MEMS PACKAGING – INFINITE VARIETY OF BONDING APPLICATIONS

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AGENDA

SÜSS MicroTec

1 MEMS Market Trends

2 Bonding Applications

3 SUSS Bonder Product Portfolio

4 Summary

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1 **MEMS Market Trends**

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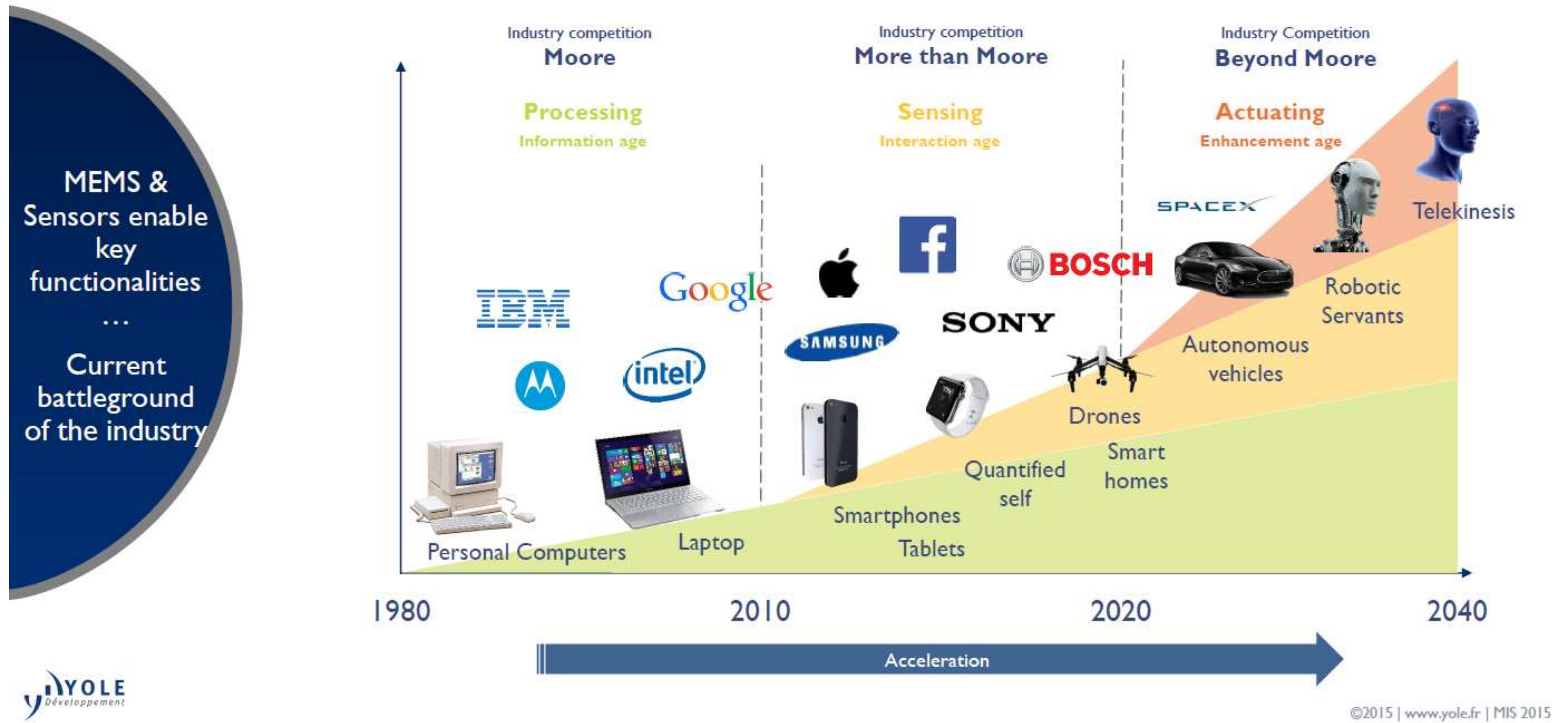


YOLE report "Status of the MEMS Industry" 2015, 12thEdition

MARKET TRENDS – PERMANENT BONDING MEMS

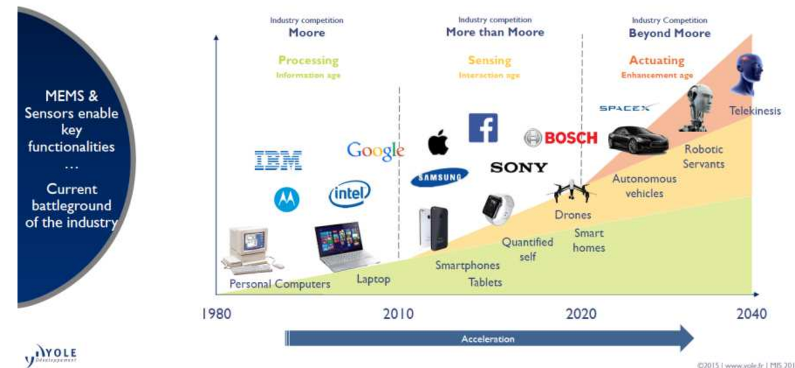
- MEMS / RF business is very fragmented and capacity expansion keeps going on with new devices entering into IoT, consumer and automotive applications (e.g. gas / pressure sensors)
- Automotive industry will continue to be the driver for new MEMS → target: autonomous car
- New packaging solutions are adopted for consumer products, e.g. TSV in Bosch BMA355
- Emerging MEMS foundries in China (150M$ investment predicted by Yole)
- Wafer size ratio 6-inch : 8-inch = 65 : 35 now and will be 60 : 40 in 5 years
- Roadmaps for 300mm MEMS line(s) under discussion (tsmc, Bosch, …); could be triggered by CMOS / MEMS on the same wafer and predicted for 2018 – 20
- CAGR expected at ~15 - 30% for next 5 years (depending on application)

2000–2020 MEMS MARKET ($M)

Continuous growth over 20 years (including glass/polymer-based microfluidics chips)

MEMS & SENSORS ROADMAP

From More than Moore towards Beyond Law



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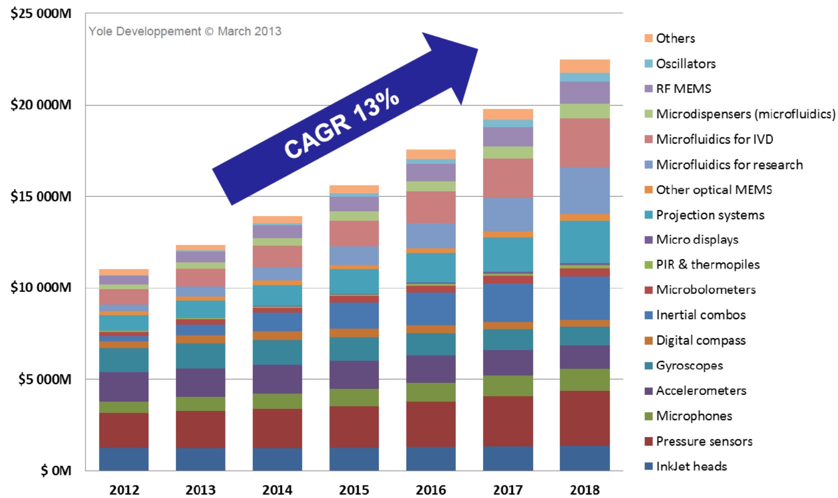
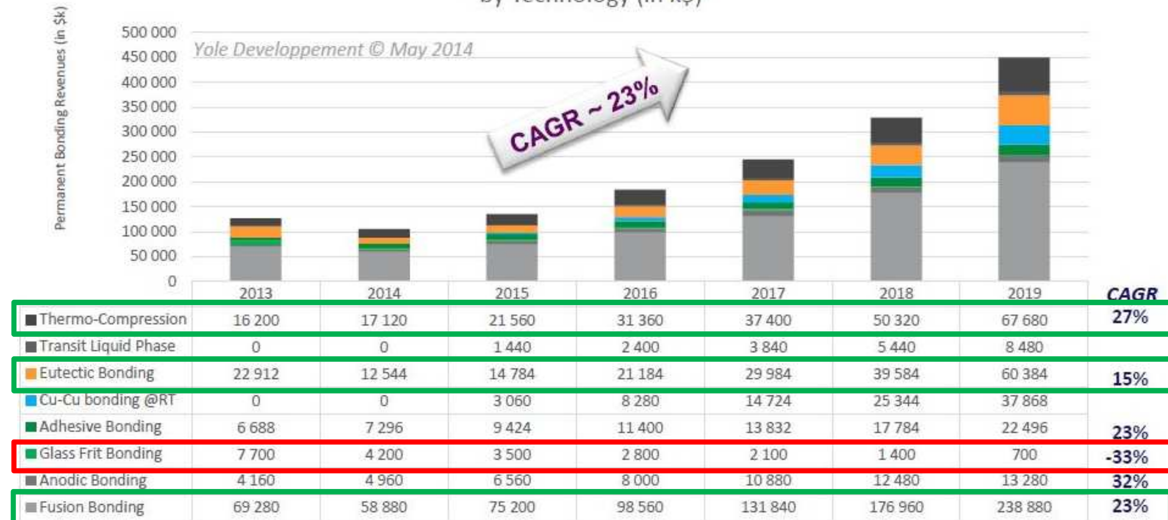
PERMANENT BONDING MARKET FORECAST
MOST RELEVANT MARKET - MEMS



MEMS Market and Application Trends:

- Strong market growth but huge segmentation
- Major new bonding technologies (MEMS):
  - Metal eutectic bonding, e.g. Au-Au
  - Thermocompression, e.g. AlGe
  - Fusion bonding
- Glass frit bonding volume is going down



	2013	2014	2015	2016	2017	2018	2019	CAGR
Thermo-Compression	16 200	17 120	21 560	31 360	37 400	50 320	67 680	27%
Transit Liquid Phase	0	0	1 440	2 400	3 840	5 440	8 480	
Eutectic Bonding	22 912	12 544	14 784	21 184	29 984	39 584	60 384	15%
Cu-Cu bonding @RT	0	0	3 060	8 280	14 724	25 344	37 868	
Adhesive Bonding	6 688	7 296	9 424	11 400	13 832	17 784	22 496	23%
Glass Frit Bonding	7 700	4 200	3 500	2 800	2 100	1 400	700	-33%
Anodic Bonding	4 160	4 960	6 560	8 000	10 880	12 480	13 280	32%
Fusion Bonding	69 280	58 880	75 200	98 560	131 840	176 960	238 880	23%

MARKET TRENDS

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Consumer market

Internet of Things: → more smart devices (watches, home appliances) require more sensors, actuators and passive **components**

- Trend to wearable and flexible electronics, key drive is "non breakable"
- Trend to integrate all type of sensors in the daily life at home (kitchen, etc.) and in the daily used electronic devices like smartphones
- General LED illumination from indoor to cars to portable devices like a flash light or beamer

Industrial market

Higher integration, with smaller packaging size. Higher reliability and less energy consumption.
Main driver is the automotive industry.

- Trend to more driver assistance systems and AI systems for autonomous function and interaction Radar / IR Sensors; Gyros and acceleration sensors; LED illumination
- Industrial automation with robots which are equipped with optical and mechanical sensors
- Higher requirements to life time and the operating range e.g. temperature range
- Trend to higher comfort and lower energy consumption

Health market

This market is asking for reliable, cheap and easy to use sensors

- Trend to local and fast analyzis of biological conditions
- Introduction of micro fluidic device for health product.

RESULTING CHALLENGES

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+ Smaller Form Factors

- Device scaling requires better hermeticity levels within the packages
- Energy efficiency
- Reduced Material consumption
- Metal Seals provide a pathway to achieve higher hermeticity with smaller seal ring geometries = smaller chip size
- Wafers sizes 4“ → 6“ → 8“ combined with new materials and material combinations

+ Integration with active devices

- Requires metal interconnects compatible with CMOS process/materials
- Must eliminate Na containing glass products
- Reduced Temperature budgets
- Migration to 200 mm

+ Superior performance

- Better sensitivity, higher resolution, higher-temperature robustness, …
- Precise bond layer thickness control, less post-bond residual stress,

+ High Yield and Short Process Cycle Time

- Precise temperature / force control
- Capability of fast heating and cooling
- Through put

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BONDING PROCESSES WITH TYPICAL BOND TEMPERATURES

Permanent Bonding

*TLP (Transient Liquid Phase) Bonding
**SLID (Solid-Liquid Inter Diffusion) Bonding

w/o Intermediate Layer — Traditional

- **Fusion**
  - **Plasma Activation**: UHV/RT, Hydrophilic/200℃
  - **Wet Chemical**: Si/SiO_2/1000℃
- **Anodic**: Pyrex/370℃,400V

w/ Intermediate Layer — Future Trend

- **Eutectic**: AuSn/290℃, AuSi/390℃, AlGe/430℃, AuGe/380℃ ...
- **Metal Diffusion**: Au-Au/300℃, Al-Al/400℃, Cu-Cu/350℃
- **TLP*/SLID**: CuSn/270℃, AuIn/180℃
- **Glass Frit**: Pb-free/450℃
- **Adhesive**: BCB/250℃, Polyimide/300℃, Epoxy/160℃, Silicone/200℃ ...

Eutectic Type	Eutectic Composition	Eutectic Temp/ Melting Temp.
Au-In	0.6/99.4 wt%	156°C
Cu-Sn	5/95 wt%	231°C
Au-Sn	80/20 wt%	280°C
Au-Ge	28/72 wt%	361°C
Au-Si	97.1/2.9 wt%	363°C
Al-Ge	49/51 wt%	~420°C

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BOND PROCESS AND FIELD OF USE

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- MEMS processes from classic to state of the art to future
- LED production
- CIS high volume / low production costs

Requirements to Bonding equipment:

- from single process requirements to a multi process environment
- Temperature tolerances / uniformity
- Bond force tolerances / uniformity
- Environment

Legend: Production / On development

			MEMS	Advanced Packaging			LED		SOI
				CIS		TSV stacks	Carrier	HB-LED	
				BSI	Capping WLP				
Permanent Bonding	Direct bonding	Fusion bonding	Production	Production		Production			Production
		Anodic Bonding	Production					Production	
	Indirect bonding	Glass Frit Bonding	Production						
		Adhesive bonding	Production	Production	Production				
		Cu-Cu/ oxide hybrid bonding @RT		On development		On development	On development		
		Solder bonding: Eutectic Bonding	Production			Production	Production		
		Solder Bonding: TLP	On development						
		Thermo-compression	Production			Production	Production		

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Au-Au Diffusion Bonding

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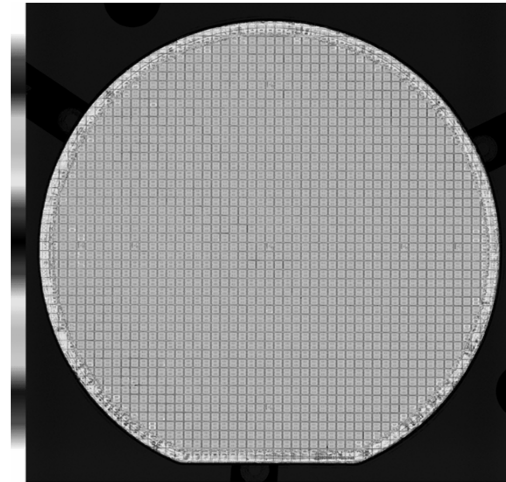
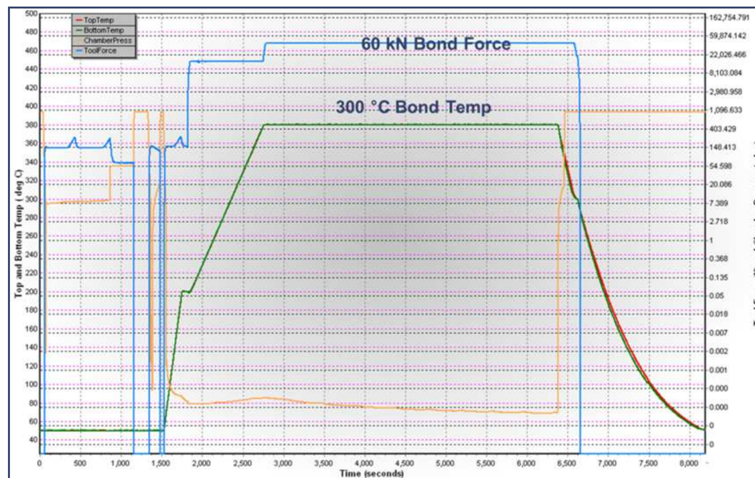
+ **Properties**
  - No oxide removal needed
  - Plasma cleaning (to remove organic contamination) to reduce bond temp.

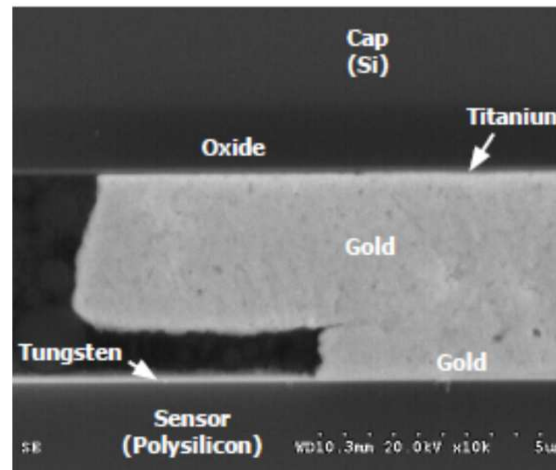
+ **Process Condition**
  - Temperature: 300 – 350 ° C
  - Force: 20kN
  - Hold time: 30 min.

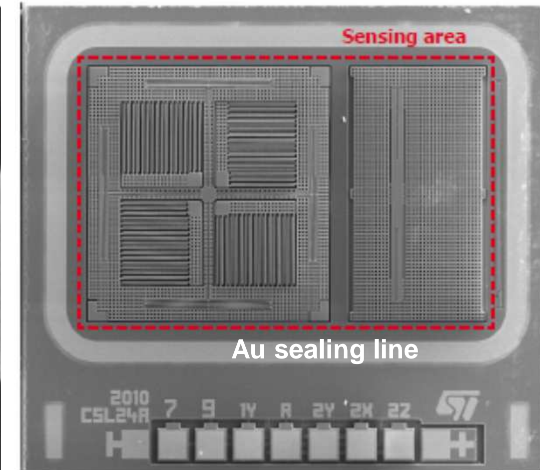


SAM image of a 6" Au-Au bonded pair.



Au-Au Process Curve





Au-Au bonding

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Cu-Cu Diffusion Bonding

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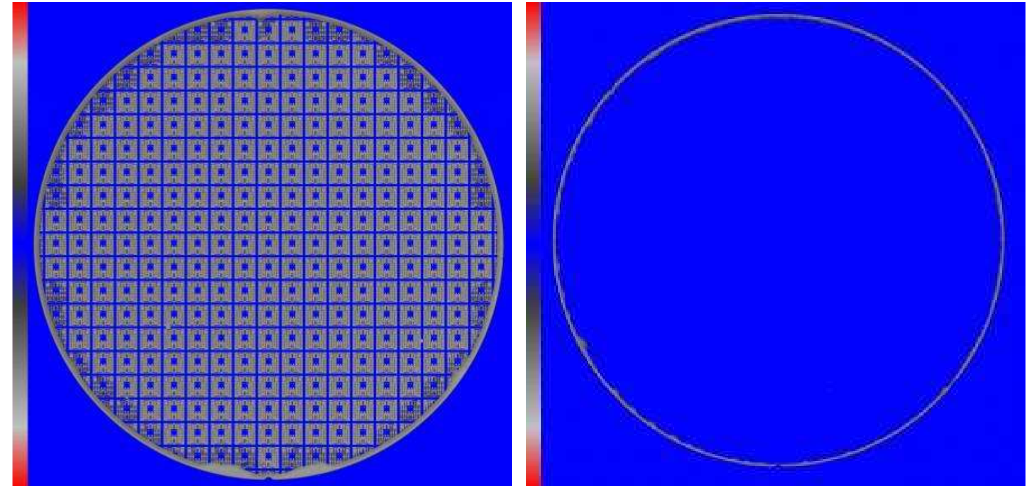
Properties

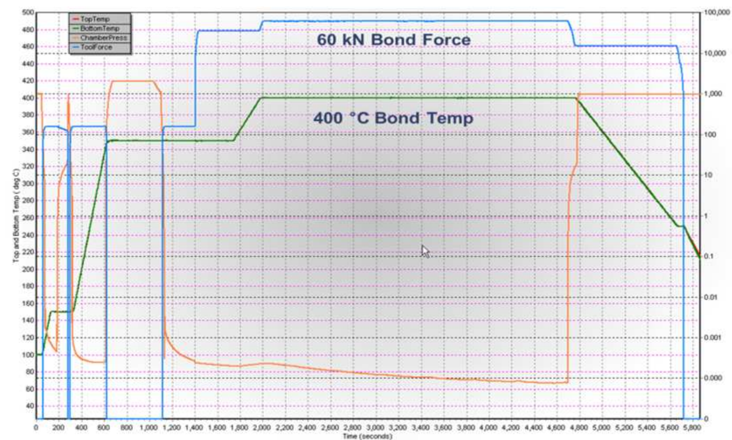
- Surface oxide removal needed
  → formic acid, forming gas, chemical treatment (i.e. EKC)

Process Condition

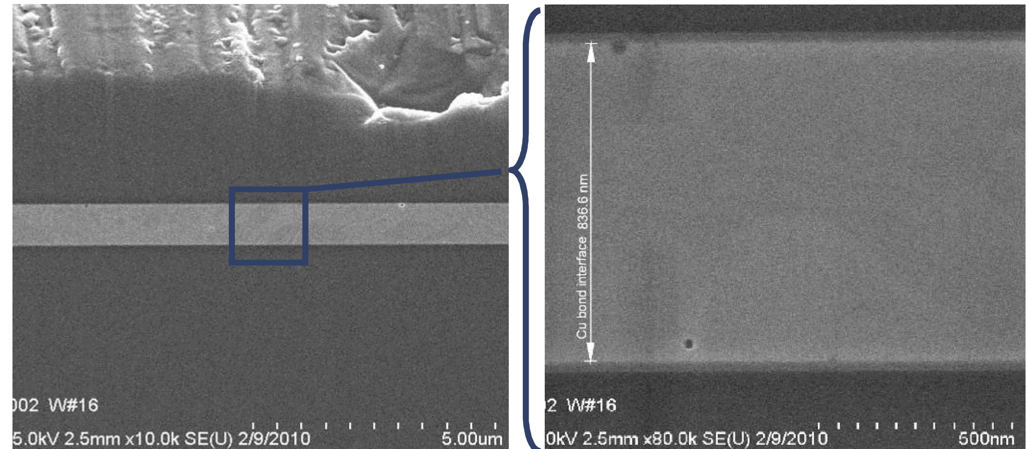
- Temperature: 250 – 450 ° C
- Force: 20-60kN @ 8"
- Hold time: 30 min.
- Forming gas pre-treatment



SAM images of a blanket and a patterned Cu-Cu bonded pair.



Cu-Cu Process Curve



SEM cross-section of a bonded Cu blanket pair. Each wafer has 300nm of ECU Cu/ 100nm PVD Cu/ 20nm Ti seed layer.

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AuSn Eutectic Bonding

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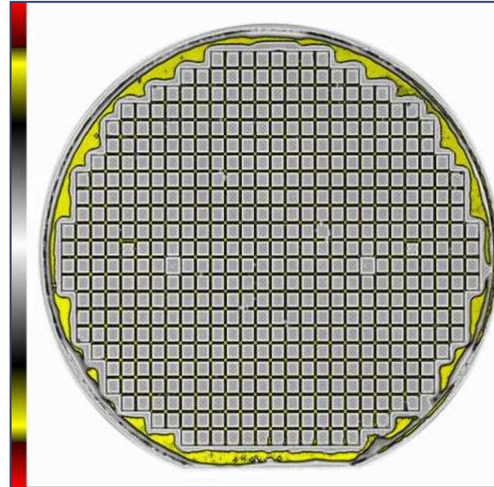
+ Properties

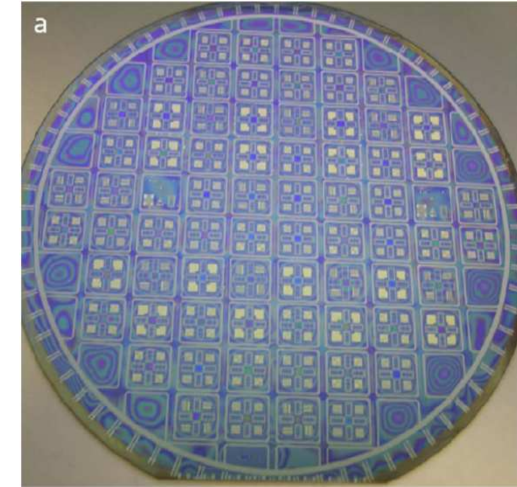
- Composition Au:Sn = 80:20 wt%
- Eutectic point = 280 °C
- Fast heating/cooling ramp is preferable

+ Process Condition

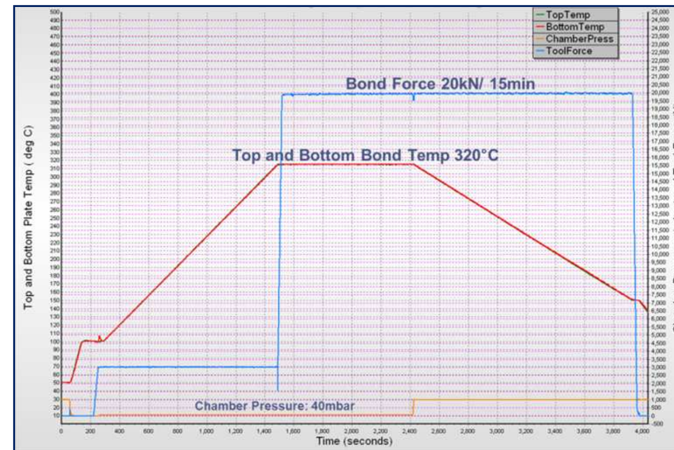
- Temperature: 290 - 320 °C
- Force: 20 kN
- Hold time: 15 min.



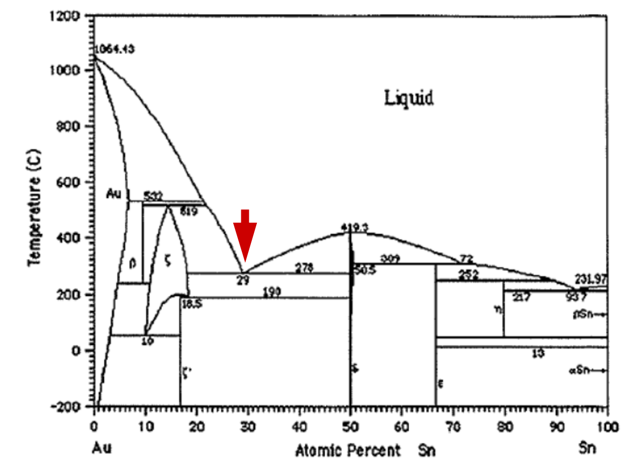
SAM image of an aligned 6" AuSn bond.



N. Belov et al., "Thin-layer Au-Sn solder bonding process for wafer-level packaging, electrical interconnections and MEMS applications."



Au-Sn Process Curve



Au-Sn phase diagram

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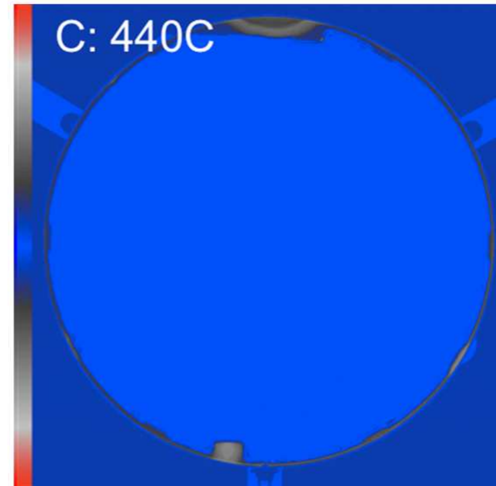
Al-Ge Eutectic Bonding

Properties

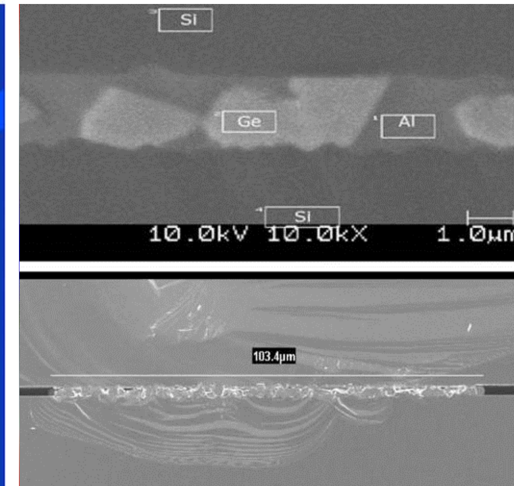
- Composition Al:Ge = 49:51 wt%
- Eutectic point = 419 ° C
- Al layer of ASIC wafer can be used
  → suitable for MEMS/ASIC integration
- Fast cooling needed

Process Condition

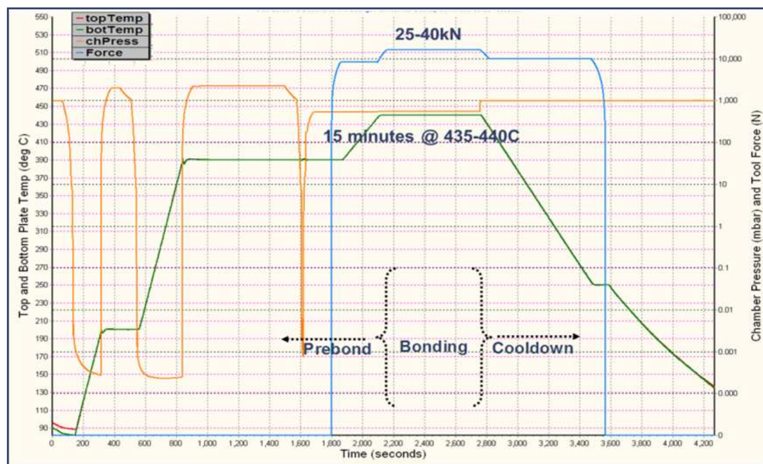
- Temperature: 430 – 440 ° C
- Force: 10-40kN@8"
- The high force is typically needed to break the Aluminum oxide film that grows on the Al.
- Hold time: 6-15 min
- Fast ramp-down has been found to be helpful in providing good eutectic formation.



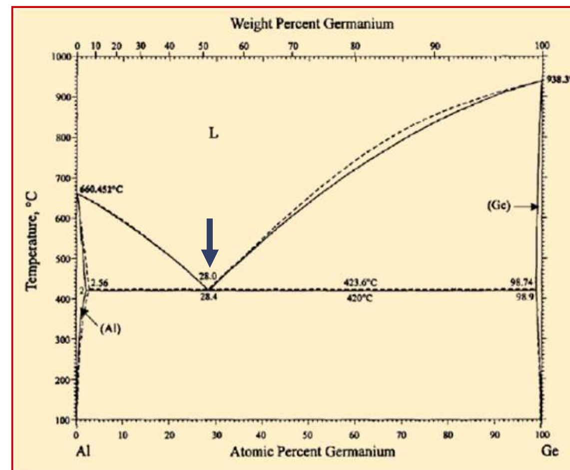
SAM images of a blanket AlGe bonded pairs showing a void-free bond.



SEM cross-sections for AlGe bonds. Bond interface cannot be identified due to good eutectic melt.



Al-Ge Process Curve



Al-Ge phase diagram

InvenSense ITG-3200 cross-section (Courtesy of System Plus Consulting)

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PERMANENT BONDING: SB8 GEN2 SYSTEM OVERVIEW

- **Up to 200mm wafers**
  - Small pieces, square substrates possible
- **Bond Temperature**
  - Independent resistive SiN top- and bottom heater with active air cooling
  - Max. Temperature 550°C
  - Temperature uniformity to ±1,5% full scale
  - Temperature control accuracy at set point ±3°C
- **Bond Force**
  - Up to 20kN
  - Repeatability ±2%
- **Chamber Pressure**
  - Vacuum 5.0E-05 mbar
  - Over pressure to 2 bar, 3 bar absolute
- **Options**
  - SSR Sequential Spacer Removal
  - Process gas selection manual / automatic
  - Formic acid
  - Cool plate option

- **New Features:**
  - Advanced cooling control system
  - Advanced bond force control system
  - Advanced top tool position stability
  - New Power and control systems

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OVERVIEW WAFER BONDER PRODUCT PORTFOLIO Q2/2015

Bond Aligner

MA/BA8 Gen3
BA8 Gen3

MA/BA8
BA8

Wafer Bonders

2 load port configuration

4 load port configuration

XBS300
Temporary Bonder
200/300mm

2 load port configuration

4 load port configuration

XBC300Gen2
Debonder and Cleaner
200/300mm

Fab

Lab

PL8 / PL12(T)
Plasma Processing and Release Layer Deposition up to 12“

CL8
Single- / Dual Side Wafer Cleaning and Fusion Bonding up to 8“

SB6/8 Gen2
Universal Bonder
up to 8”, 20kN

LF12
Temp. Bonder
8”/12”

DB12T
Mech. Debonder
up to 12”

ELD300
Excimer Laser Debonder
up to 12”

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SUMMARY

- New devices & applications
  - New large volume markets (wearables, IoT…)
  - Pressure sensors for consumer
  - New MEMS device such as gas/chemical, humidity, pulse sensors
  - A shift in value from Si (material) to the full solution (MEMS+CMOS!)

- More open platforms ease development of new applications of established devices
  - standard interface to connect all kinds of different sensors to the controller

- Opportunities still for new types of MEMS devices
  - MEMS devices will find additional ways to replace conventional mechanical parts with silicon e.g. MEMS autofocus and autospeakers

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