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DEVICE PACKAGING

WekoPa Resort and Casino
Fountain Hills, Arizona USA

nanium®

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

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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

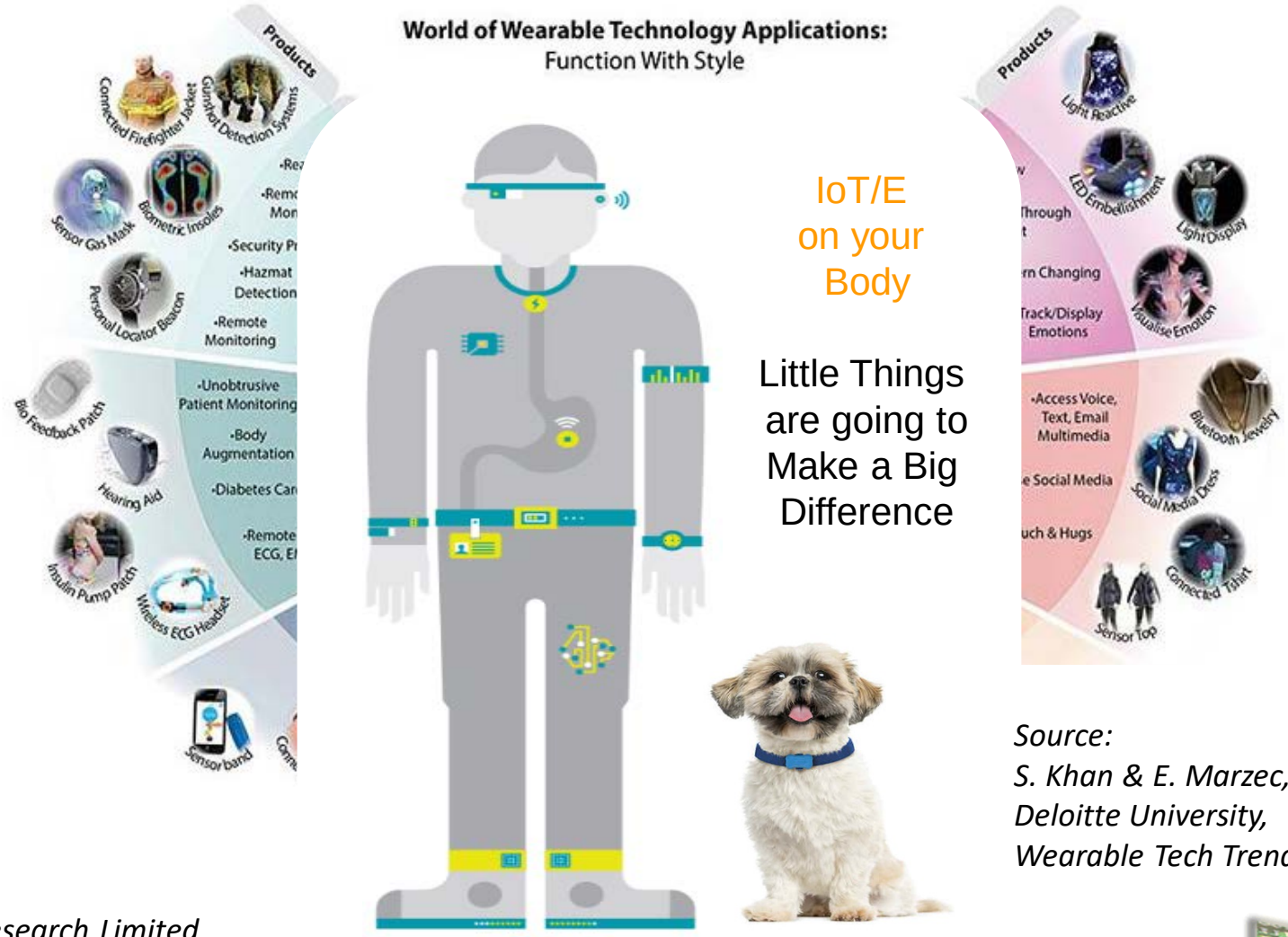
*) "Emergence of Trillion Sensor Opportunity," SemiconWest, http://www.semiconwest.org/sites/semiconwest.org/files/docs/SW2013_Janusz Bryzek_Fairchild Semiconductor.pdf.

**) "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

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

↓

Analyze and Make it Meaningful Data

↓

Secure Data

↓

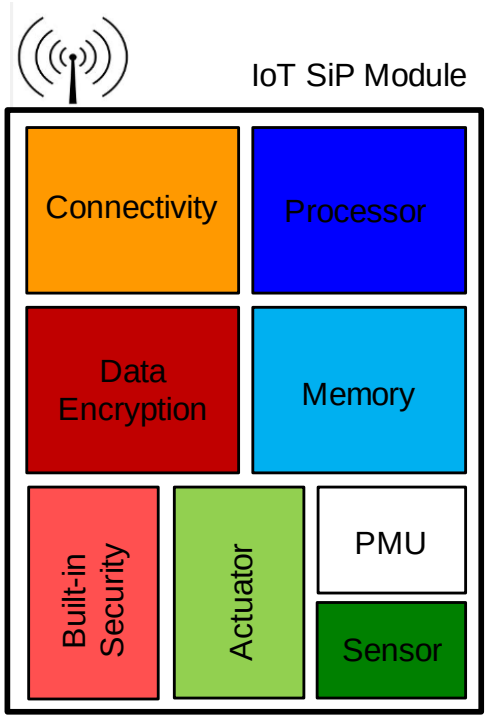
Send Data TX

↓

Receive Data RX

↓

Acting



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

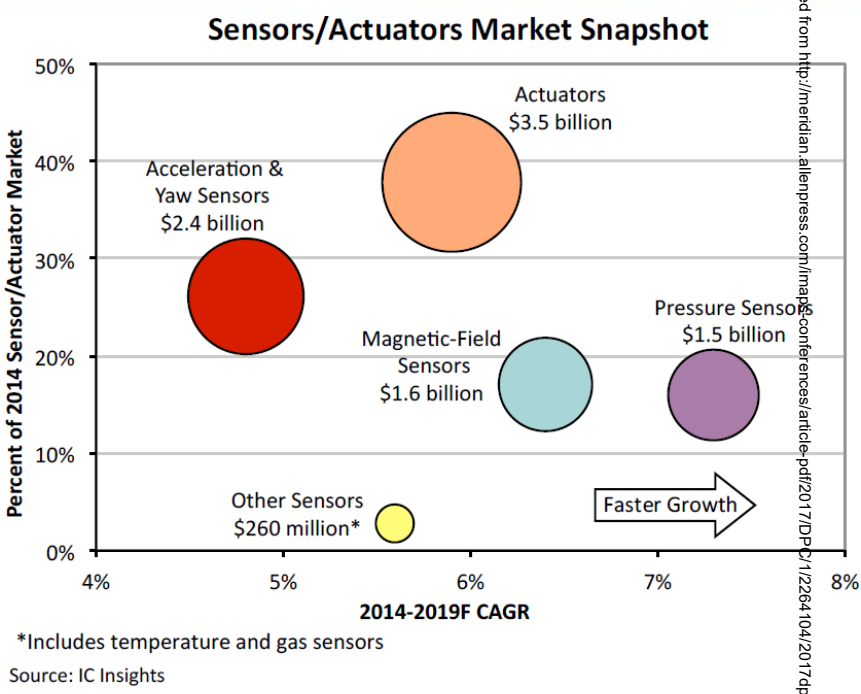
Key trends in MEMS

- 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“

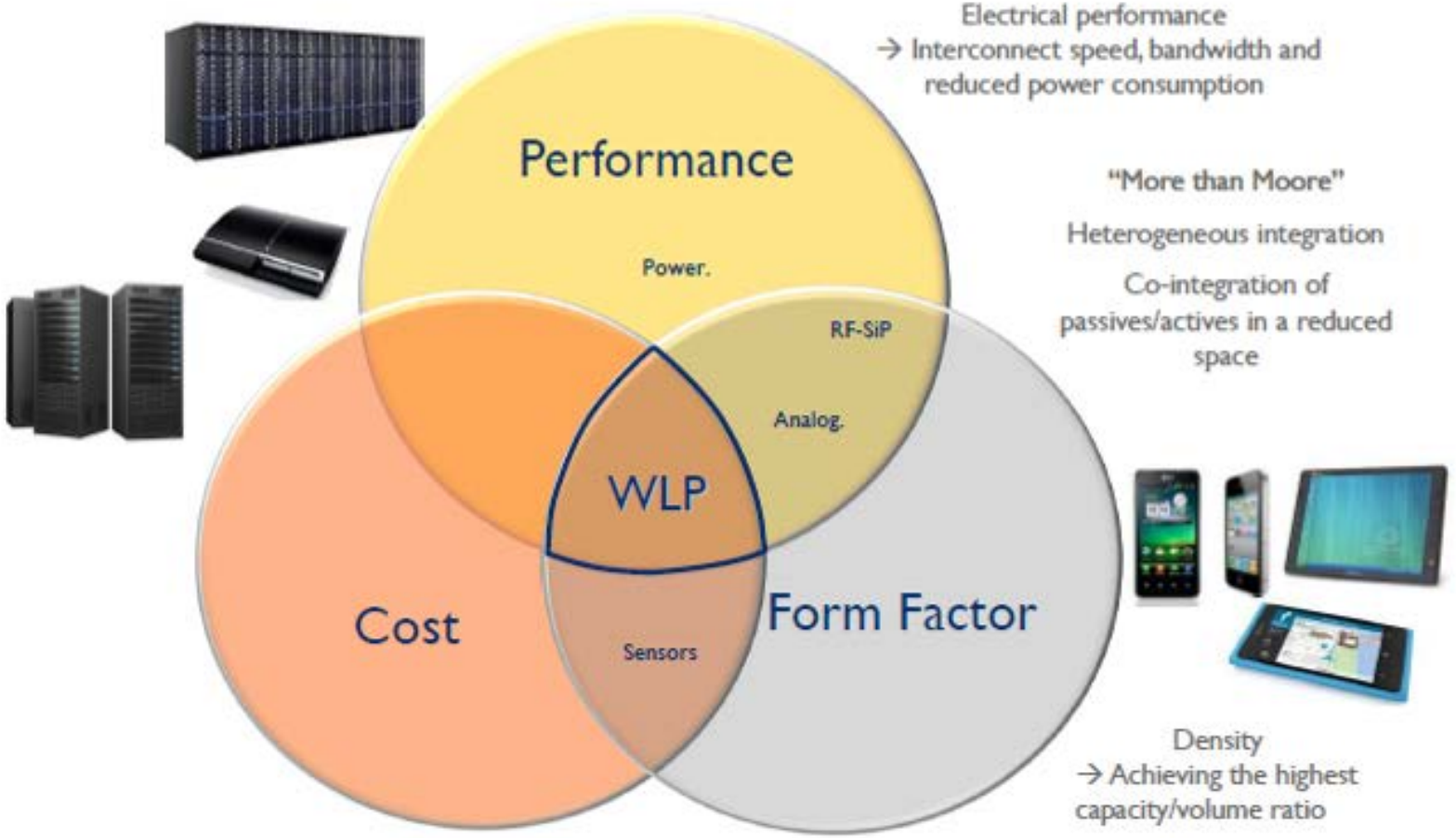
→ Challenges:

- 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 Manufacturing Format

The Future: A MEMS/ Sensors Enabled World

Which Packaging Technology for IoT/ IoE Modules?

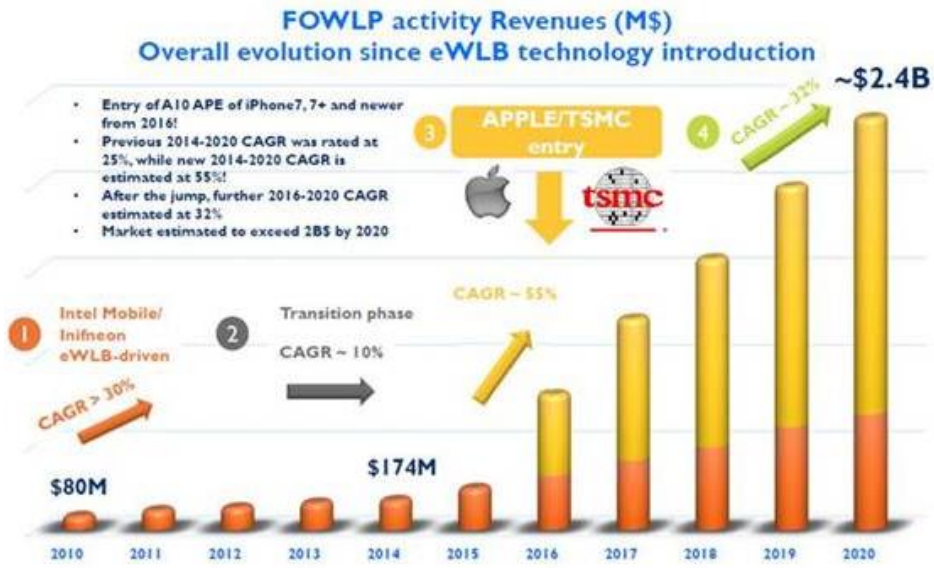
FOWLP offers best trade between performance, cost, and form factor

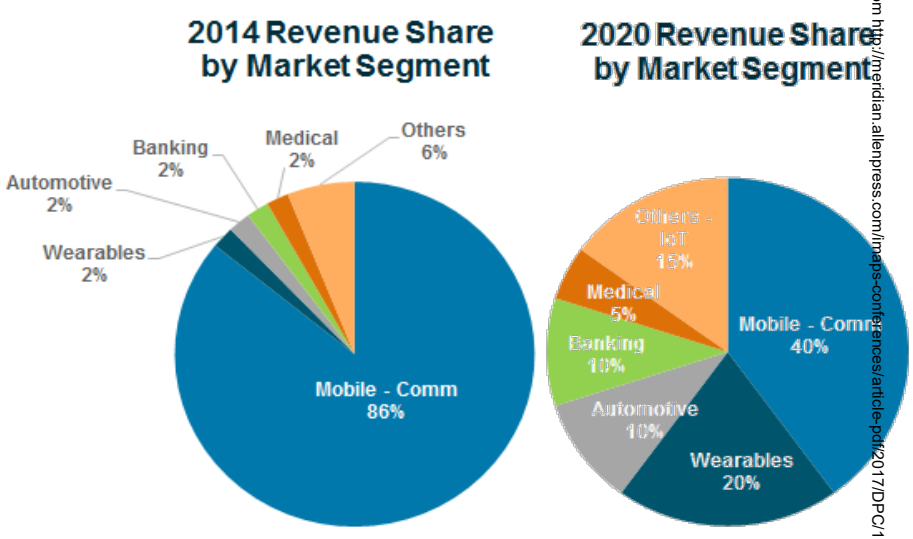


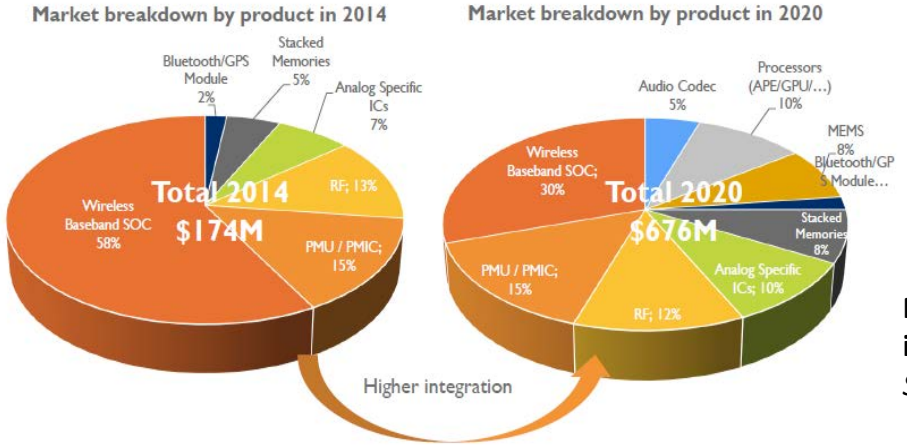
Source: *"Fan-out and Embedded Die: Technology and Market", Yole Développement Report, 2015.*

The Future: A MEMS/ Sensors Enabled World

Which Packaging Technology for IoT/ IoE Modules?







NANIUM's anual revenue by market segment In 2014 and projection for 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

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

NANIUM Package Roadmap

From Single Die Packaging to System Integration on Wafer-Level

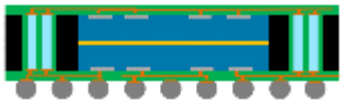
Fan-Out WLP/ Embedding

SS-SL-WLFO-BGA

SS-ML-WLFO

DS-WLFO/ WLSIP

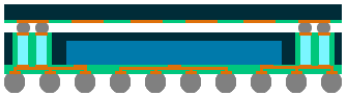
WLSTACK



SS-SL-WLFO-LGA

WLMCM

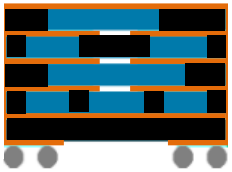
WLPOP/ WL3D-1



MEMS Integration

Bio-Medical Sensor

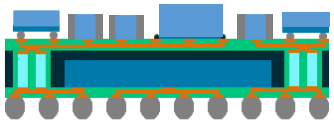
WLFO-POP

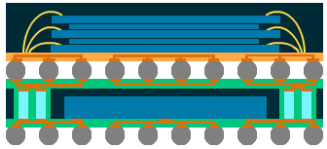


WLSIP/ WLPIP

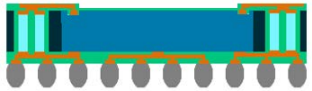
WL3D-F2F

WLPOP/ WL3D-2



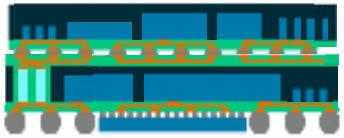


Optoelectrical WL3D



Antenna Integration

Fingerprint Sensor



E2CP - WLFO embedded in PCB

Fan-In WLP

WB-RDL

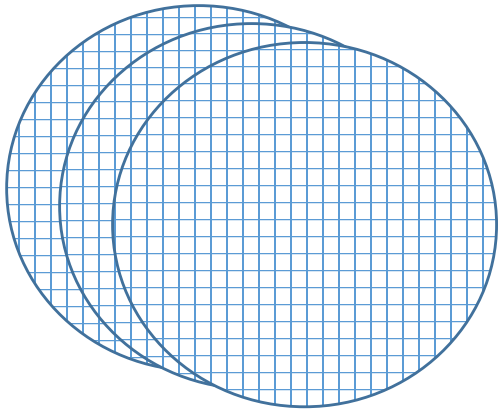
WLCSP

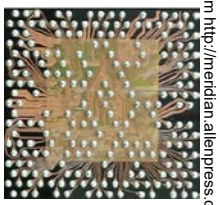
WLCSP+

2010 2012 2014 2016 2018 2020

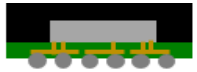
Introduction to NANIUM's WLFO Technology

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.

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 close to 1 billion WLFO packages in the last 6.5 years;
- Proven mature WLP technology with 99.5 (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 and 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**

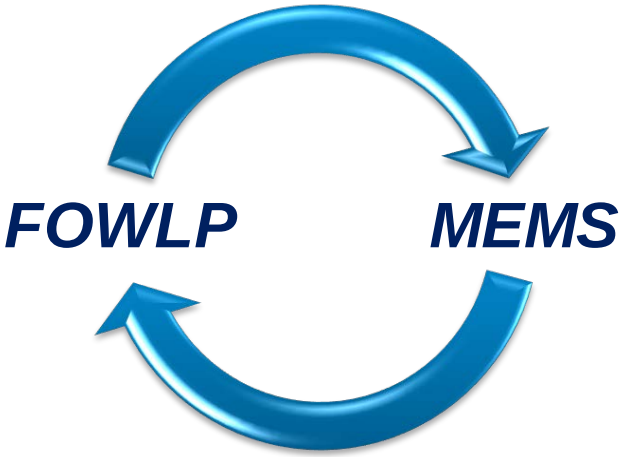
→ **Sensor Integration ?!**

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?

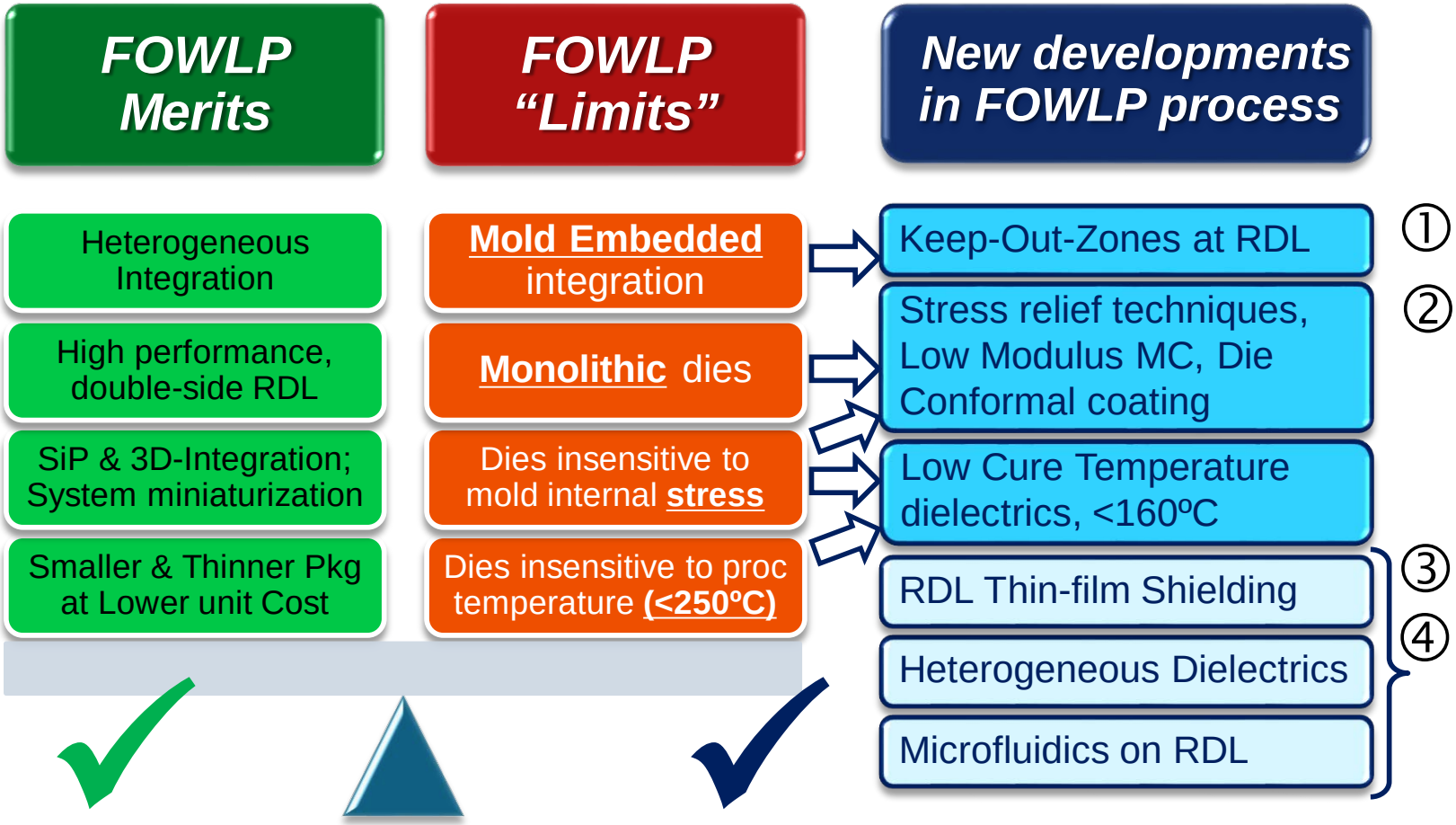
FOWLP Merits	FOWLP "Limits"	Disables or Limits function on:
Heterogeneous Integration	**Mold Embedded** integration	Environmental sensing, Optical path, biochips
High performance, double-side RDL	**Monolithic** dies	***MEMS are not monolithic!*** Pressure sensors (membr), SAW/ BAW accelerometers, hollow chips, **MOEMS**, …
SiP & 3D-Integration; System miniaturization	Dies insensitive to mold internal **stress**	
Smaller & Thinner Pkg at Lower unit Cost	Dies insensitive to proc temperature **(<250ºC)**	Magnetic spin-based sensors, biochips

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



OK for MEMS/Sensors integration on FOWLP

Enables most of MEMS/ Sensors Improves performance

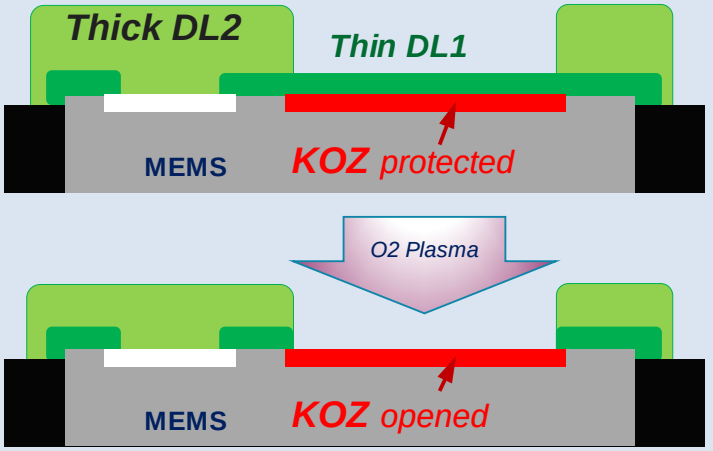
MEMS in FOWLP – Developments 1/4

Enabler: Keep-Out-Zones

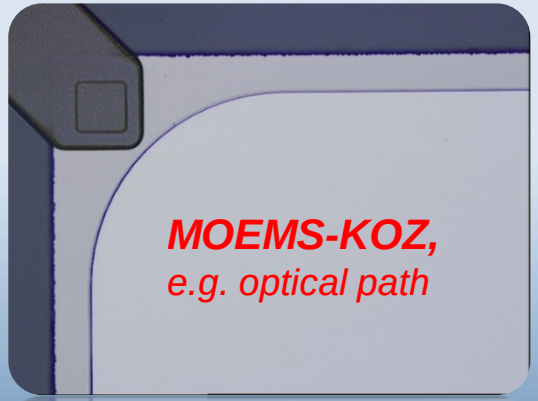
❖ Keep-Out-Zones – Protection of Sensitive Areas during FOWLP process

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



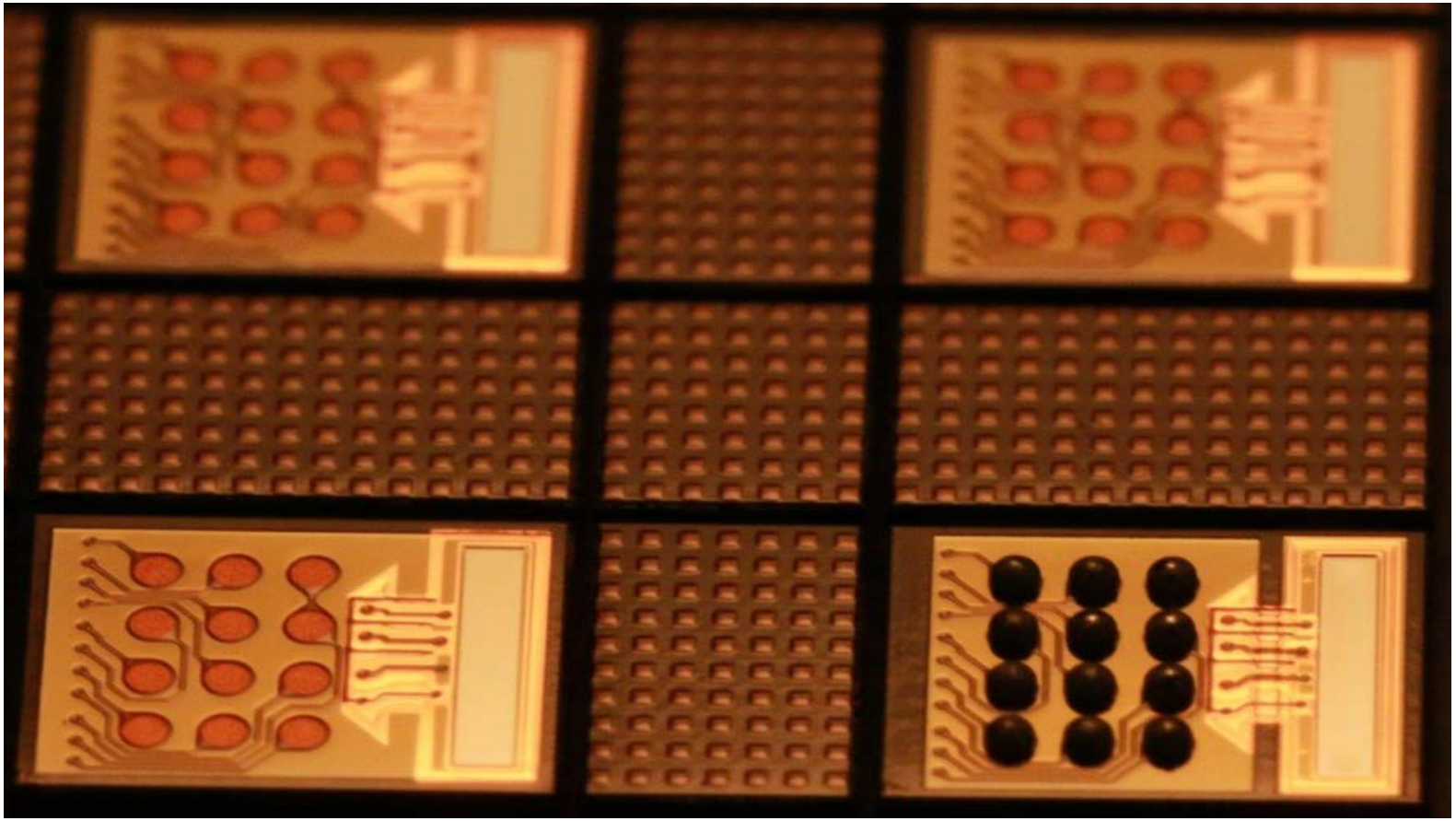
- ✓ **Using existing RDL structure**
- ✓ Process line compatibility
- ✓ All at wafer-level 12" process



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

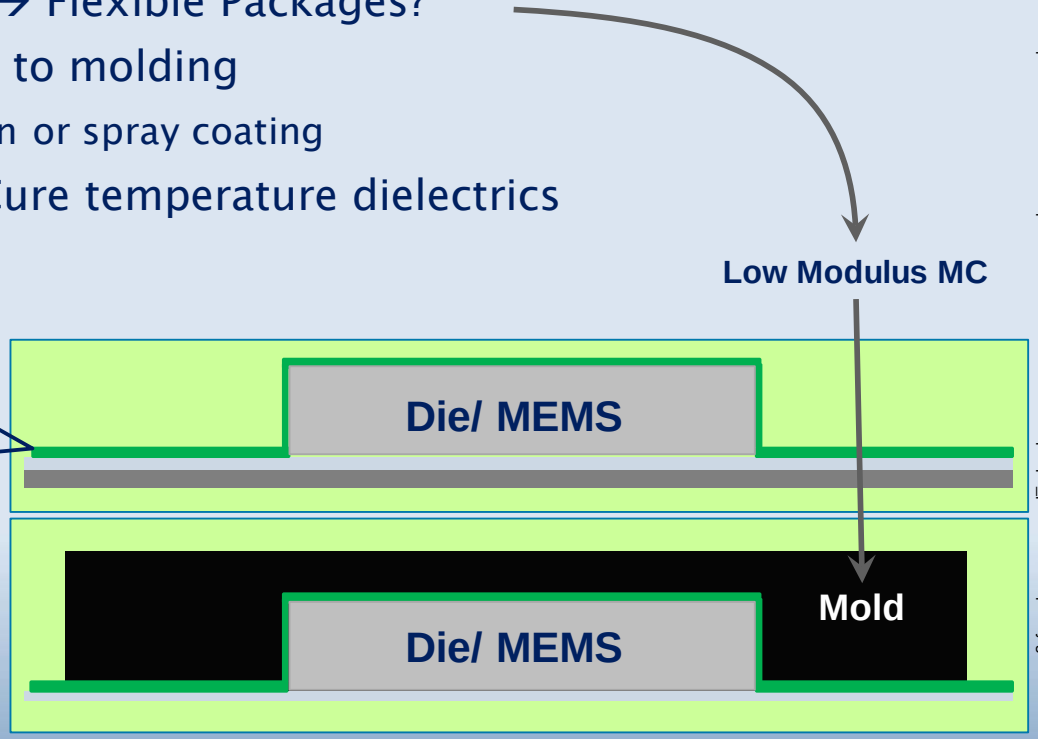
❖ **Stress Relief on Dies** for mold pressure sensitive devices

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



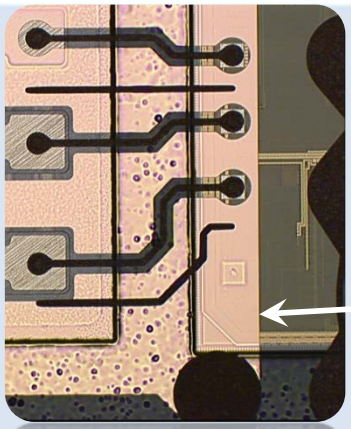
MEMS in FOWLP – Developments 3/4

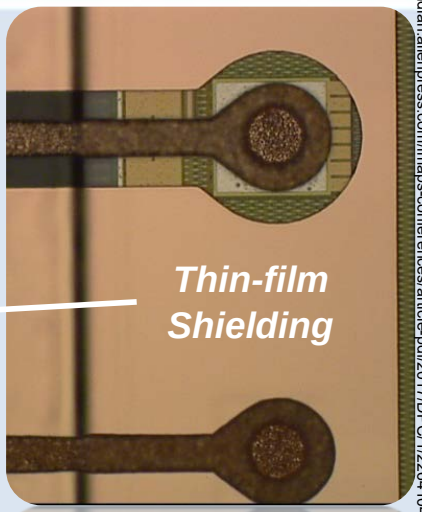
Enabler: Shielding

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

How:

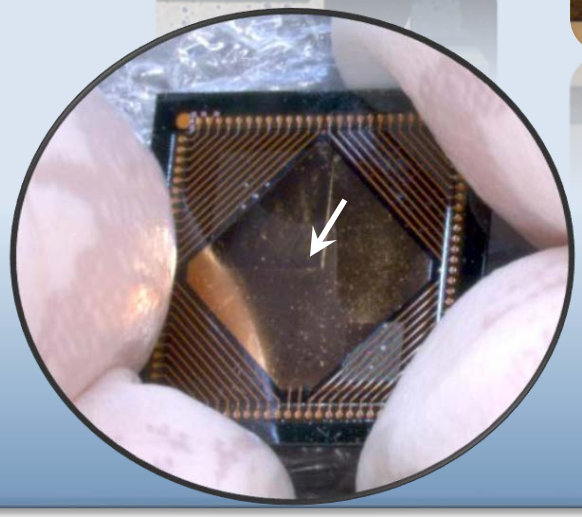
- Partial remove of Seed Layer (Ti or TiW) after Electroplating process, with a mask for wet-etch shaping





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

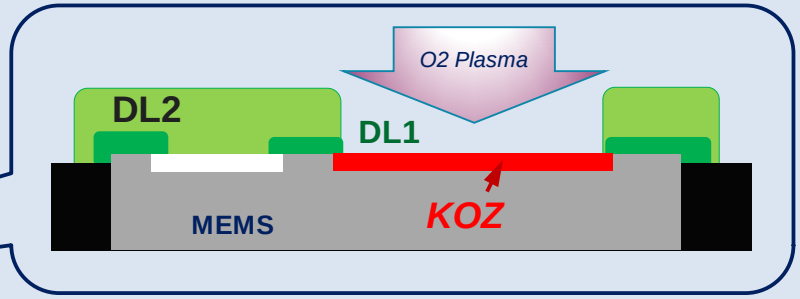
❖ Heterogeneous Dieletrics – Symbiotics effect

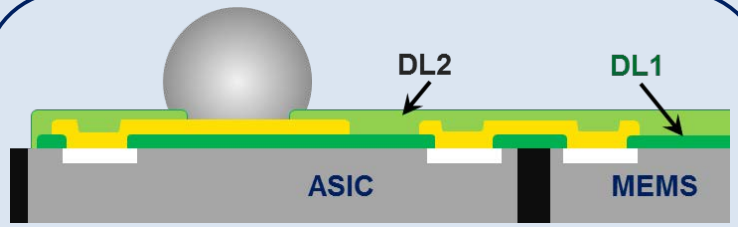
Advantages:

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

Examples:

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



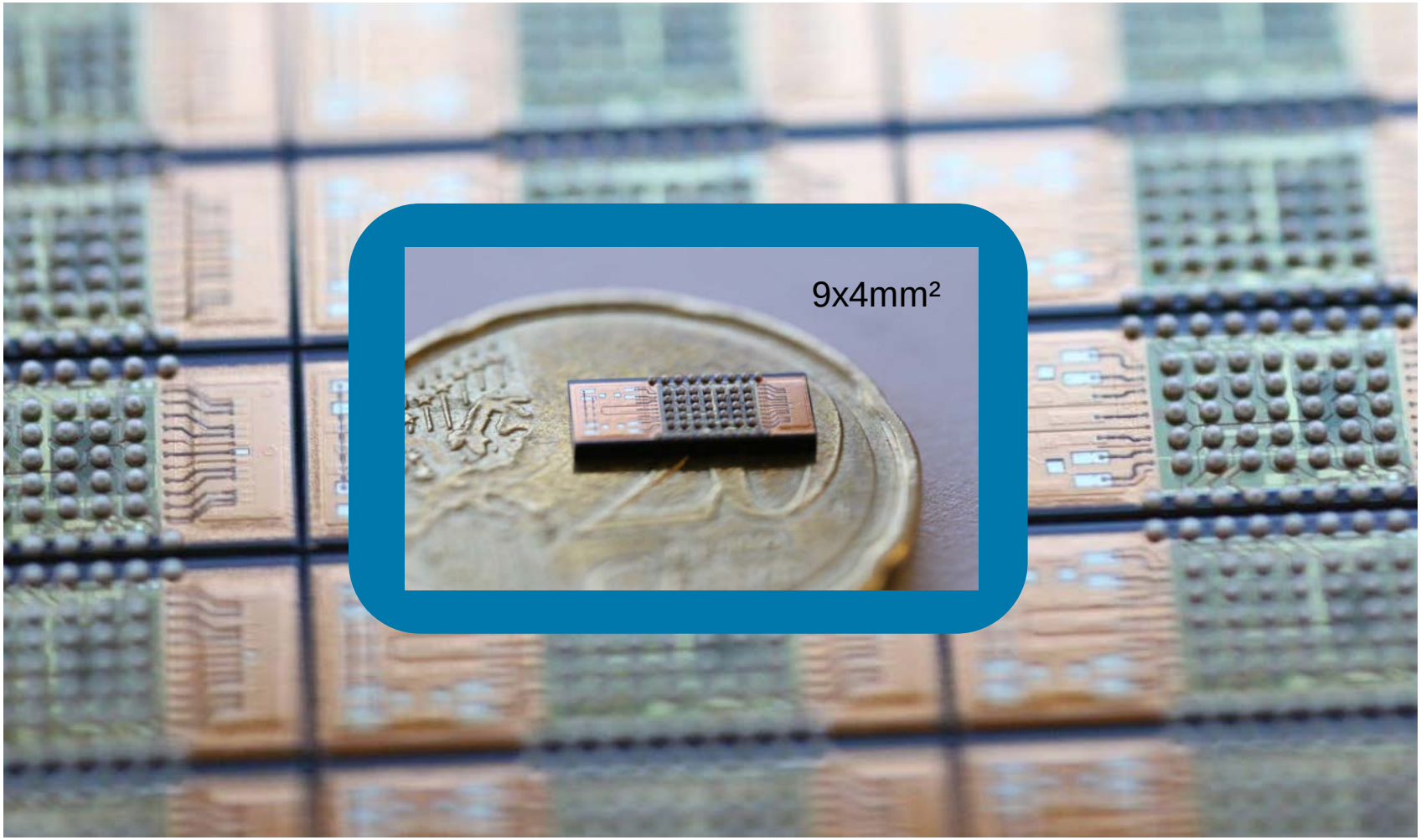


DL2 – High mechanical robustness, e.g., Polyimide

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

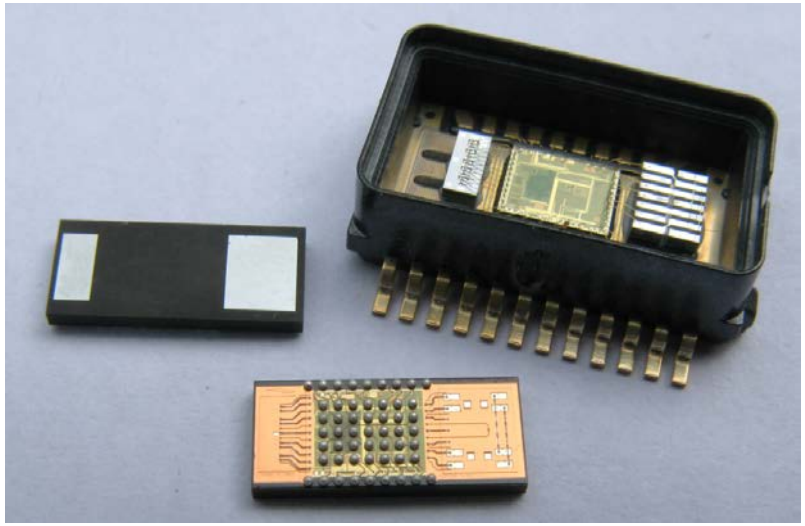
What‘s Next? Higher Integration Levels …

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



Heterogeneous System Integration on WL

Sensor and MEMS Integration in WLFO based WLSiP



WLFO (9x4mm²) developed for Inertial Combo-Sensor (gyro and three-axis accelerometer) for automotive ESC- and ADAS-systems; **achieved form-factor reduction of 20X** compared to currently commercially used conventional packaging method with pre-molded leadframe

Source:
NANIUM and MuRata, August 2016

WLFO (10x4mm²) with 8mm long fluid channel, developed for 5.5x1.2mm² bio-detection chip; utilization for high volume low cost disposable **biomedical microfluidic applications**

Source:
NANIUM and Magnomics, September 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 de-coupling from internal package stress;
  - **Thin-Film Shielding** using PVD seed layer for ECD as functional layer (is there anyway);
  - **Heterogeneous Dielectrics Stacking** (different materials with different functions).

Thank you for your attention

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