nanium®

Beyond State-of-the-Art:

Integration of MEMS in Fan-Out Wafer-Level Packaging Technology based System-in-Package (WLSiP)

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- **NANIUM is highly committed to IP protection.**
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The Future: A MEMS/ Sensors Enabled World

Vision and Projections

- In 2020, 300 billion sensors are making lifestyle enhancements in our daily lives.*
- The intelligent sensor market is a $10.5 billion industry in 2020.**
- The market for printed and flexible sensors reaches $7.3 billion in 2020.***

IoT / IoE

Internet of Things
Internet of Everything

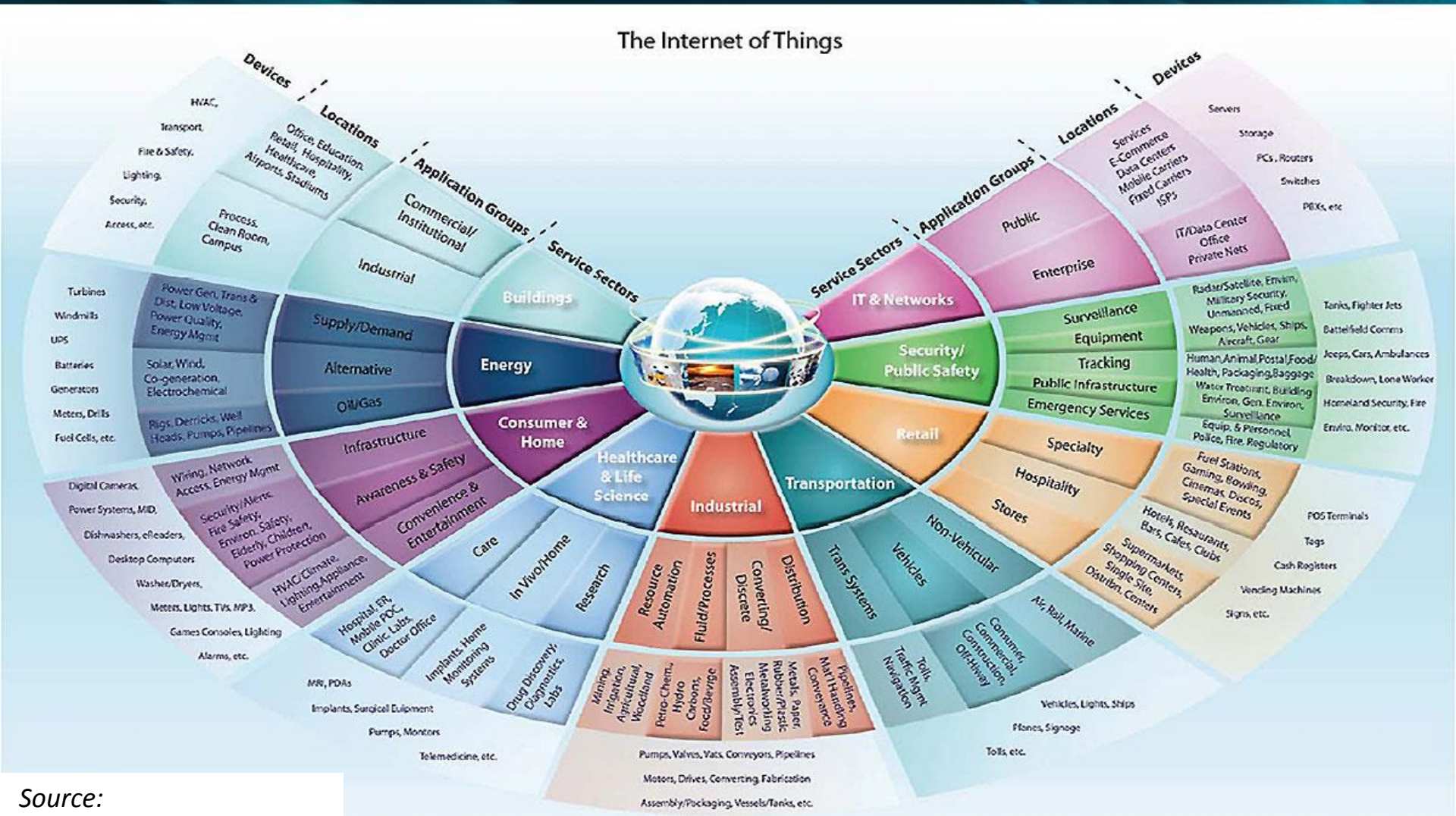
*) "Emergence of Trillion Sensor Opportunity," SemiconWest, http://www.semiconwest.org/sites/semiconwest.org/files/docs/SW2013_Janusz Bryzek_Fairchild Semiconductor.pdf.

**) "Smart/Intelligent Sensor Market worth $10.46 Billion by 2020," Military and Aerospace Electronics, http://www.militaryaerospace.com/news/2014/03/12/smart-intelligent-sensor-market-worth-10-46-billion-by-2020.html.

***) "IDTechEx: Printed sensors market will increase by more than $1 billion by 2020," Drupa, http://www.drupa.com/cipp/md_drupa/custom/pub/content,oid,30443/lang,2/ticket,g_u_e_s_t/local_lang,2.

The Internet of Things/ Everything

Wearable Electronics is only one Part of this Big Wave



Source:
Beecham Research Limited

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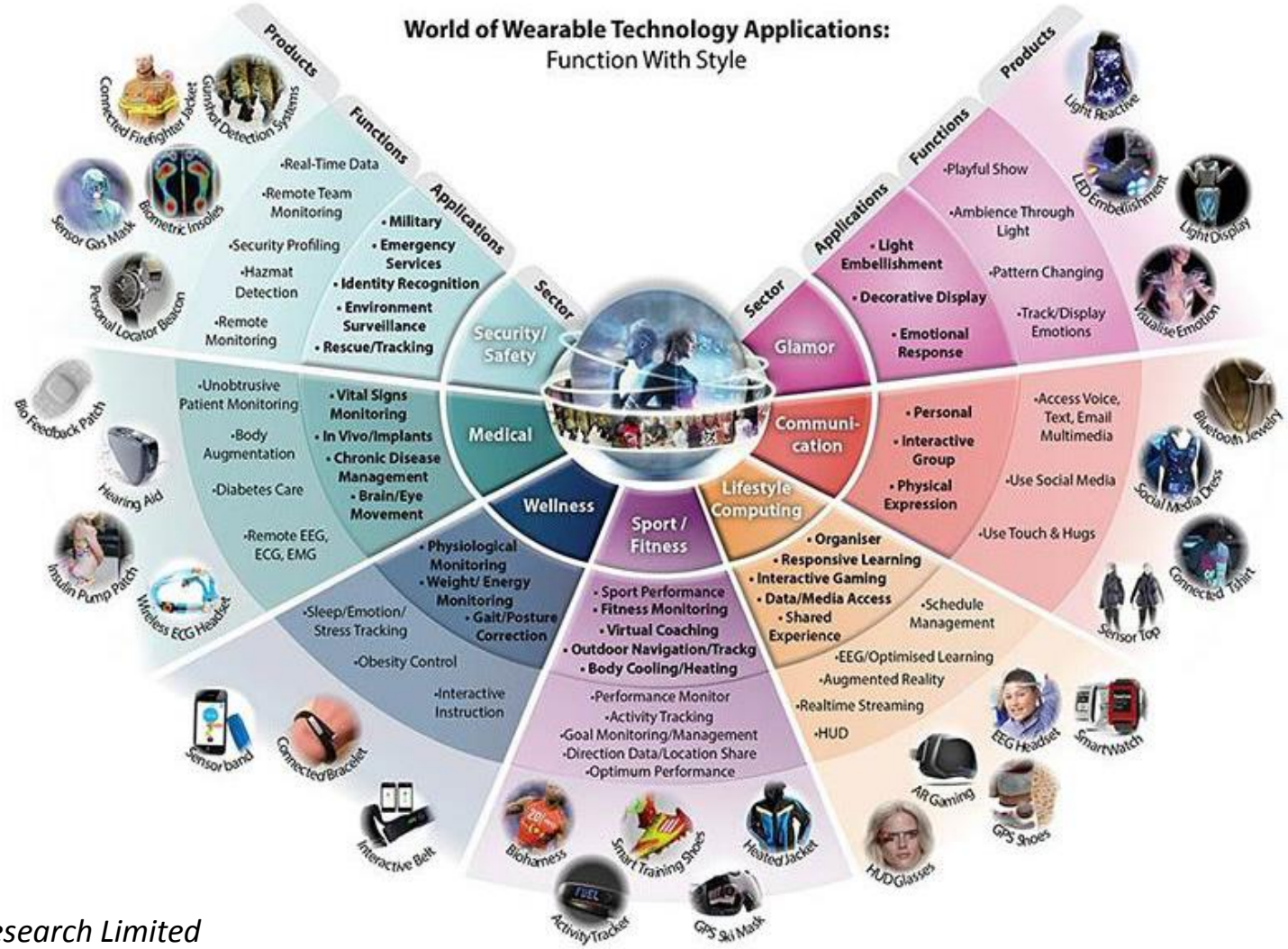

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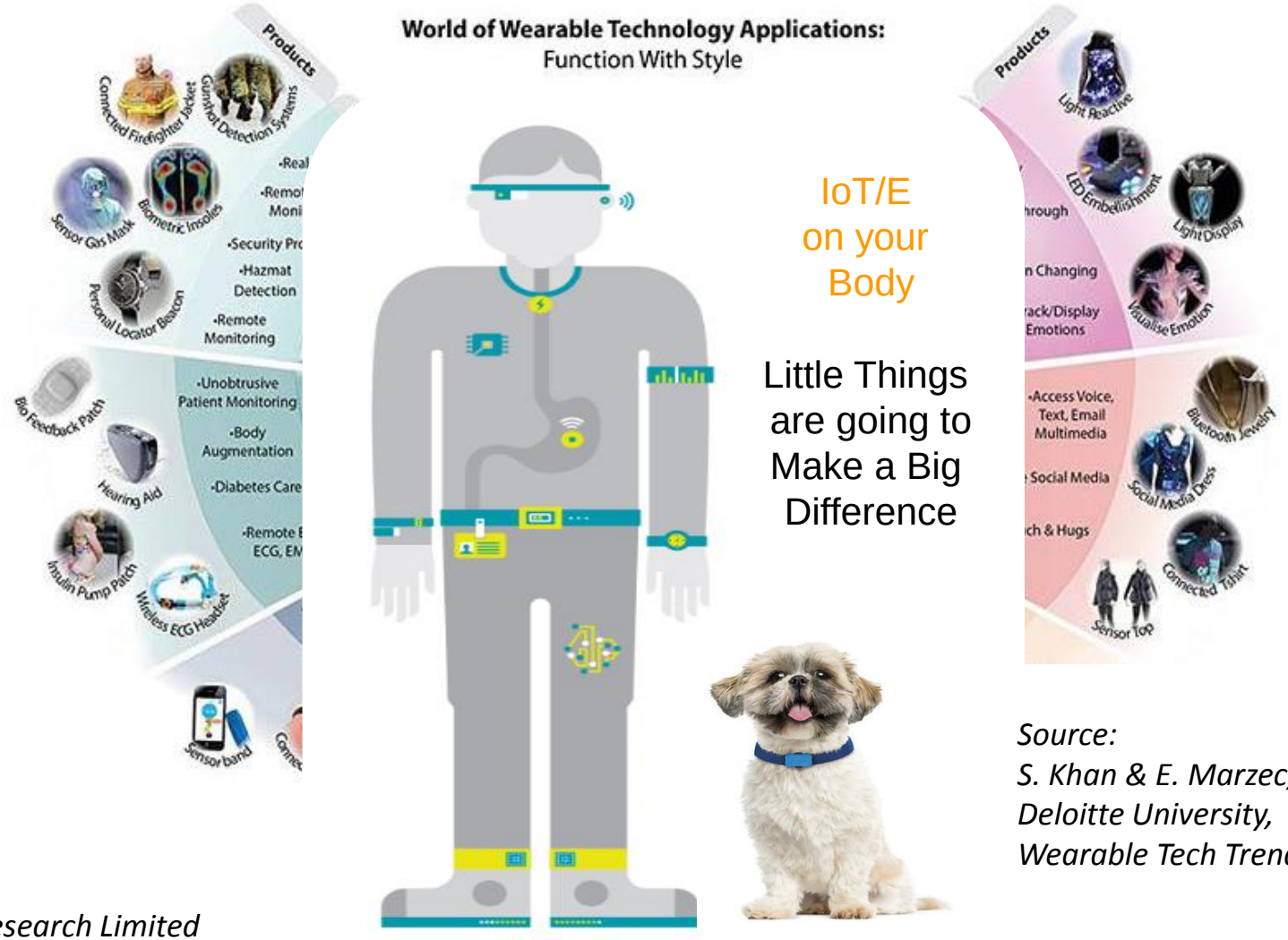


Source:
Beecham Research Limited

Source:
S. Khan & E. Marzec,
Deloitte University,
Wearable Tech Trends 2014

Functionality Integration in Package → WLSiP

The Critical Triad of Packaging: **Performance - Form Factor - Cost**

IoT / Wearable Electronics

Secure Sensing

↓

Raw Data Storage

↓

Analyse and Make it Meaningfull Data

↓

Secure Data

↓

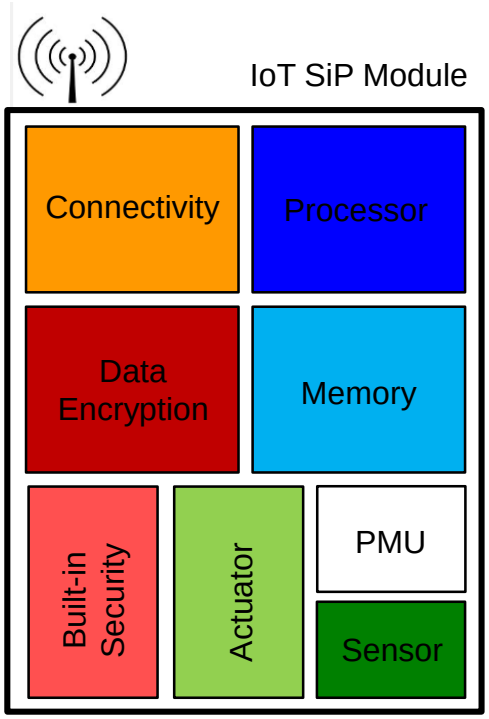
Send Data

↓

Receive Data

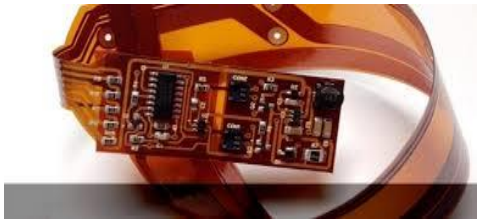
↓

Act



Rigid Substrate PCB

Flexible Substrate 3D



Small & Thin WLP/ FOWLP SiP/ 3D

High Functionality on Little Space
System Miniaturization in WLSiP

The Future: A MEMS/ Sensors Enabled World

MEMS/ Sensor Market

MEMS/ Sensors market is growing fast…

F **MEMS are replacing most conventional sensors needed in IoT devices at a lower cost and better performance**

Details on next slide

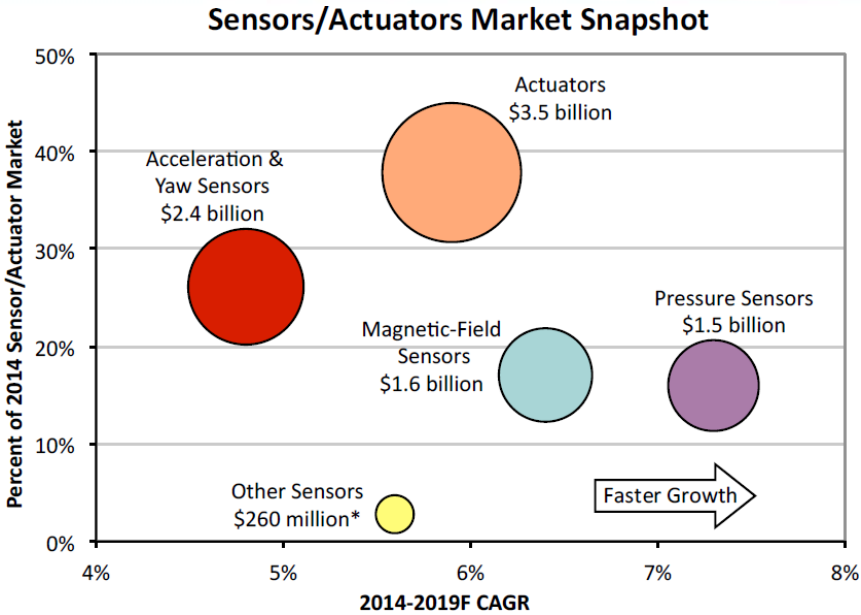
Key trends in MEMS

- Cost and size of MEMS are decreasing while performance is increasing
- Integration of MEMS into 1 building block is on-going (e.g., IMU[1] combos)
- Integration of MEMS with logic expected in next 5 years

MEMS can be used across all IoT verticals — ✓ MEMS suitable

	Wear-ables	Smart home	Medical electro-nics	Indus-trial auto-mation	Connec-ted cars	Smart cities
Microphone	✓	✓	✓	✓	✓	✓
BAW filter[2]	✓	✓	✓	✓	✓	✓
Pressure sensors	✓	✓	✓	✓	✓	✓
Accelerometer	✓		✓	✓	✓	
Magnetometer	✓			✓	✓	
Gyroscope	✓			✓	✓	
Lab-on-chip			✓	✓		
Flow sensor			✓	✓		
Temperature	✓	✓	✓	✓	✓	✓

MEMS in IoT aplications. *Source: Mckinsey Report – The internet of Things – May 2015*



*Includes temperature and gas sensors

Source: IC Insights

… in ever increasing application fields

- ***Wearables, IoT, Biomedical…***

The Future: A MEMS/ Sensors Enabled World

Which Packaging Technology for IoT/ IoE Modules?

Target:

- 300 billion MEMS/ Sensors by 2020 for IoT/ IoE Enabling

Packaging Requirements:

- Small Form-factor/ Miniaturization of IoT/ IoE Modules
- High Volume Manufacturability, High Performance at Low Cost

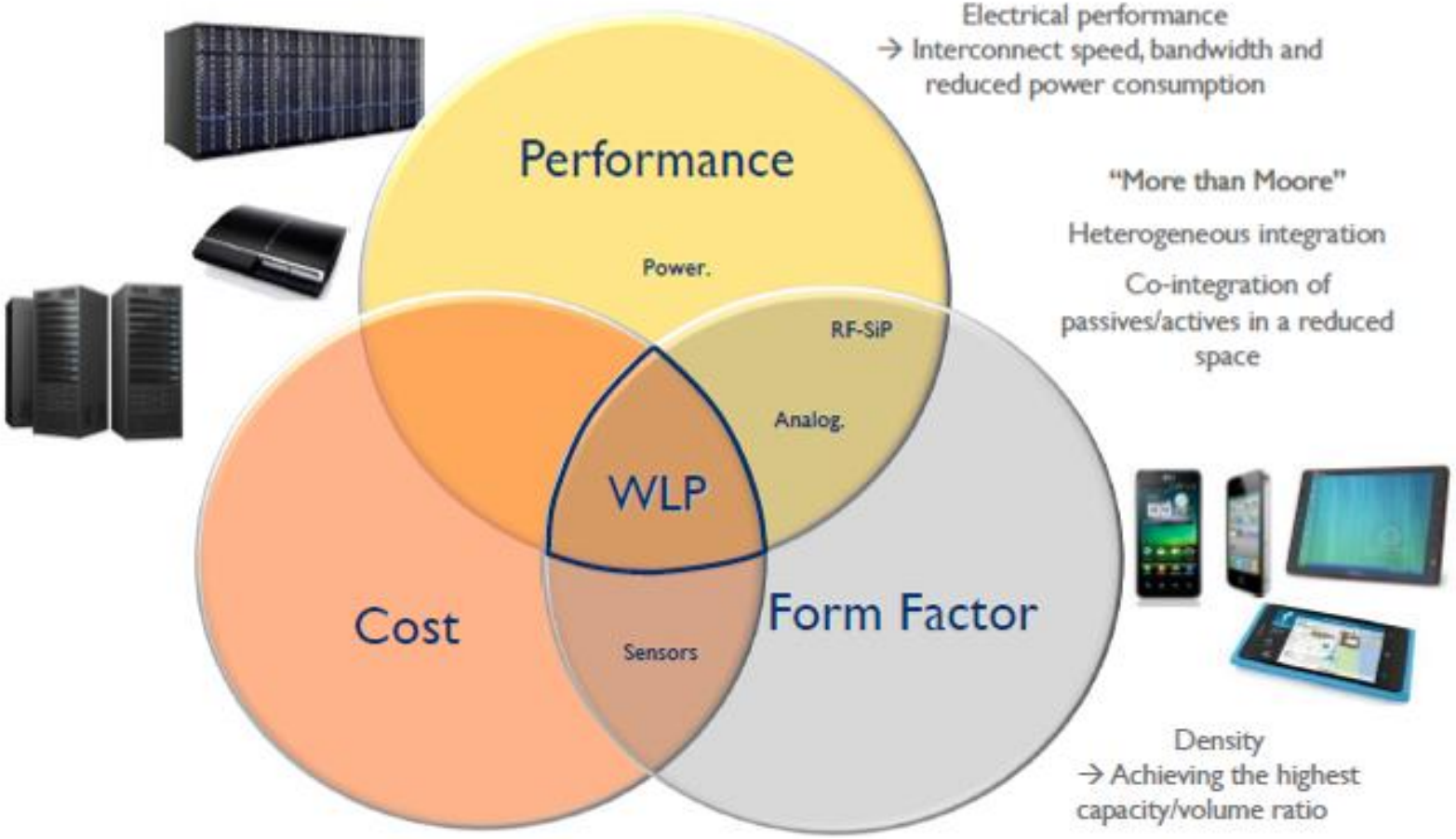
→ Solution:

- System Integration and effective Sensor Fusion in the Modules
- The right Packaging Technology: WLP/ FOWLP = „Active Interposer“

→ Challenges:

- Electrical and Thermal Performance of Miniaturized Systems
- MEMS/ Sensor Design and Robustness → Co-Design with Packaging
- MEMS/ Sensor Integration in High Volume/ Low Cost Packaging Process
  - Mold Embedding/ Encapsulation
  - Batch Processing in Large Panel Format

FOWLP offers best trade between performance, cost, and form factor



Source: *"Fan-out and Embedded Die: Technology and Market", Yole Développement Report, 2015.*

The Future: A MEMS/ Sensors Enabled World

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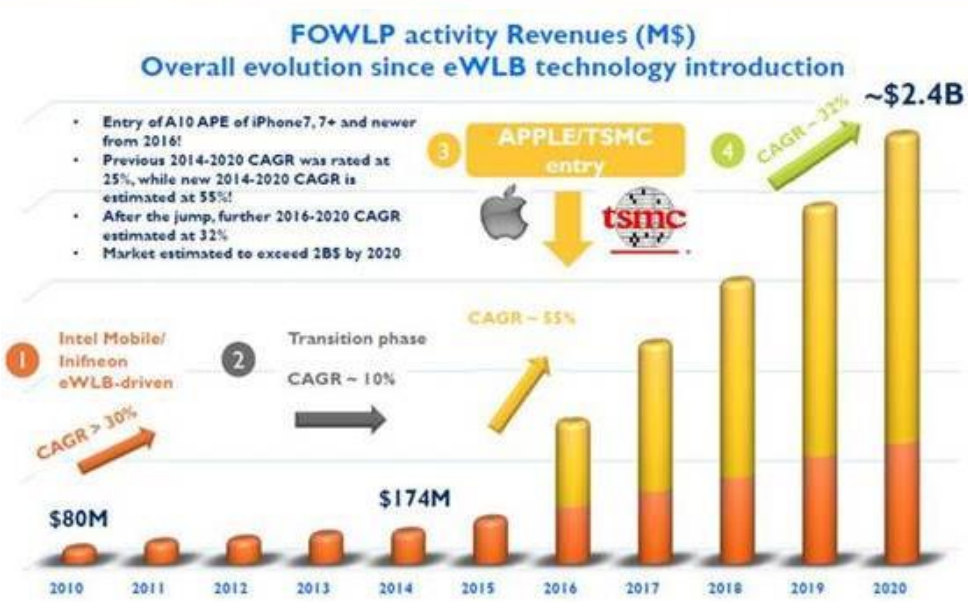
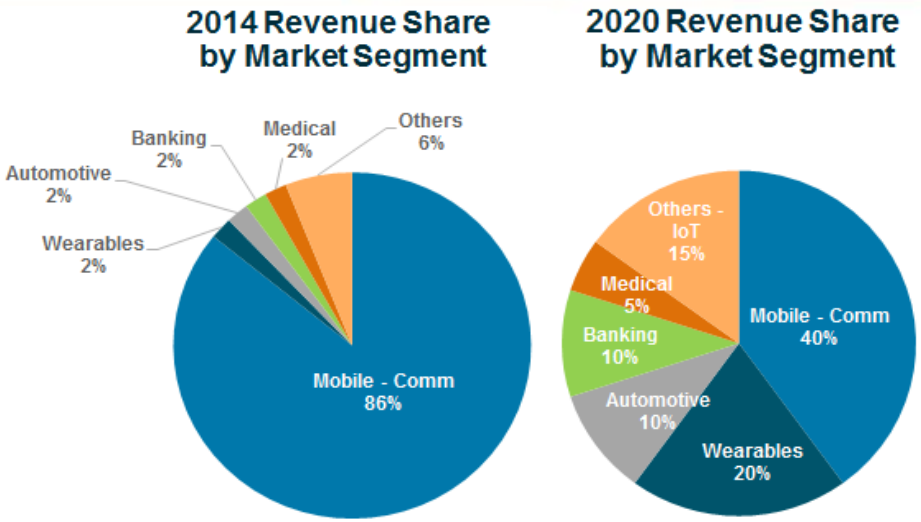
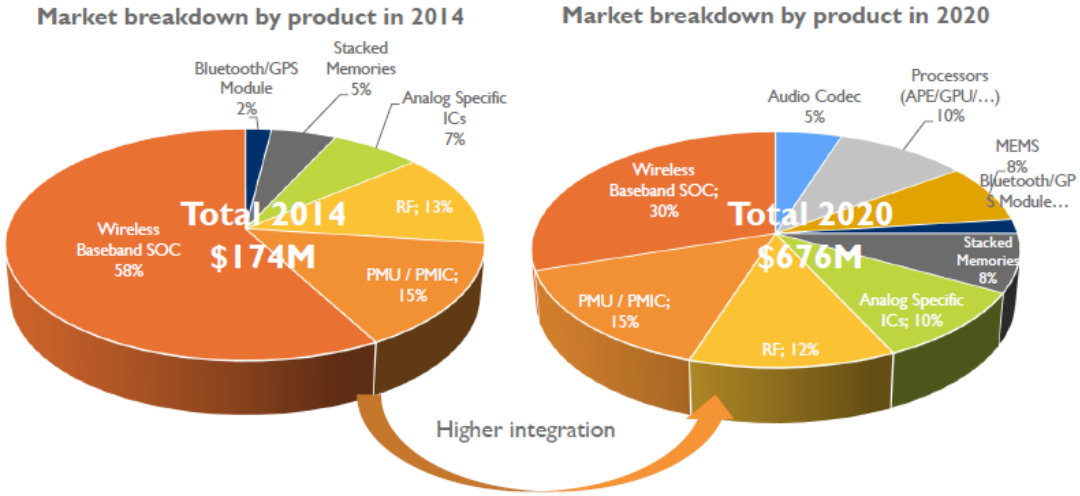




Market segments of FOWLP technology by product in 2014 and projections for 2020. *Source: YOLE Report March 2015*

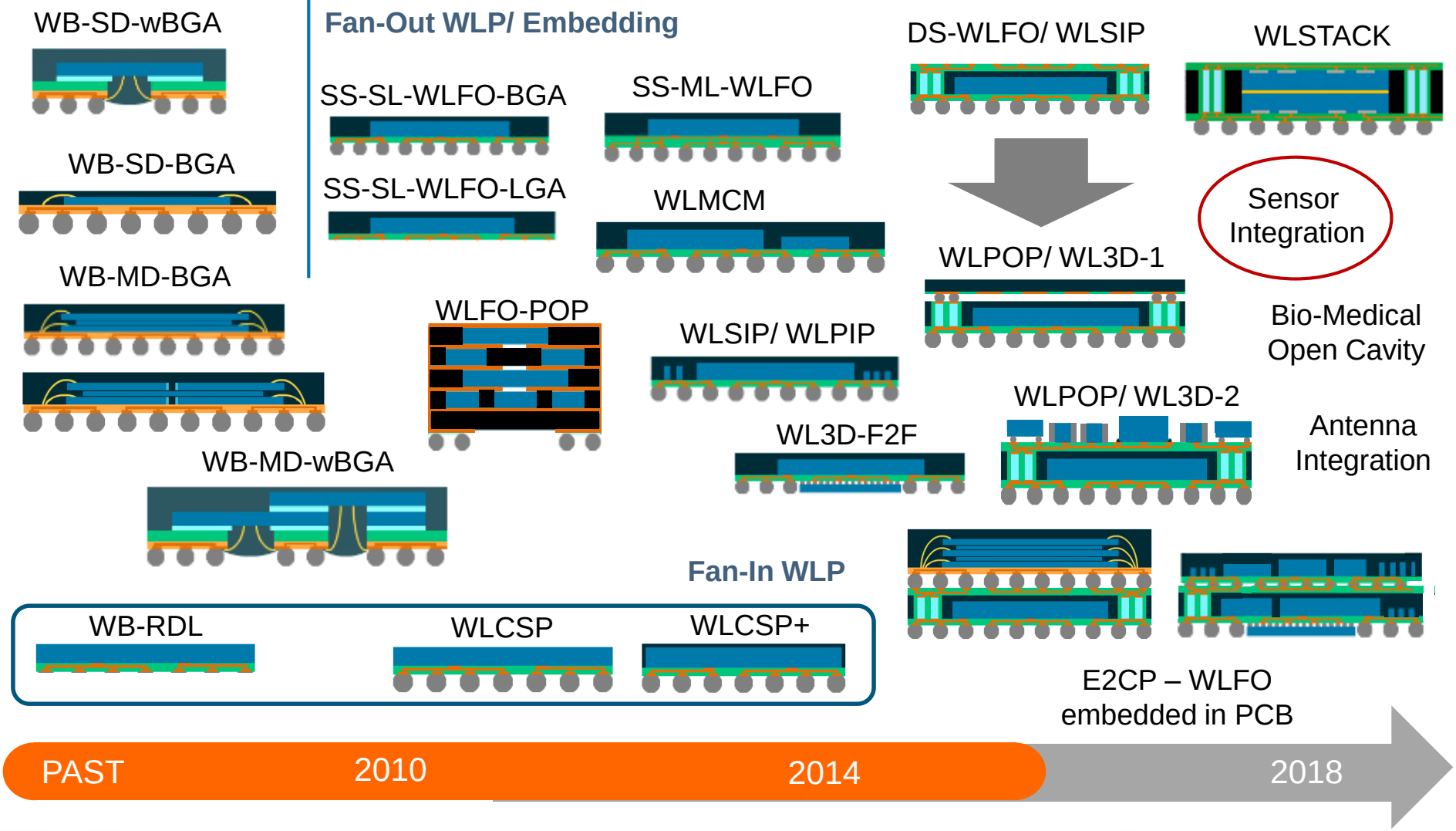


NANIUM's anual revenue projection by market segment 2014/ 2020 – Higher integration capability of FOWLP will give access to markets where nowadays FCBGA-based PoP/SiP are dominating

MEMS will represent $54M market for NANIUM

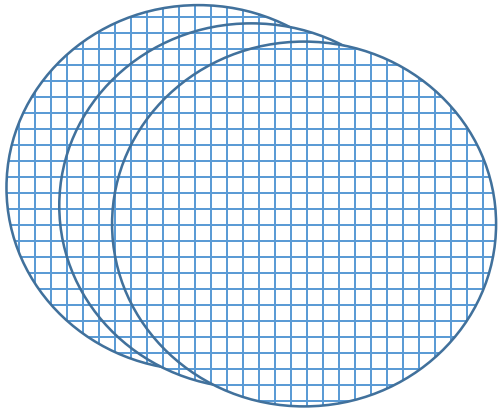
NANIUM Package Roadmap

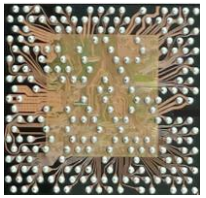
From WB-SD-wBGA to System Integration on Wafer-Level



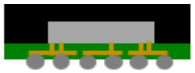
Introduction to NANIUM's WLFO Technology

Basic Process Flow for Single Die, Single-Sided Package

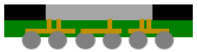




a) Overmold (5S)



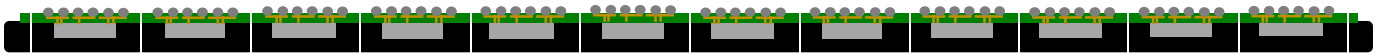
b) Exposed Die (4S)



Incoming probed wafer w/ KGD;
Wafer diameter independent;
Wafer material independent.

WLFO –
RECONSTITUTION on mold carrier;
Compression molding on mold carrier;
Recon panel ready for REDISTRIBUTION.

a) Overmold → For Reliability and Robustness (5-side protection – 5S)



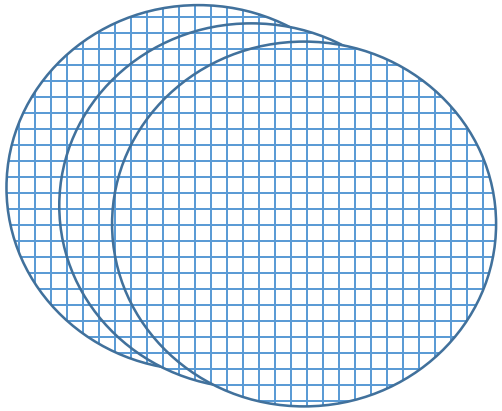
b) Exposed Die → For Very Thin Package and/ or Heat Dissipation (4-side protection – 4S)

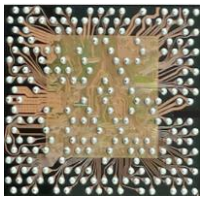
Compression Molding
Die Placement
Thermal Release Tape
Metal Mold Carrier

Marking, Singulation
Solder Ball Drop
Thin Film Processing

Introduction to NANIUM's WLFO Technology

Basic Process Flow for Single Die, Single-Sided Package





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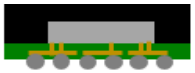

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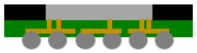


Incoming probed wafer w/ KGD;
Wafer diameter independent;
Wafer material independent.

WLFO –
RECONSTITUTION on mold carrier;
Compression molding on mold carrier;
Recon panel ready for REDISTRIBUTION.

Interesting Facts about NANIUM's WLFO:

- Based on Infineon's/ Intel's eWLB (embedded Wafer-Level Ball Grid Array);
- First 300mm round panel based eWLB realization for HVM in 2010;
- Production line running HVM since Q3/2010;
- Shipped more than 600 million WLFO packages in the last 5 years;
- Proven mature WLP technology with 99.5% plus (99.8% in HVM) yield levels.

Introduction to NANIUM's WLFO Technology

Main Advantages Compared to WB and FC Packages

- Reconstituted mold panel size independent of incoming wafer diameter;
- Independent of material (Si, GaAs, SiGe, Glass, Passives, Packaged Parts);
- Adaptable fan-out area, and solution for I/O gap between die and board;
- Substrate-less package, the interposer is built-up in Thin-Film Process;
- **Smaller footprint, and thinner (!) compared to WB and FC packages;**
- Superior electrical and thermal performance due to short connections;
- Lower unit cost due to large format batch processing;
- Simplified Bill of Material (BOM), low inventory, and short Supply Chain;
- **Enabler for heterogeneous dense system integration on Wafer-Level driving system miniaturization.**

→ **WLSiP and WL3D**

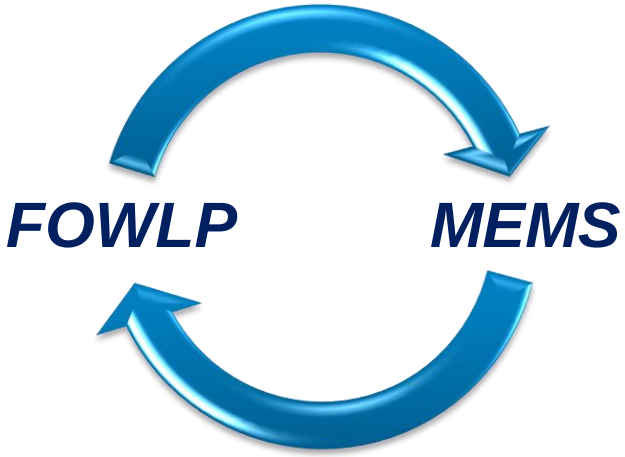
→ **Sensor Integration ?!**

MEMS in FOWLP – Closing the Gap

Two fast growing markets

How does each world contributes to the other?

Technology Partner,
Application Enabler

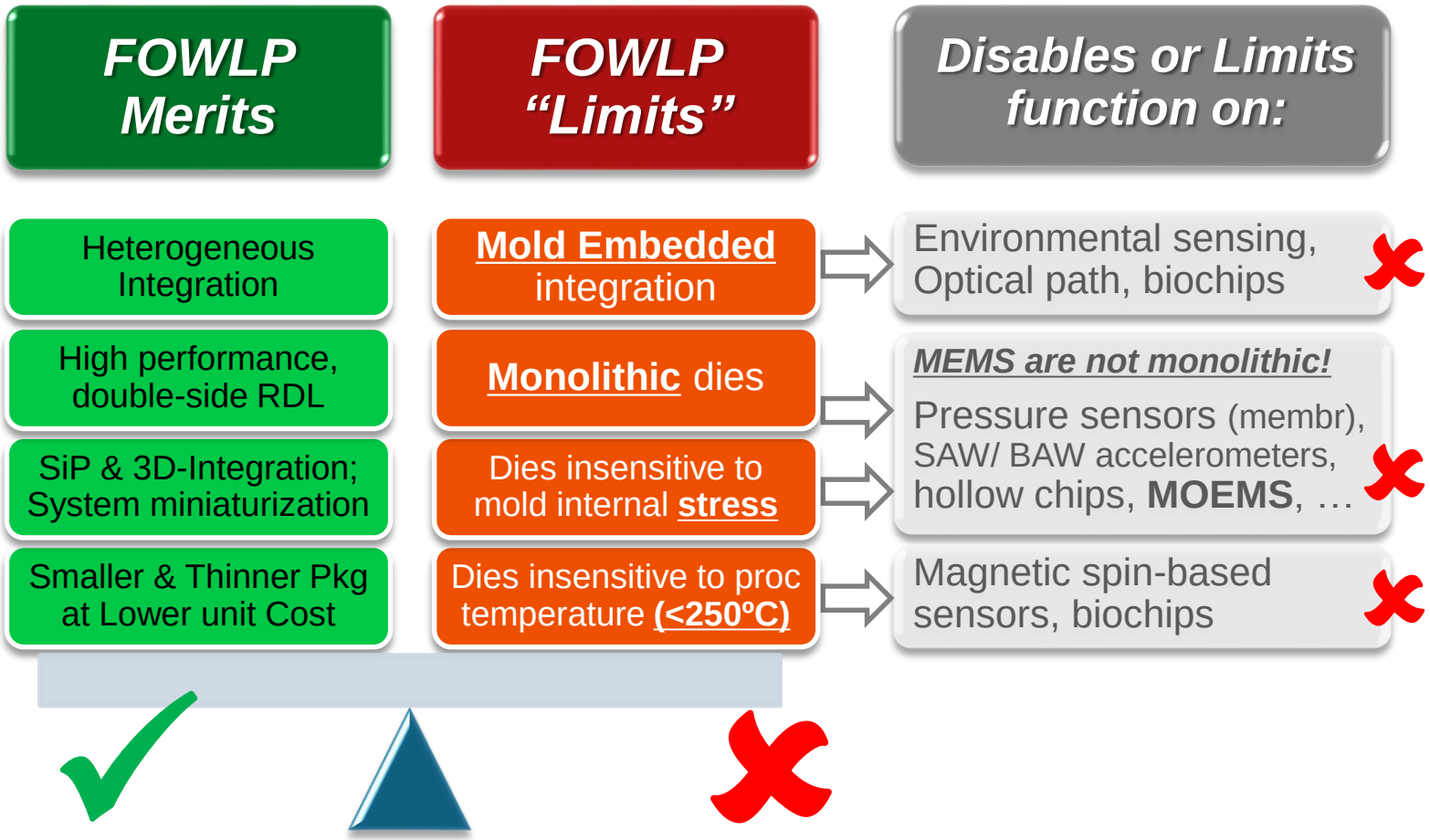


Market Opportunity,
Catching "MEMS-Train"

Is FOWLP ready for MEMS/ Sensors?

MEMS in FOWLP – Closing the Gap

FOWLP ready for MEMS?

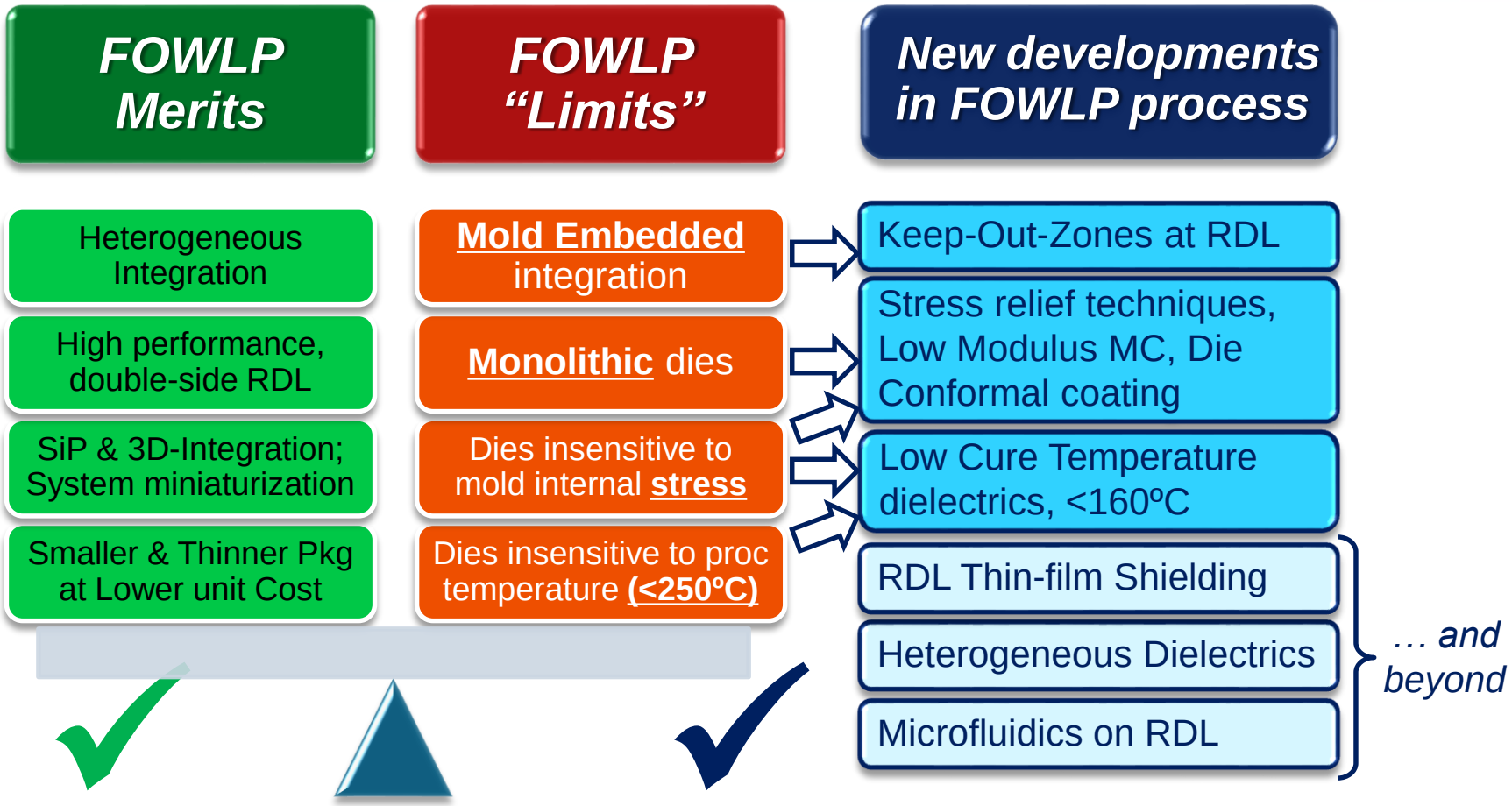


OK for MEMS/Sensors integration on FOWLP

Not OK for a *large group* of MEMS/ Sensors

MEMS in FOWLP – Closing the Gap

Beyond the SoA - Making FOWLP ready for MEMS



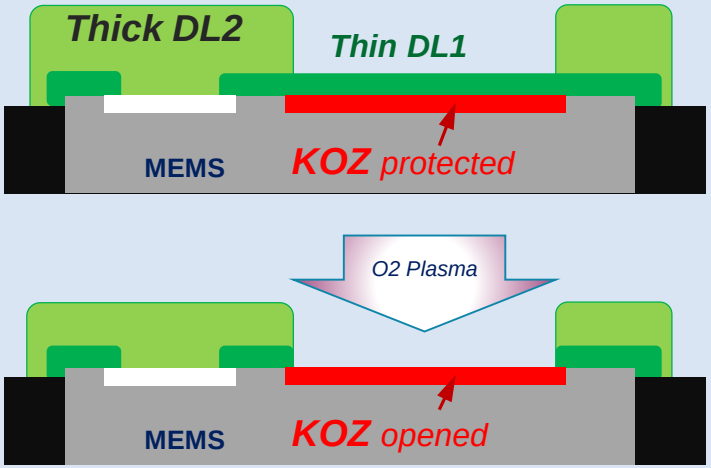
MEMS in FOWLP – Developments 1/4

Enabler: Keep-Out-Zones

❖ Keep-Out-Zones – Protection of Sensitive Areas during FOWLP process

How:

- DL1 protects KOZ against RDL process (Sputtering, Wet Etch, …)
- A thick DL2 exposes DL1 at KOZ
- KOZ opened with O_2 Plasma Ashing, for very low damage
- DL1/DL2 Ashing discrimination:
  - Thickness ratio > 4:1
  - Different Dielectrics



- ✓ **Using existing RDL structure**
- ✓ Process line compatibility
- ✓ All at wafer-level 12” process

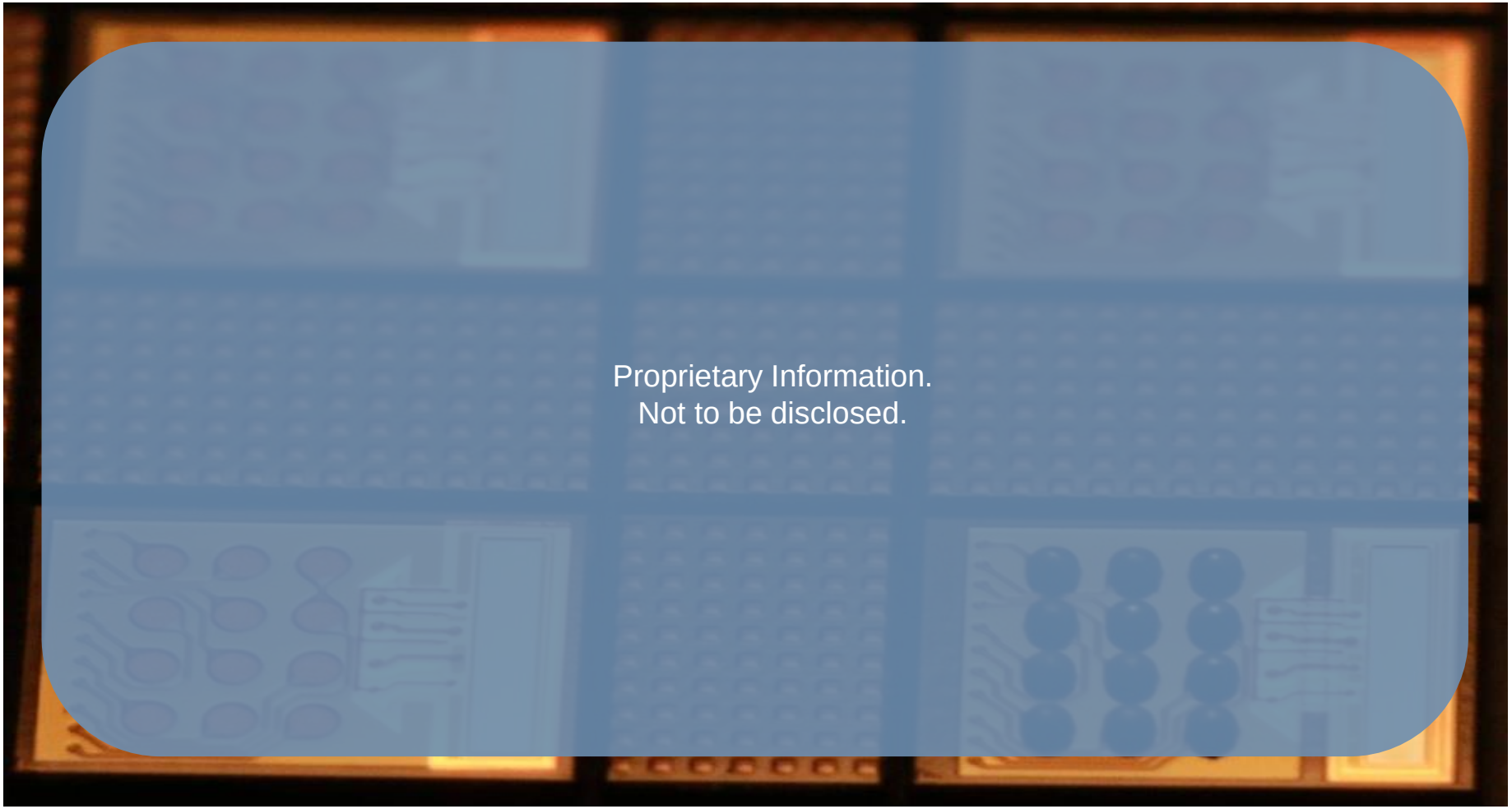
MOEMS-KOZ, e.g. optical path

MEMS-KOZ e.g. Membrane

MEMS in FOWLP – Developments 1/4

Enabler: Keep-Out-Zones

❖ **Keep-Out-Zones** – Protection of Sensitive Areas during FOWLP process



MEMS in FOWLP – Developments 2/4

Enabler: Mold Stress Relief

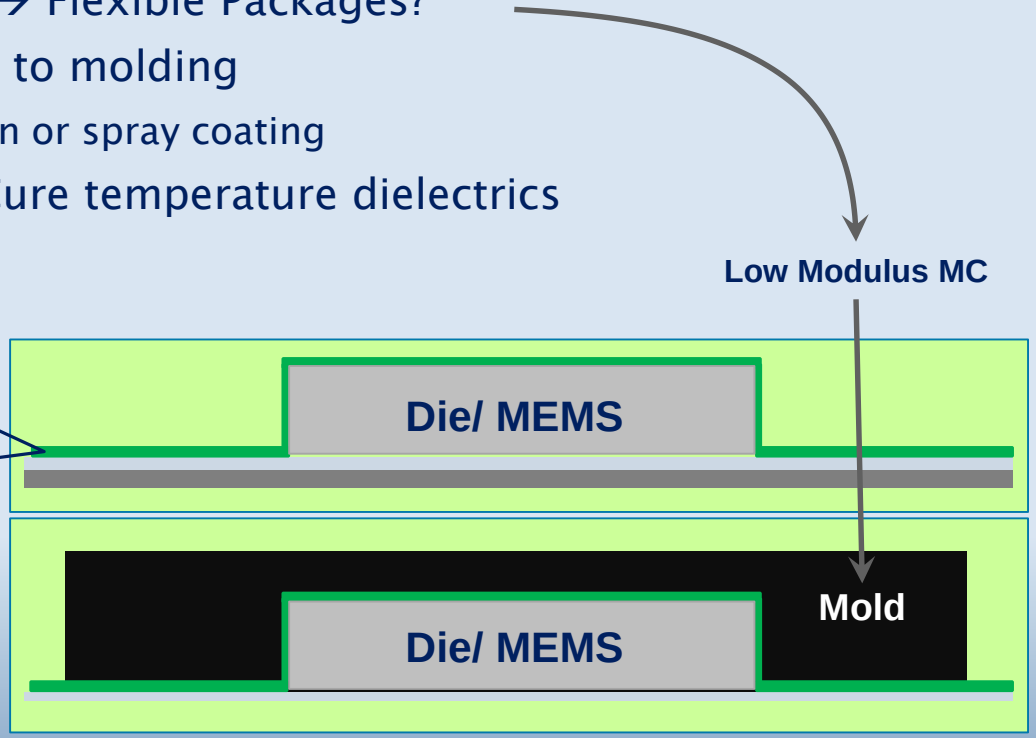
❖ Stress Relief on Dies for mold pressure sensitive devices

How:

- Low Modulus Mold Compound → Flexible Packages?
- Conformal coating of dies prior to molding
  - Deposition via vacuum lamination or spray coating
- Also: Positive effect from Low Cure temperature dielectrics

Under research:

- Modulus <2GPa at RT
- Conformal behavior
- Which material? Silicone?
- Thickness?
- Dielectric or compatible



MEMS in FOWLP – Developments 3/4

Enabler: Shielding

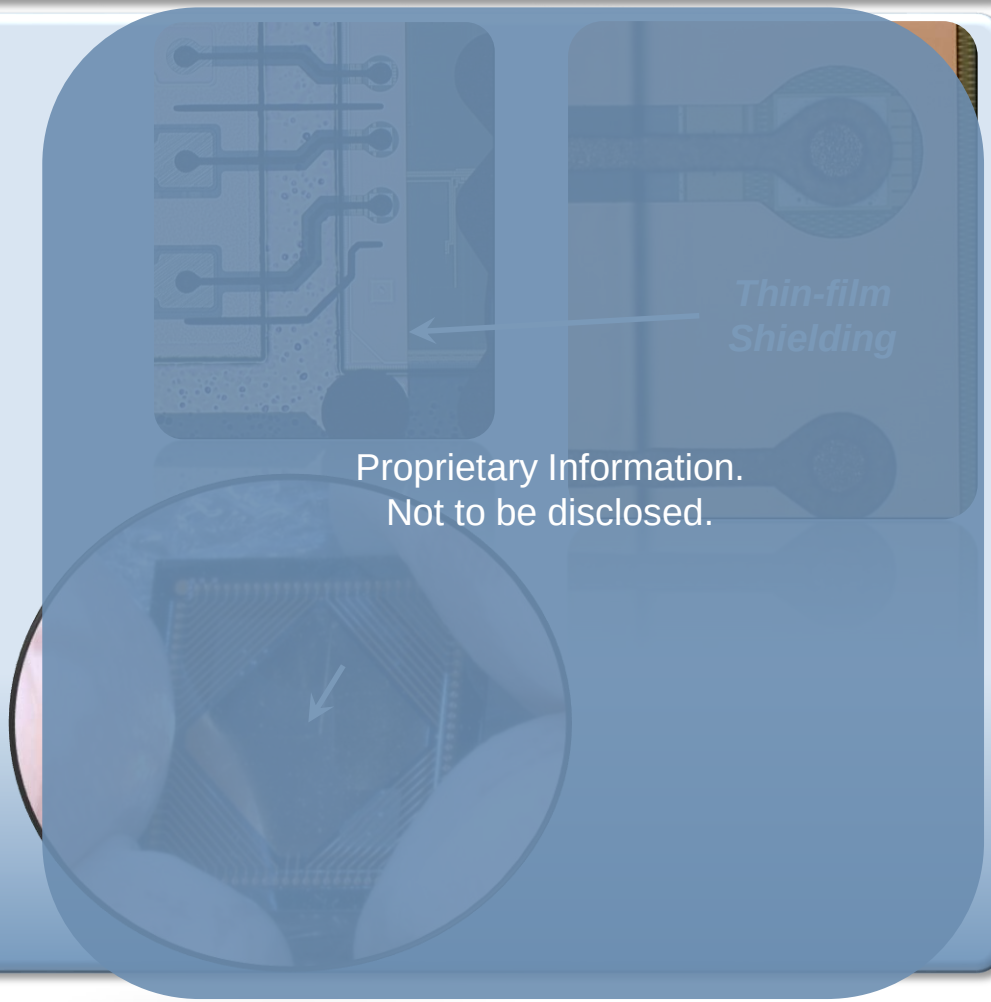
❖ Thin-Film Shielding – Seed Layer as a Functional Player!

How:

- Partial remove of Seed Layer (Ti or TiW) after Electroplating process, with a mask for wet-etch shaping

Advantages:

- ✓ Electrical performance improvement
  - ✓ EM protection; Noise decoupling
  - ✓ Moisture uptake effect mitigation
- ✓ Capacitive effect is possible
- ✓ Semi-additive process, no waste
- ✓ All in 12" FOWLP standard process
- ✓ **Very low cost!!**



MEMS in FOWLP – Developments 4/4

Enabler: Heterogeneous Dielectric Stacking

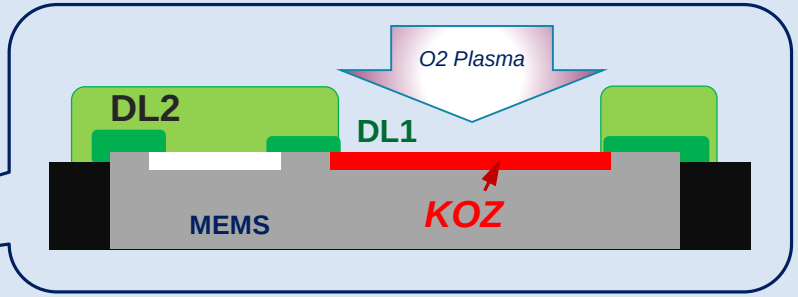
❖ Heterogeneous Dieletrics – Symbiotics effect

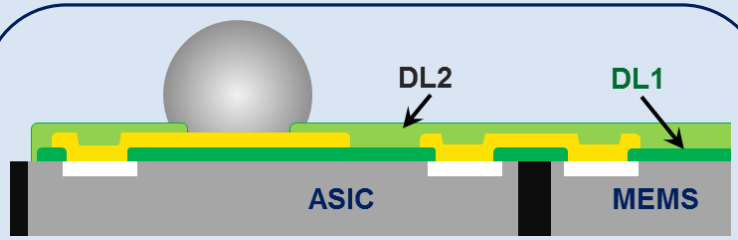
Advantages:

- ✓ Additional packaging functionality
- ✓ Using 12” FOWLP existing process

Examples:

- ✓ KOZ mechanism
- ✓ Electro-mechanical advantages
- ✓ Micro fluids in RDL
- ✓ …





DL2 – High mechanical robustness, e.g., Polyimide

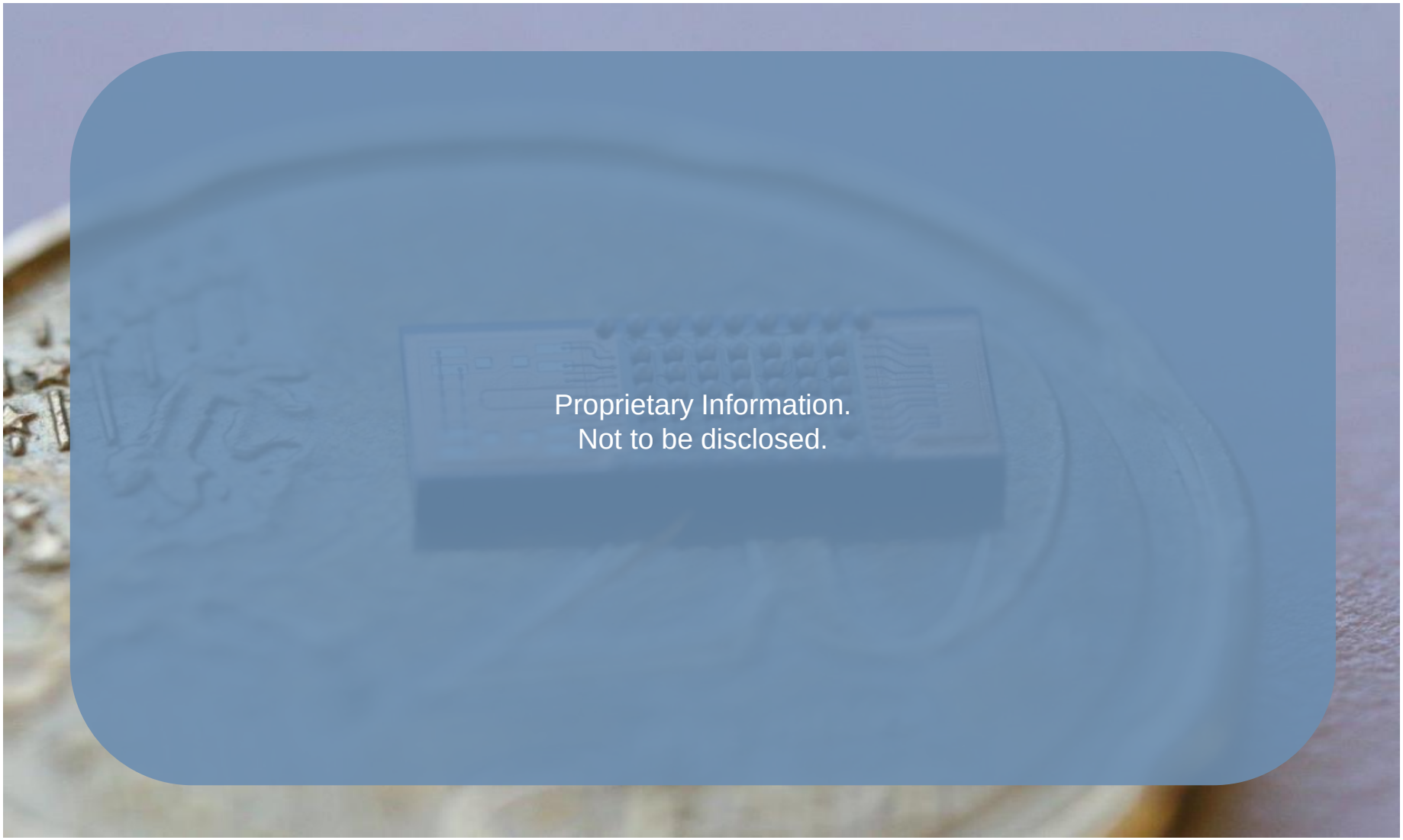
DL1 – Low moisture uptake, e.g., PBO, acting as moisture barrier to MEMS

What‘s Next?

NANIUM Demonstrated Dual-MEMS Integration in FOWLP in Q2/2016

What‘s Next?

NANIUM Demonstrated Dual-MEMS Integration in FOWLP in Q2/2016



Summary and Conclusions

- Billions of IoT/ IoE Modules require **single or multiple MEMS/ Sensors integration**
- Success of IoT/ IoE Modules will also depend on the selection of the right **PACKAGING Technology** offering the following key capabilities:
  - **Miniaturization** by dense System Integration
  - Effective **MEMS/ Sensor Fusion** into the systems
  - Manufacturability of **High Volume and Low Cost**
- Wafer-Level Packaging (WLP), namely **Fan-Out WLP Technologies** such as eWLB/ WLFO, RCP, M-Series, InFO, NTI, SLIM and SWIFT, are **showing great potential**
- FOWLP is growing with forecasted CAGR between 50-80% until 2020
  - **System Integration solutions** (WLSiP and WL3D) will dominate volumes in future compared to current single die FOWLP packages for mobile communication
- Recent developments for **eWLB/ WLFO Technology** to overcome current limits for MEMS/ Sensor Integration related to FOWLP technology merits have been shown
  - **Processing Keep-Out Zones** for MEMS/ Sensor access to environment in molded packages
  - **Mold Stress Relief** on dies, MEMS/ Sensor die decoupling from internal package stress
  - **Thin-Film Shielding** using PVD seed layer for ECD as functional layer (is there anyway)
  - **Heterogeneous Dielectrics Stacking** (different materials fulfilling different functions)

Thank you for your attention

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