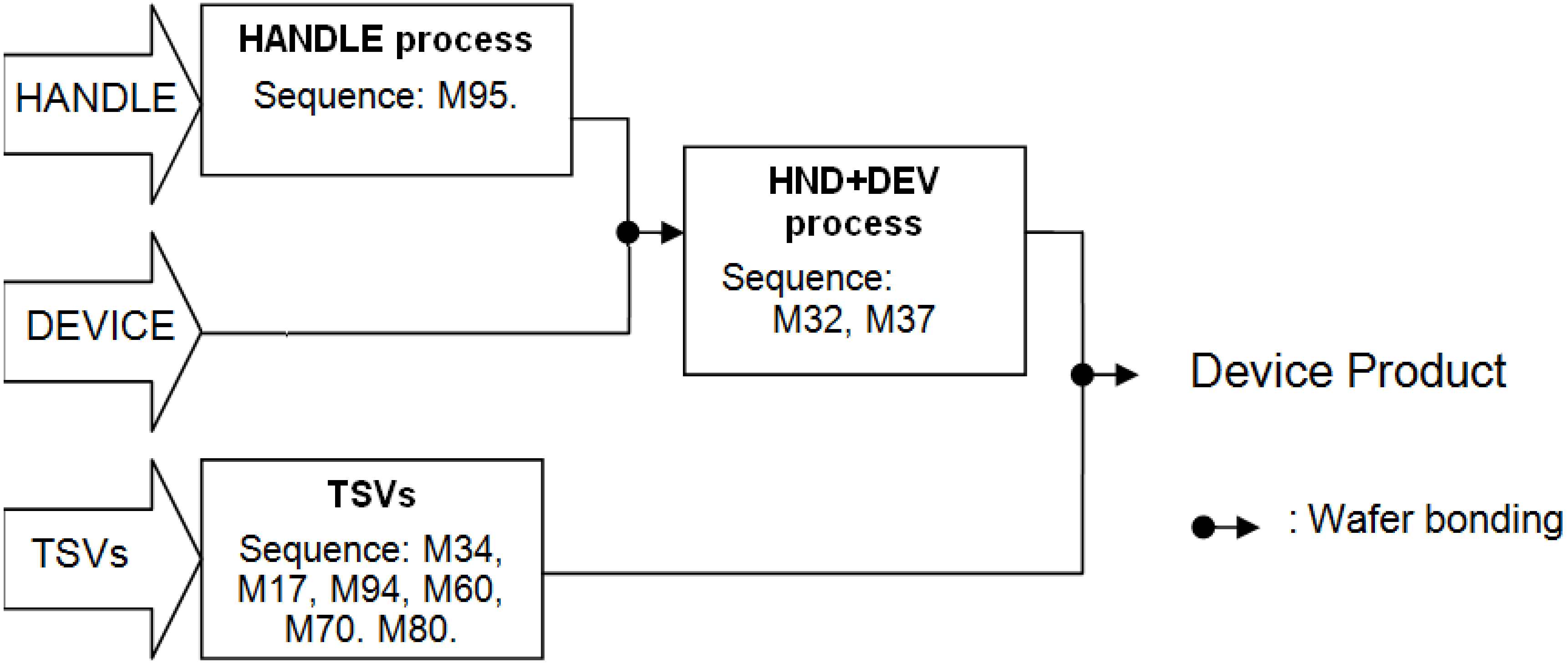
Introduction to MIDIS™

- Cross Section of Typical MIDIS™



Introduction to MIDIS™

- Cross Section of Typical MIDIS™



HANDLE

HANDLE process

Sequence: M95.

DEVICE

HND+DEV process

Sequence: M32, M37

TSVs

TSVs

Sequence: M34, M17, M94, M60, M70. M80.

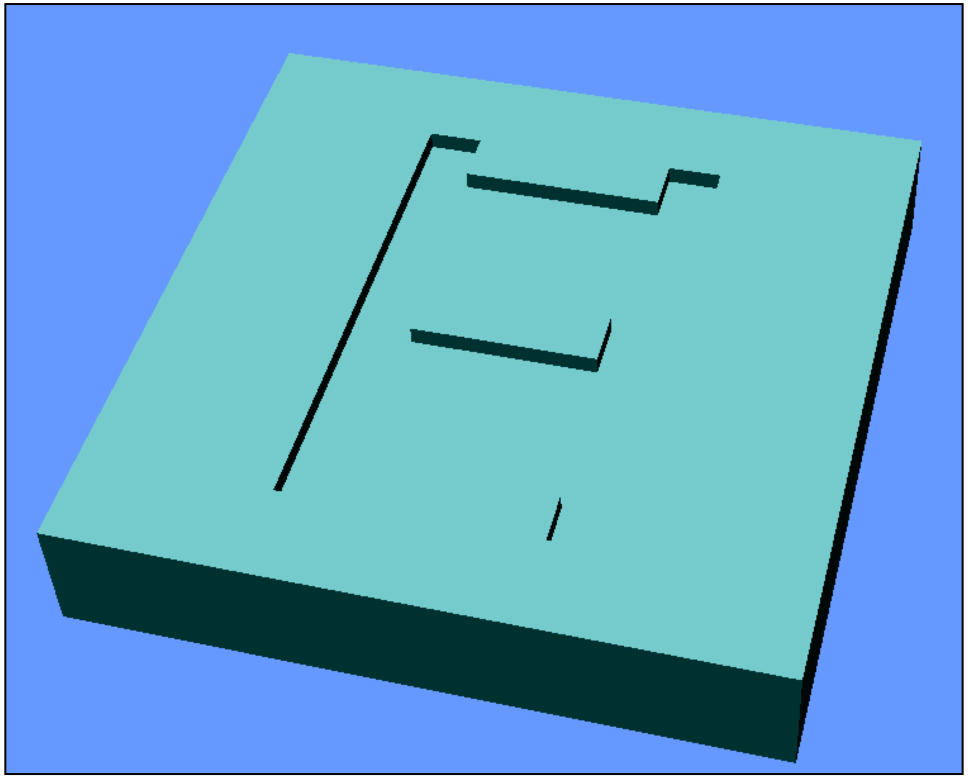
Device Product

●→ : Wafer bonding

Fabrication protocol with substrates identification

Introduction to MIDIS™

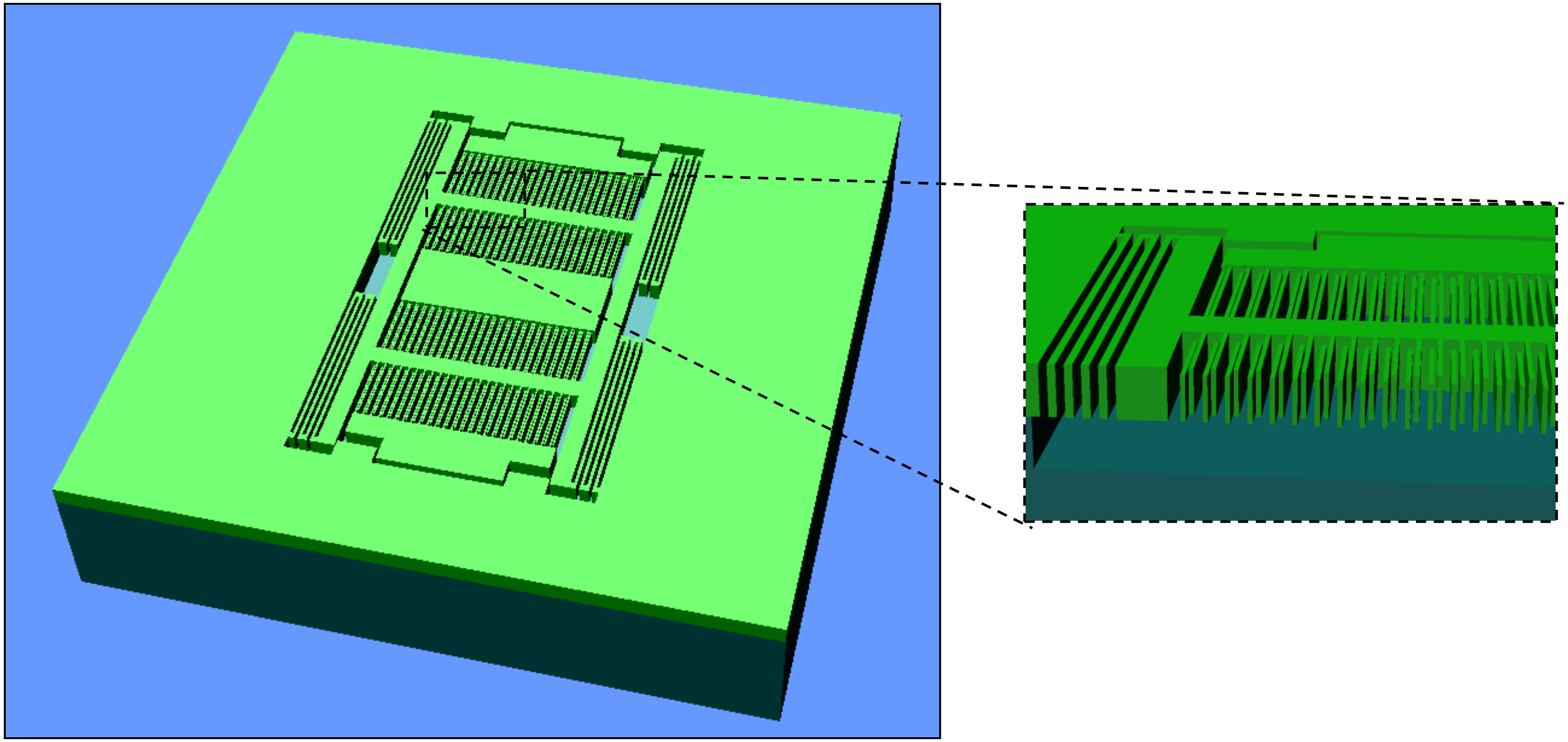
- Cross Section of Typical MIDIS™



HANDLE wafer lower cavity pattern (30µm deep) using M95

Introduction to MIDIS™

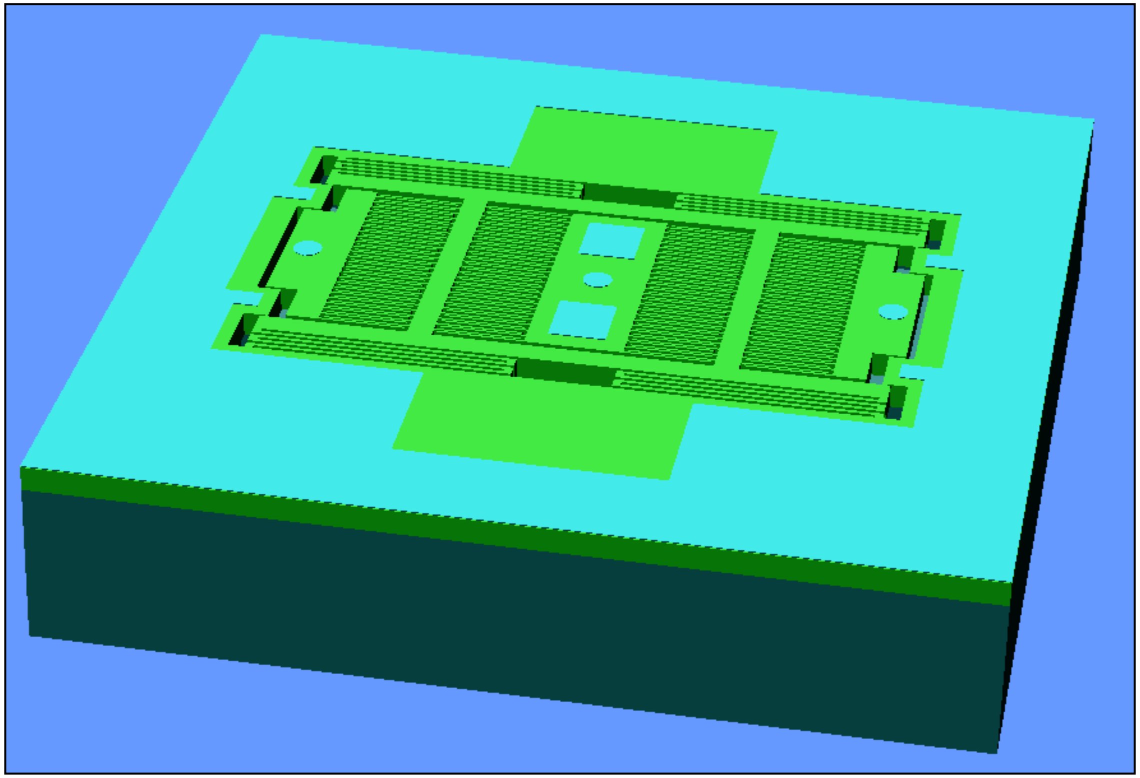
- Cross Section of Typical MIDIS™



HANDLE wafer + DEVICE wafer bond. DEVICE (30µm thick) pattern using M32 & M37

Introduction to MIDIS™

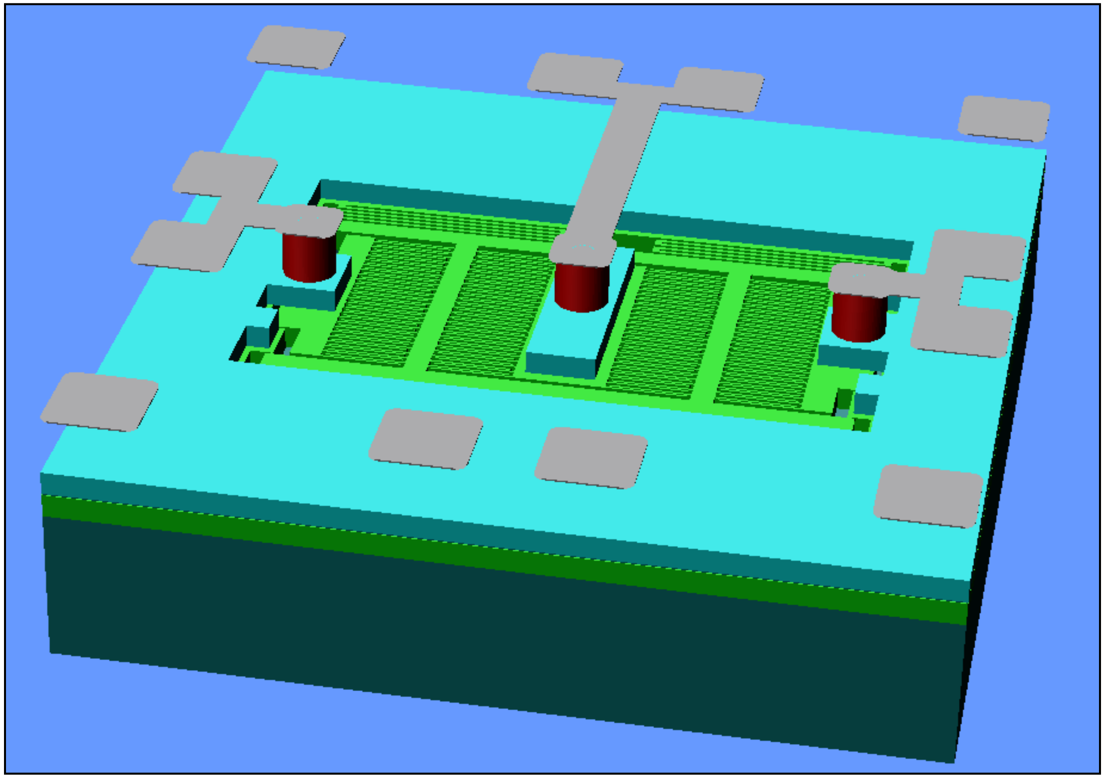
- Cross Section of Typical MIDIS™



TSV wafer upper sense cavity (2.0um high) using M34

Introduction to MIDIS™

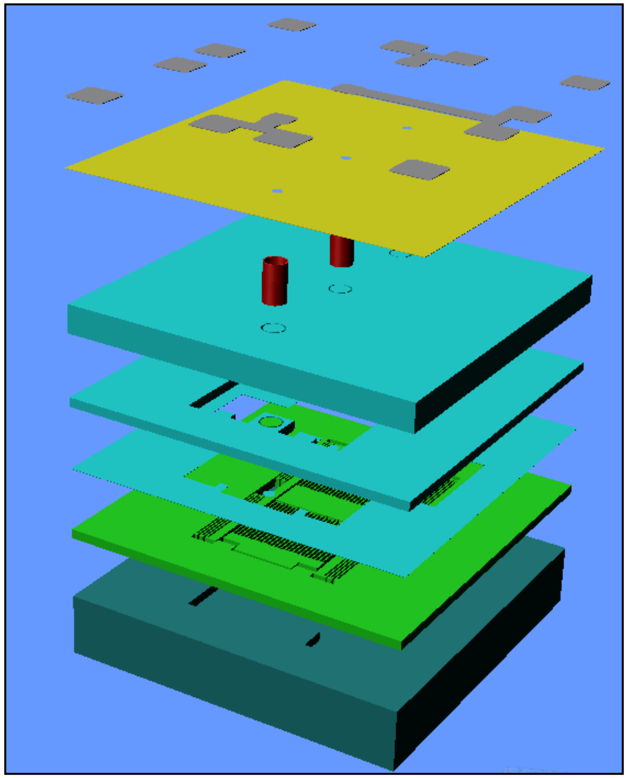
- Cross Section of Typical MIDIS™



TSV wafer upper cavity (30µm high) using M94
Fabrication of TSV using M17 followed by contacts using M60 (not shown)
HANDLE/DEVICE wafer + TSV wafer bond. Interconnects using M70 & M80

Introduction to MIDIS™

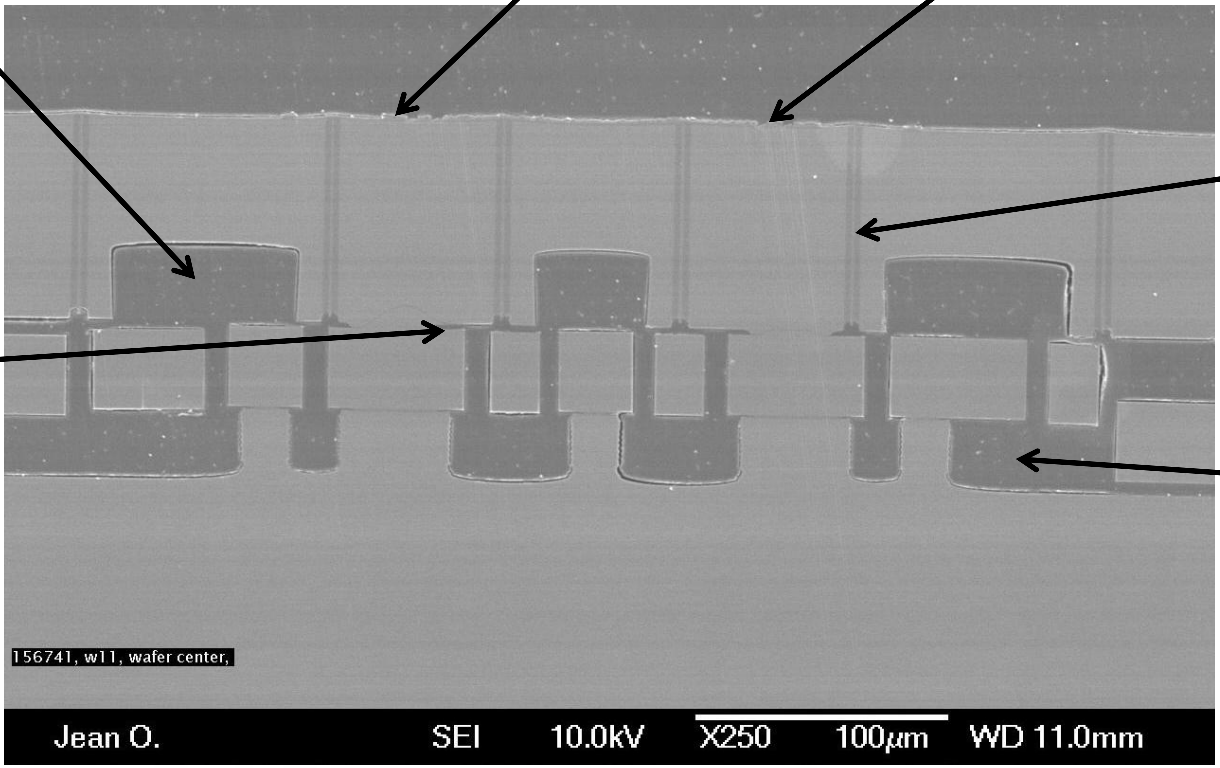
- Cross Section of Typical MIDIS™



Exploded view of final stack

Introduction to MIDIS™

- Cross Section of Typical MIDIS™



Top Cavity (M94)

Interconnects & Pads (M70, M80)

Contact (M60)

Isolation Trench (M17)

Electrode Recess (M34)

Bottom Cavity (M95)

Introduction to MIDIS™

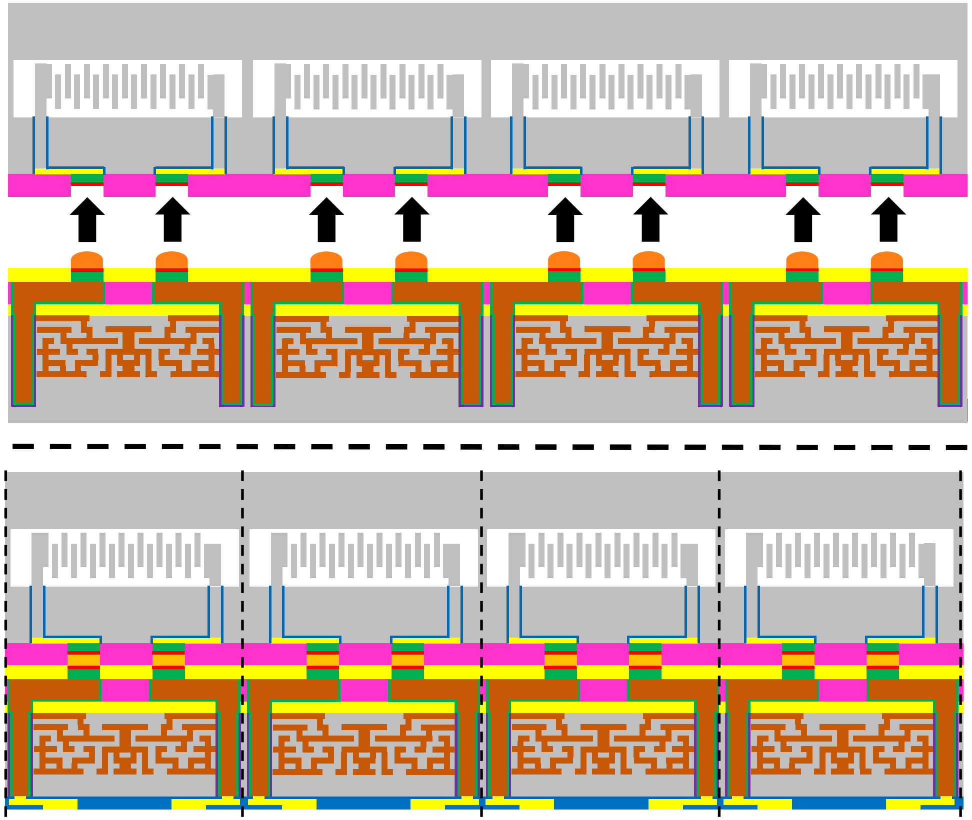
- Equipment Set to Manufacture MIDIS™
  - Operation : 250 m2 SMIF Class 1
  - Chase Area 1 : 250 m2 Class 10
  - Chase Area 2 : 500 m2 Class 1,000
  - Sub-Fab Area: 1000 m2 Class 10,000
- Fully automated 200mm equipment set
- Advanced manufacturing and metrology tool set
- Market penetration using C2MI infrastructure
- Transfer to Teledyne DALSA volume environment

Introduction to MIDIS™

- Equipment Set to Manufacture MIDIS™

Wafer-Level Integration of MIDIS™ to CMOS ASIC

- Low Cost Fabrication with Integrated MIDIS™



6-axis IMU MEMS Wafer

Align Within +/ 1.0um, 3 sigma

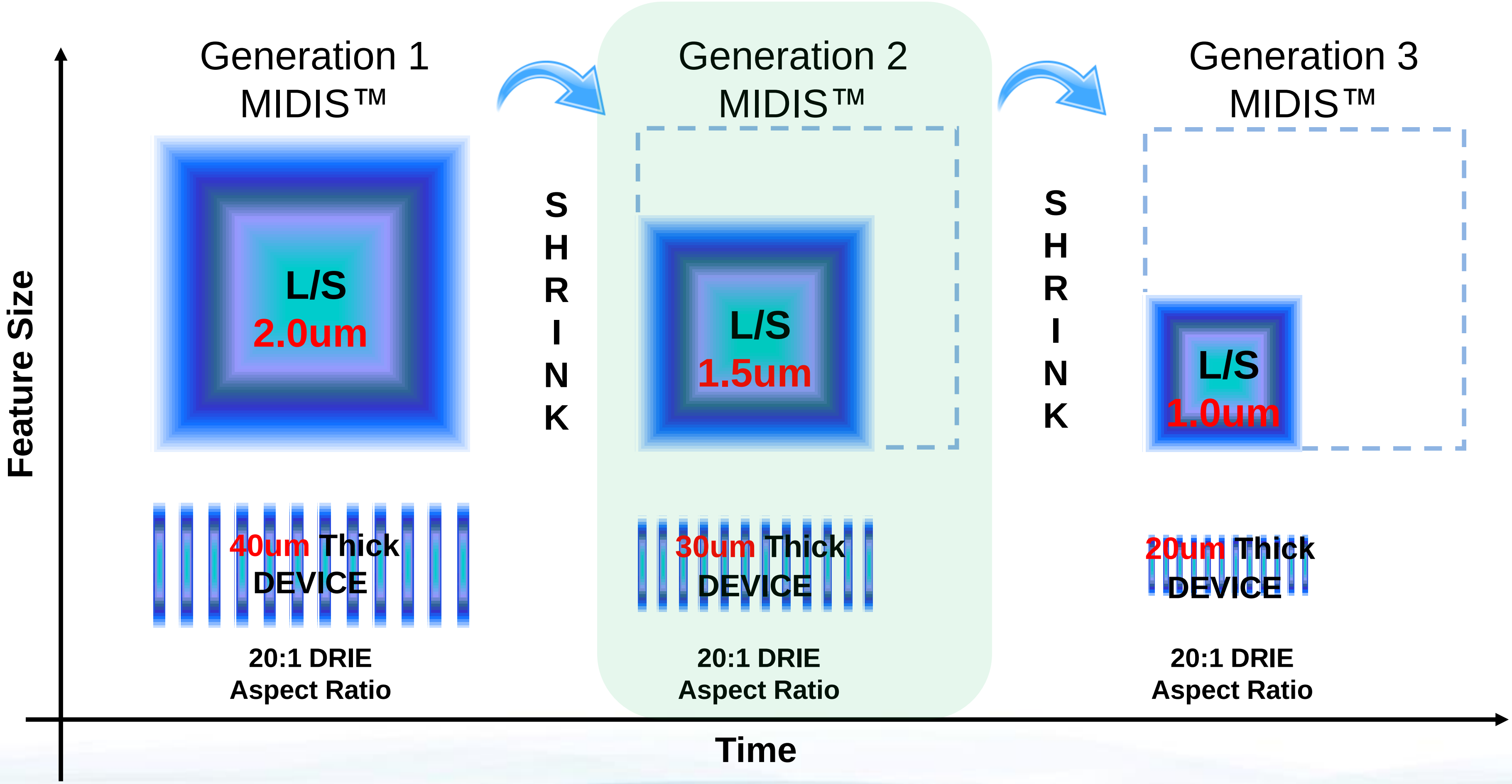
CMOS Wafer (200mm Foundries, 130/180nm nodes)

Low-cost Electro-mechanical Embedded System!

■ **Si** ■ **SiO_2** ■ **AlCu** ■ **Ni** ■ **Au** ■ **Polymer** ■ **Au/Sn** ■ **Cu** ■ **Insulator**

Wafer-Level Integration of MIDIS™ to CMOS ASIC

- Low Cost Fabrication with Integrated MIDIS™



Feature Size

Generation 1
MIDIS™

L/S
2.0um

40um Thick
DEVICE

20:1 DRIE
Aspect Ratio

SHRINK

Generation 2
MIDIS™

L/S
1.5um

30um Thick
DEVICE

20:1 DRIE
Aspect Ratio

SHRINK

Generation 3
MIDIS™

L/S
1.0um

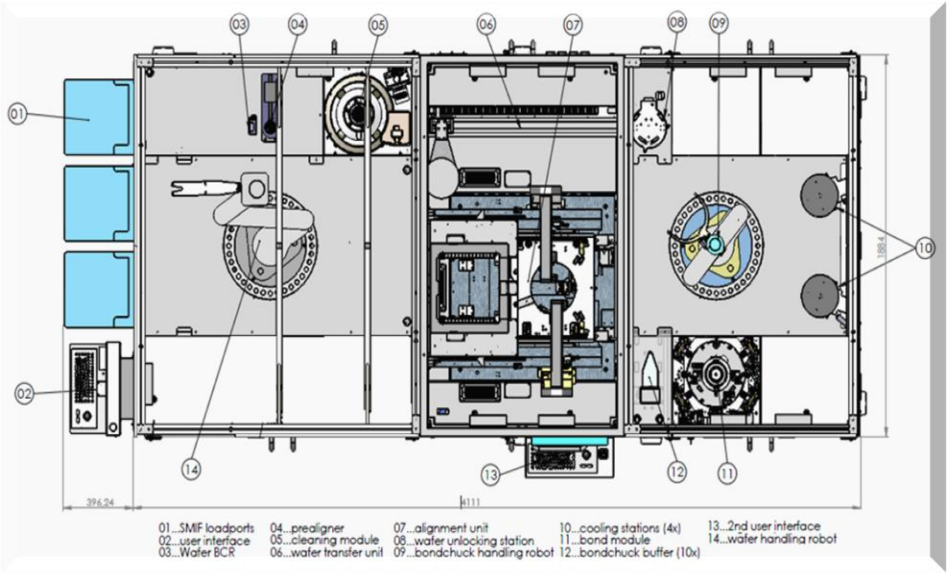
20um Thick
DEVICE

20:1 DRIE
Aspect Ratio

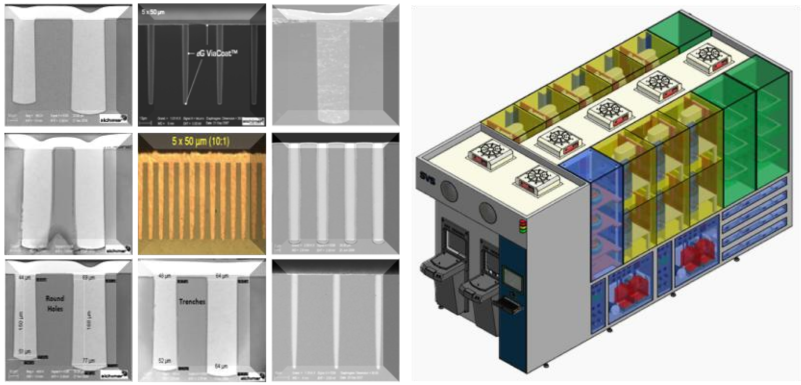
Time

Wafer-Level Integration of MIDIS™ to CMOS ASIC

- Low Cost Fabrication with Integrated MIDIS™
  - Align/bond 200mm ASIC wafers within 1.0µm to MIDIS™ (10µm µ-pads)
  - Use 5x50µm TSVs to connect µ-pads through CMOS ASIC wafer
  - Eliminate I/O & ESD pads (MEMS' Outputs to ASIC's Inputs)
  - Improve S/N ratio (Reduced Wire Bond Inductance & RC effects)



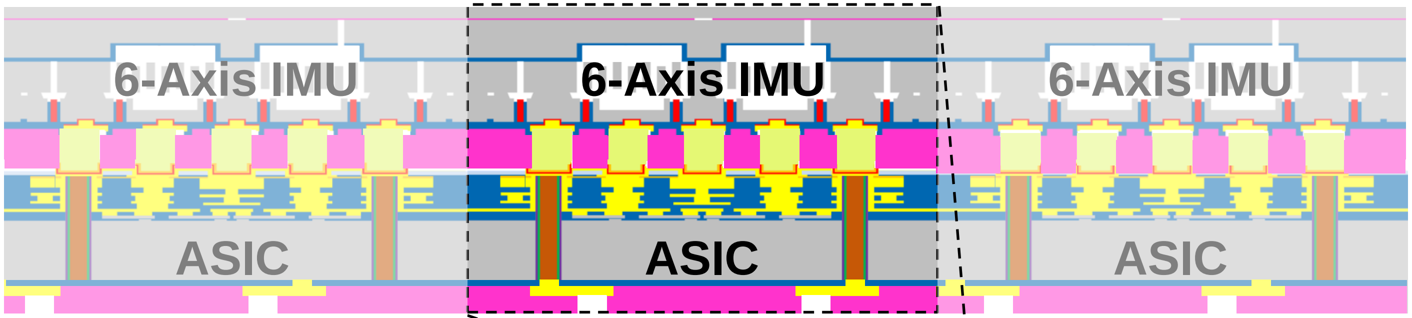
EVGroup Gemini

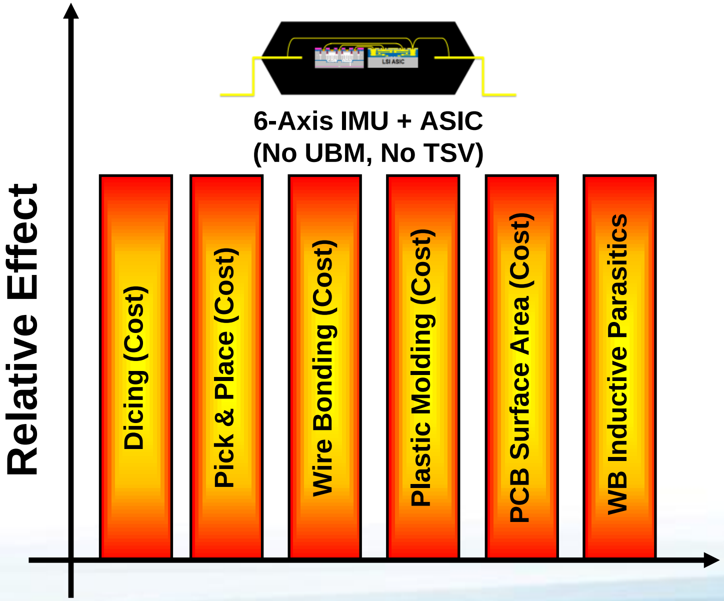


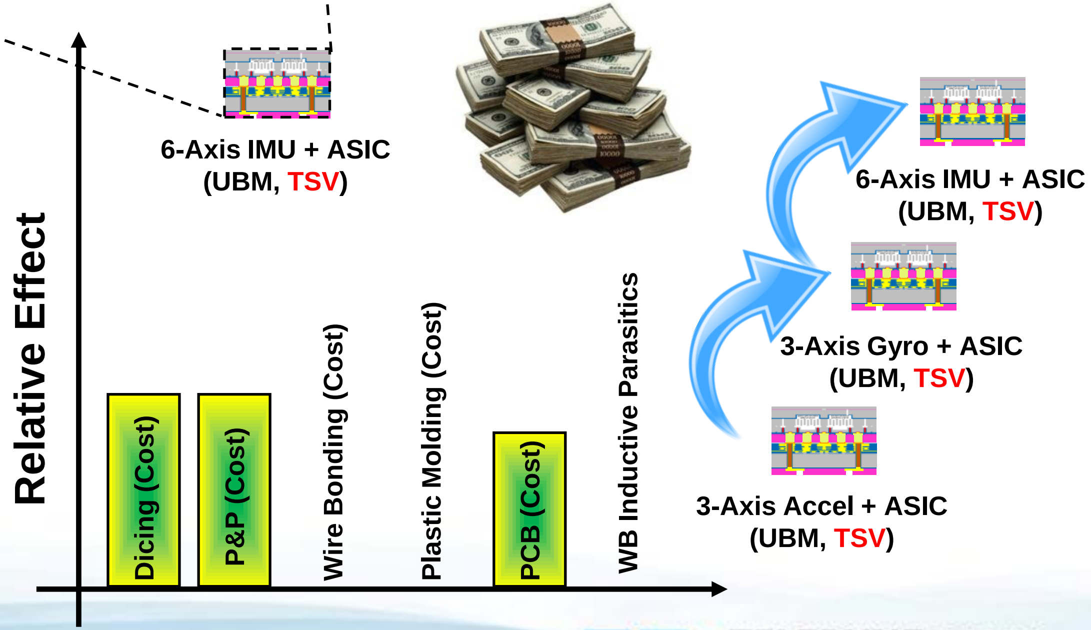
Alchimer-SVS TSV

Wafer-Level Integration of MIDIS™ to CMOS ASIC

- Low Cost Fabrication with Integrated MIDIS™



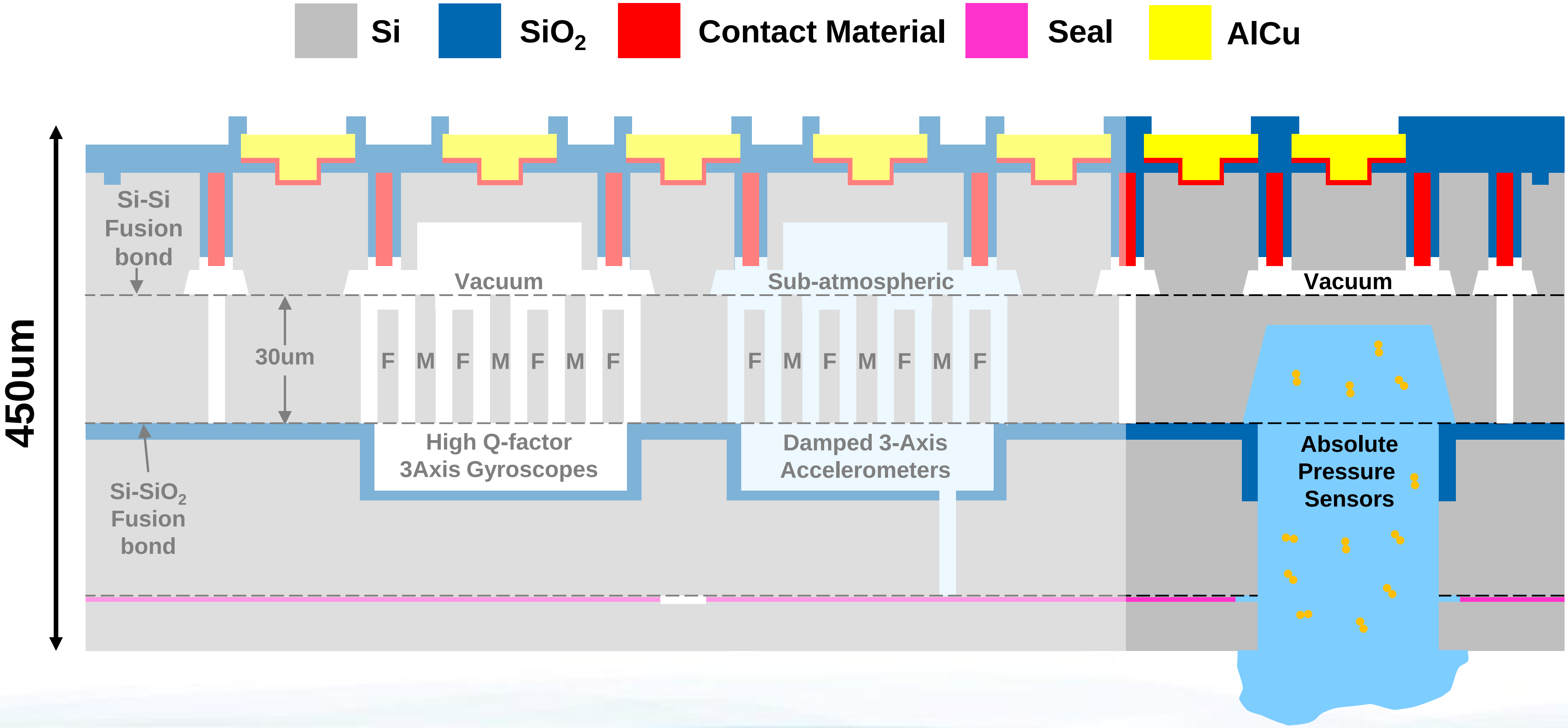




Possible Future Integrations in MIDIS™

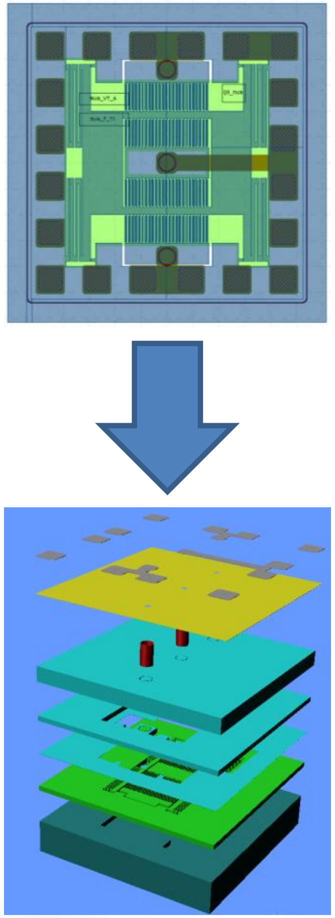
- Absolute Pressure Gauge in MIDIS™

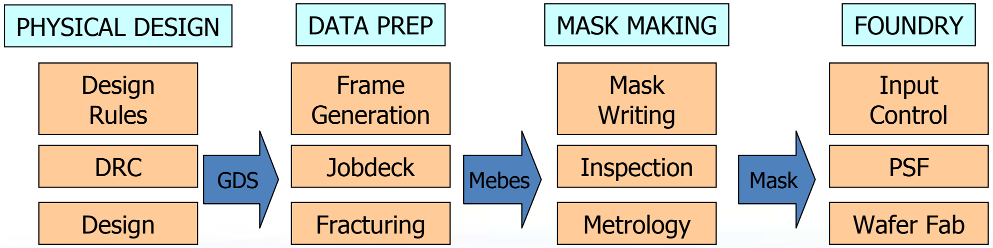
Integration of a 6-Axis IMU Combo + Pressure Sensor



Design Access to MIDIS™

- Process Design Kit (PDK) from Teledyne DALSA
  - Process parameters specifications
  - Design rules
  - DRC deck
  - Technology files for solid model generation
  - … etc
- MIDIS^{TM} solid model generation
  - Offers a truly representative 3D view of your design
  - Ready for design review
  - Multi-physics simulations





PHYSICAL DESIGN
Design Rules
DRC
Design

GDS

DATA PREP
Frame Generation
Jobdeck
Fracturing

Mebes

MASK MAKING
Mask Writing
Inspection
Metrology

Mask

FOUNDRY
Input Control
PSF
Wafer Fab

Design Access to MIDIS™

- Shuttle Runs
- Multi-Projects-Wafers (MPW)
- Through Canadian Microelectronics Corporation (CMC):

http://www.cmc.ca/

With a 25-year history, CMC Microsystems enables and supports the creation and application of micro- and nano-system knowledge by providing a national infrastructure for excellence in research and a path to commercialization of related devices, components and systems.

Thank You !

CMC MICROSYSTEMS

http://www.cmc.ca/

C2MI

http://www.c2mi.ca/

TELEDYNE DALSA
Everywhereyoulook™

http://www.teledynedalsa.com/semi/