IEEE SF Bay Area MEMS & Sensors Chapter

November 19, 2014

http://sites.ieee.org/scv-mems/

Past Meetings

2014	TITLE	Guests	IEEE	Total
Jan. 22nd	Emerging Trillion Sensors Movement (Dr. Janusz Bryzek)	39	41	80
Feb. 26th	FBAR and FMOS Technology from a MEMS Perspective (Dr. Stephen Gilbert) Advanced Metal Eutectic Bonding for High Volume MEMS (Sumant Sood)	35	35	70
Mar. 18th	Coupled-Filed MEMS Simulations (Dr. Metin Ozen)	25	7	32
April 30th	MEMS Wars: A New Hope (Dr. Kurt Petersen)	37	39	76
May 28th	MEMS in SEMI – The Role of a Global Association in Advancing the MEMS Industry (Bettina Weiss)	11	12	23
June 25th	MEMS on Alternate Substrates: A Case Study with Biometric Sensors (Dr. KG Ganapathi)	21	29	50
July 23rd	AdCom/Volunteers meeting	11	10	21
Aug. 27th	RF MEMS: From Research to Products (Prof. Gabriel Rebeiz)	30	46	76
Sept. 24th	IEEE MEMS Happy Hour (No invited talk).	12	12	24
Oct. 22nd	MEMS-enabled microscopes for in-vivo studies of cancer biology	29	31	60
	Total	**250**	**262**	**512**

IEEE

Officers and Program Committee

The MEMS and Sensors Chapter is run by volunteers organized as Officers (elected every year), Program Committee, and Advisory Board. If you are interested in volunteering, please send an email to SFBA-MEMS-OFFICERS@listserv.ieee.org.

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Dr. Kurt Petersen, President, KP-MEMS Inc.

Meeting Sponsor

Complimentary food and refreshments sponsored by SoftMEMS Inc.

Thanks to
Dr. Mary Ann Maher,
President / CEO

Upcoming Meetings

Feb. 25th, 2015 (Wednesday) 7:45 PM to 8:45 PM. **Note: NEW LOCATION!!!**
Title: Building Successful MEMS Company: From Start to IPO
Speaker: Mr. Steve Nasiri, Nasiri Ventures
Location: Texas Instruments Building E Conference Center, 2900 Semiconductor Dr., Santa Clara, CA 95052 (Directions)
Food: Pizza and beverages will be available at 7:15 pm for a **$5 donation** at the door.
Sponsor: Sponsorship opportunities are available. Interested parties please email SFBA-MEMS-OFFICERS@listserv.ieee.org

Mar. 25th, 2015 (Wednesday) 5:30 PM to 7:30 PM. Online registration coming soon.
IEEE MEMS and Sensors Happy Hour
Location: Steelhead Brewing Company, 333 California Drive, Burlingame, CA 94010
This is a no-host event. Please pay for your own food and drinks.
Sponsor: Sponsorship opportunities are available. Interested parties please email SFBA-MEMS-OFFICERS@listserv.ieee.org

Invited talk by Mr. Holger Doering

Nov. 19th, 2014 (Wednesday) 7:45 PM to 8:45 PM.
Title: Innovative Pressure Sensing Solutions.
Speaker: Mr. Holger Doering, COO, Silicon Microstructures, Inc.

Holger Doering is the Chief Operating Officer (COO) at Silicon Microstructures Inc (SMI). He joined SMI in 2007 as a Consultant in Operations, then took over the VP Operations position in 2008 and was promoted to COO in 2011.

He is responsible for Production, Process Engineering, IT, Assembly, Test, and Facilities Management. He started at ELMOS in 1995 as a Process Engineer and became Production Engineering Manager in 1997. From 1999 he was responsible for Production, Process Engineering and Equipment Maintenance in the Plasma-Module of the ELMOS fab. In 2003 he began to transfer the 0.8 µm process from the 6-inch fab in Dortmund to the 8-inch line of the joint ELMOS/ Fraunhofer IMS fab in Duisburg and in 2005 became responsible for the complete 8-inch Operations in Duisburg.

Holger holds a diploma in Electrical Engineering from the University of Dortmund (Germany) with a focus on semiconductor manufacturing. His diploma thesis work was carried out at ELMOS in 1994 where he developed a CMOS-compatible process module to produce monolithic integrated piezoresistive pressure sensors in a EU-funded project. .

Innovative Pressure Sensing Solutions

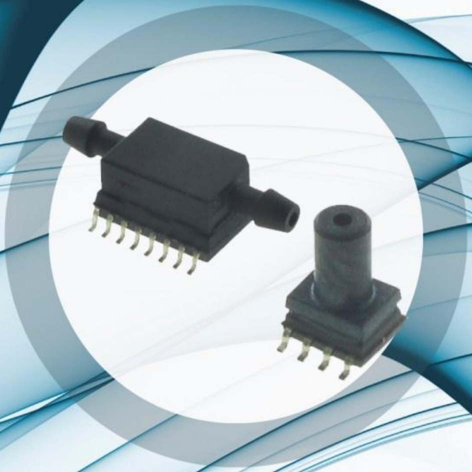
Abstract: Silicon Microstructures Inc (SMI) is a premier semiconductor sensor company developing and manufacturing MEMS-based pressure sensors for automotive, medical, and industrial markets. It has a long history rooted in Silicon Valley since 1991. This talk will present the recent developments in pressure sensor R&D and production at SMI. It will cover the following aspects:

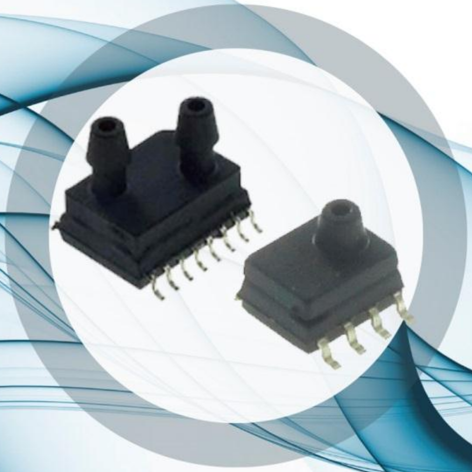
1. Company overview on products, R&D and Manufacturing capabilities
2. DRIE etch is essential for pressure sensor miniaturization. This talk will present SMI ultra-small pressure sensor development with DRIE process.
3. Automated Optical Inspection (AOI) for defect detection in MEMS devices. This talk will cover the application criteria and inspection capabilities.

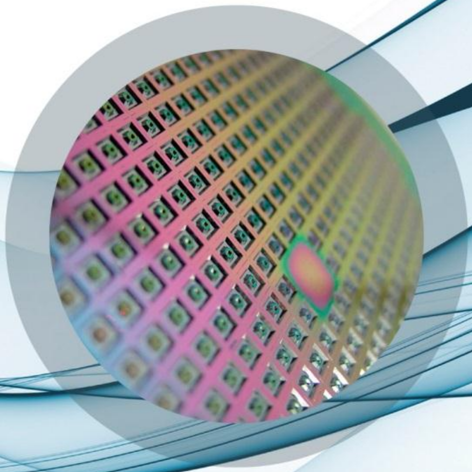
Innovative Pressure Sensing Solutions

Created by Dr. Shaoxin Lu, Abhishek Davray, Raul Figueroa and Holger Doering

November 18, 2014







Supporting customer success in Automotive, Medical and Industrial markets since 1991

SMI Mission

PRESSURE SENSORS

Enabling our customers' success in improving health, safety, and the environment by providing creative pressure sensing solutions leveraging our leading MEMS technology.

Content

1) SMI Company Overview

2) DRIE Etch for MEMS pressure sensor miniaturization

3) Automated Optical Inspection (AOI) for
defect detection in MEMS Devices

Content

1) SMI Company Overview

2) DRIE Etch for MEMS pressure sensor miniaturization

3) Automated Optical Inspection (AOI) for defect detection in MEMS Devices

Pioneering Innovation and Expertise

Leader in MEMS-based Pressure Sensing Solutions

- **Lowest pressure**: down to 4 mbar range (1.5” H_2O)
- **Media Resistant**: noble metallization w/ backside entry.
- **Smallest size**: down to 0.9 mm × 0.25 mm × 75 µm

23 years of development and manufacturing expertise

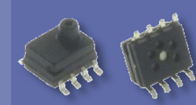
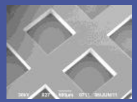
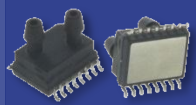
- 100% subsidiary of Elmos Semiconductor AG (Germany)
- More than **500M sensors sold** into Automotive, Medical, Consumer, HVAC and Industrial markets

Captive Wafer Fab in Silicon Valley (USA)

All functions in one location:

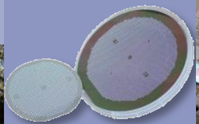
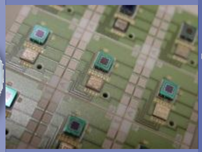
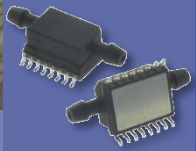
- R&D, Process Development
- Logistics & Quality Control

Company History


1991	2001	2002	2004	2006	2007	2012	2013	2014
Founded in Fremont (CA)	Acquired by elmos in Dortmund (Germany)	Acquisition of MEMS fab, relocation to Milpitas (CA)	Start of 6“ MEMS production.	TS16949 Certification SO-16 package platform	SO-8 package platform	Die Portfolio Refresh	New Product Introductions SM9541	New Product Introductions SM68E



Process & Quality - Manufacturing Processes

PRESSURE SENSORS

Superior Quality and Long-Term Supply

ISO/TS 16949:2009 (Automotive)
ISO 9001:2008
ISO 14001:2004 (Environmental)

Foundry
Create electrical components

Etch Plant
Create mechanical components

Die Plant
- Final probe
- Singulation
- Inspection

Packaging
Housing of pressure sensor and ASIC

Test
- Calibration & compensation
- Final test

Frontend Processes (Foundry, Etch Plant) · Backend Processes (Die Plant) · Assembly & Test (Packaging, Test)

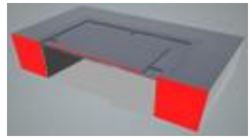
State of the Art MEMS Manufacturing

Fully Equipped Wafer Fab

Product Overview - Areas of Expertise

SMi PRESSURE SENSORS

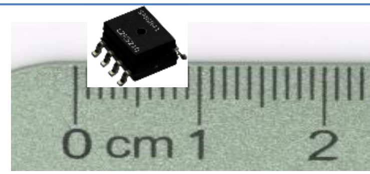
Low Pressure



Typical Applications:
Medical (CPAP),
Industrial (HVAC)

Low Pressure Sensor: 4 mbar
SMI patented Technologies

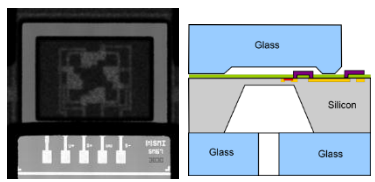
Ultra Small



Typical Applications:
Automotive (TPMS),
Industrial (Barometric)

Ultra-Small Die and Packaged Sensor for OEM Use

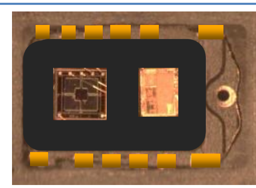
Harsh Environment



Typical Applications:
Automotive transmission,
Diesel Particle Filter (DPF)
Exhaust Gas Recirc. (EGR)

Harsh Environment Pressure Sensor Die

Signal-Conditioned

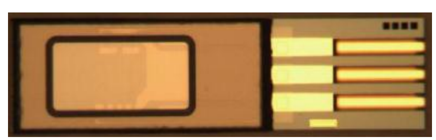


Typical Applications:
Respiration
Ventilators
HVAC & Pressure
Transmitters

Dual Chip Intelligent Pressure Sensor, SO-16 Package

Custom Design

0.24 mm



0.9mm

Custom Pressure Sensor for Arterial Catheter:
(900 x 240 x 75 µm)

Markets and Applications

Medical

Respiration

- CPAP
- Ventilation

Hospital Beds

Fluid Evacuation

Blood Pressure

Wound Therapy

Industrial

HVAC

VAV Controllers

Pressure Transmitters

Liquid Level & Pressure

Barometric Pressure

Process Control

Refrigeration

Automotive

Tire Pressure Monitoring Systems (TPMS)

Manifold Air Pressure (MAP)

Diesel Particulate Filter (DPF)

Exhaust Gas Recirculation (EGR)

Oil Pressure

Side Air Bag

Transmission Oil Pressure

Seat Ergonomics

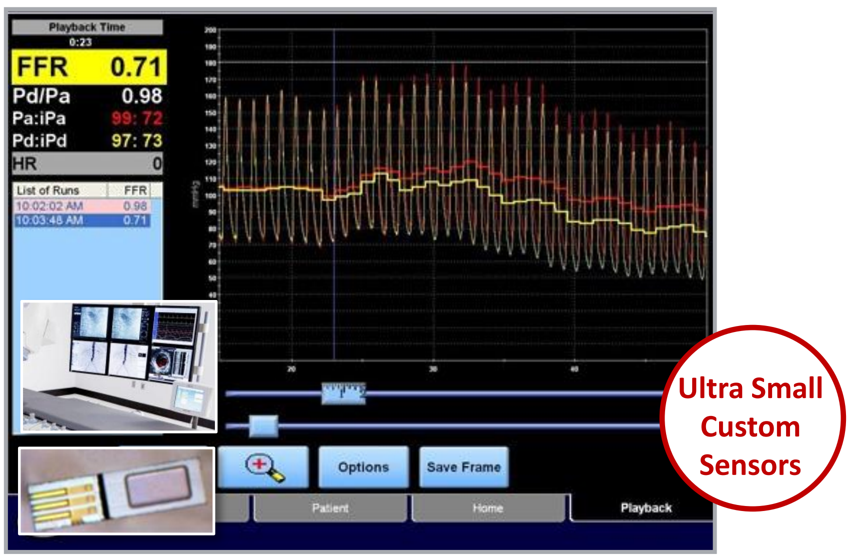
Applications - Medical

Sleep Apnea Treatment

- CPAP (Continuos Positive Airway Pressure)
- Sleep disorder with abnormal pauses in breathing
- CPAP uses mild air pressure to keep an airway open

-> Feedback of applied air pressure in the mask

-> µC manages compressor to generate required pressure



Interventional Cardiology

FFR (Fractional Flow Reserve) guide-wire based procedure

-> accurately measure blood pressure and flow through a specific part of the coronary artery

-> assess whether or not to perform angioplasty and / or stenting on "intermediate" blockages.

-> FFR reduces procedure cost & increases success rate

-> Biocompatibility and blood as harsh environment

Applications - Industrial

Pressure Transmitters/HVAC

- HVAC (Heating, Venting, Air Conditioning)
- Differential pressure transmitters to detect over- / under- and differential pressure.

-> Monitoring and control of ventilation and air-conditioning, fans and filters.

-> requires measurement of very low-pressure signals

Valve Positioner

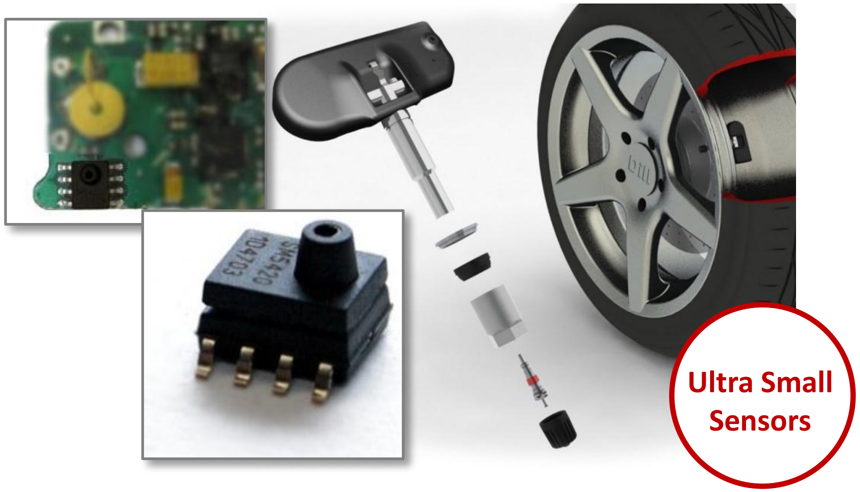
- Intelligent digital valve controllers
- Remote ambient pressure measurement

-> valve positioning & monitoring of supply pressure

-> support advances in building technology and energy efficiency mandates

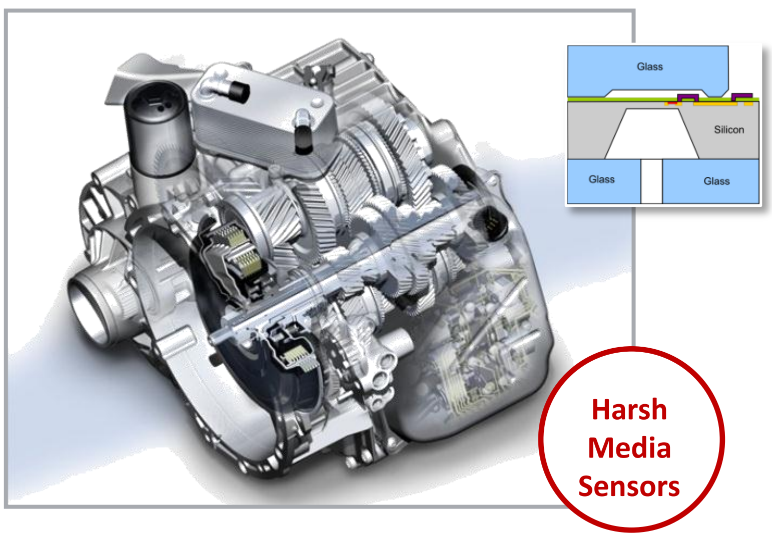
Applications - Automotive

PRESSURE SENSORS



Tire Pressure Monitoring Systems (TPMS)

- Ultra small absolute pressure sensor for integration in tire inflation valve
- Legislation in USA (2007) requires all new cars to be equipped with TPMS.
- 2013 – Europe started with 100% compliance in 2014.
- 2014 – South Korea confirmed legislation.
- 2017 – Japan intends to legislate.
- 2018 – China intends to legislate.
- 2019 – India intends to legislate.



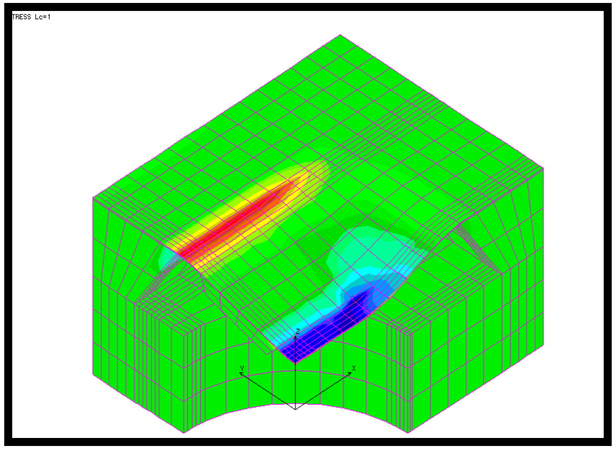
Dual-clutch Automated Manual Gearbox

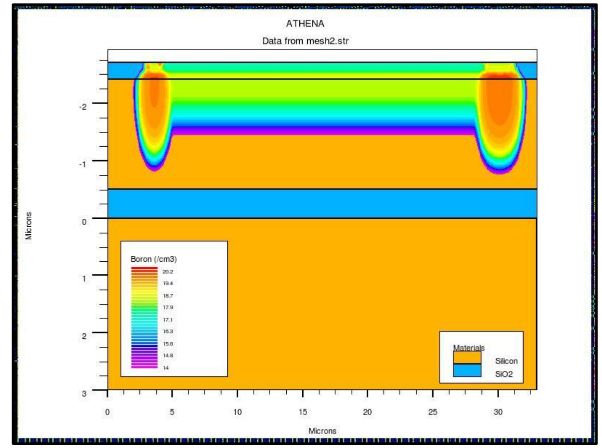
- Backside entry absolute pressure sensor with harsh media compatibility
- Direct contact to hot transmission oil at high pressure in the application

New DSG (Direkt Schalt Getriebe) transmission offers

- better fuel economy
- extremely fast shift times
- no loss of torque during gear shifts
- Pressure sensors monitor correct operation.

Design & Simulation of Advanced Pressure Sensors



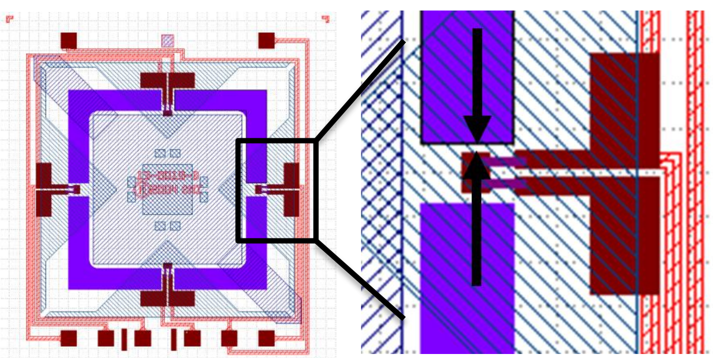


Finite Element Modeling

- Optimize structure and predict results
- Mechanical stress and strain
- Resistance and temperature

Process and Device Modeling

- Determine doping profiles from process
- Predict electrical characteristics of devices
- 2D device modeling

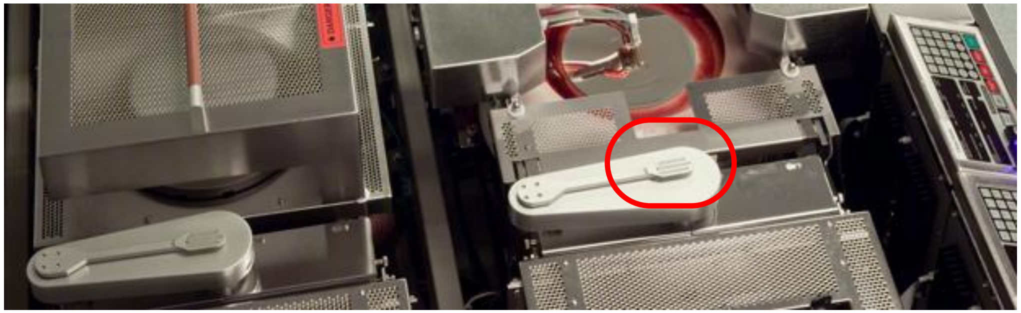


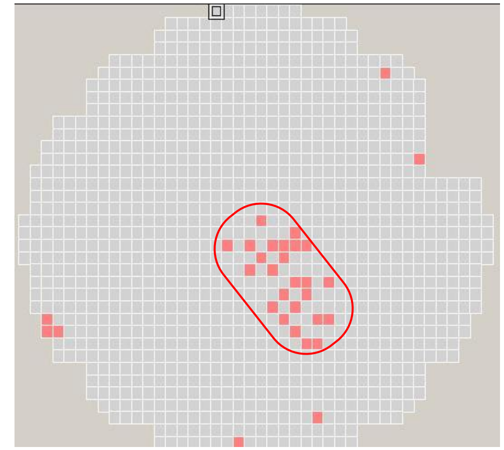
Design Rule Checking of Device Layout

- Verify placement tolerances of electrical components
- Check predicted distances between electrical and mechanical components of MEMS structures

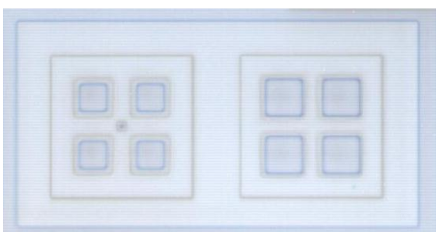
Process Requirements of Advanced Pressure Sensors

- Double side polished wafer processing – defects on wafer backside from conventional handling arms





- Front to Back Alignment and Overlay / IR Measurement



- Stable micro machining technology:
  - Deep Reactive Ion Etching / KOH Etching using Electro Chemical Etch Stop

Content

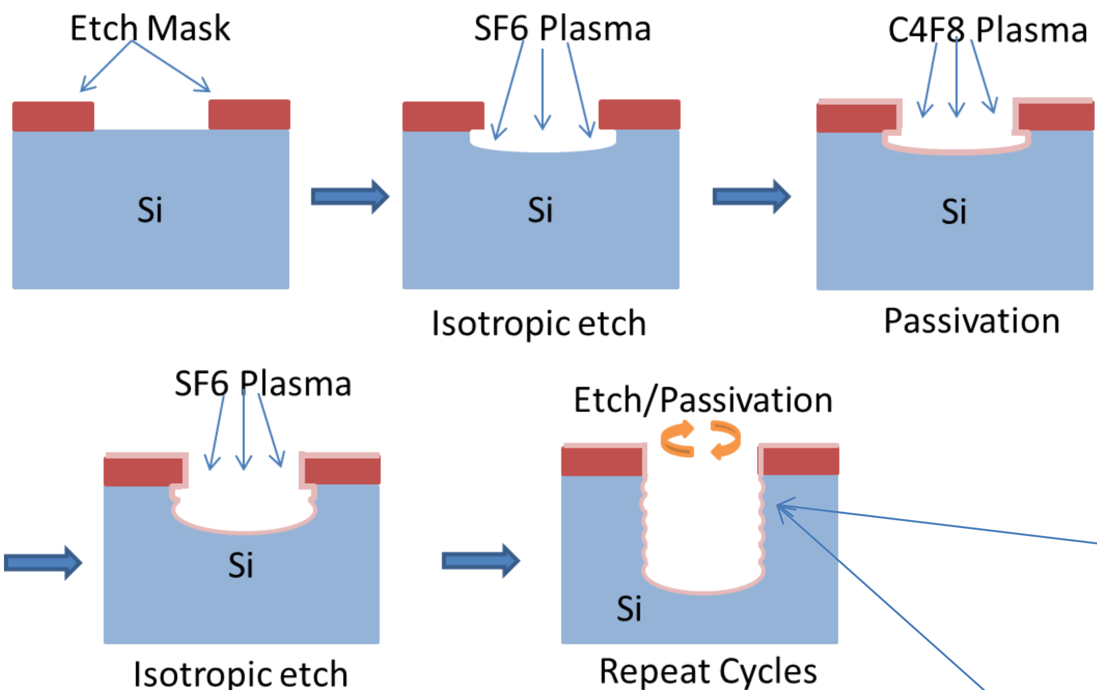
1) SMICompany Overview

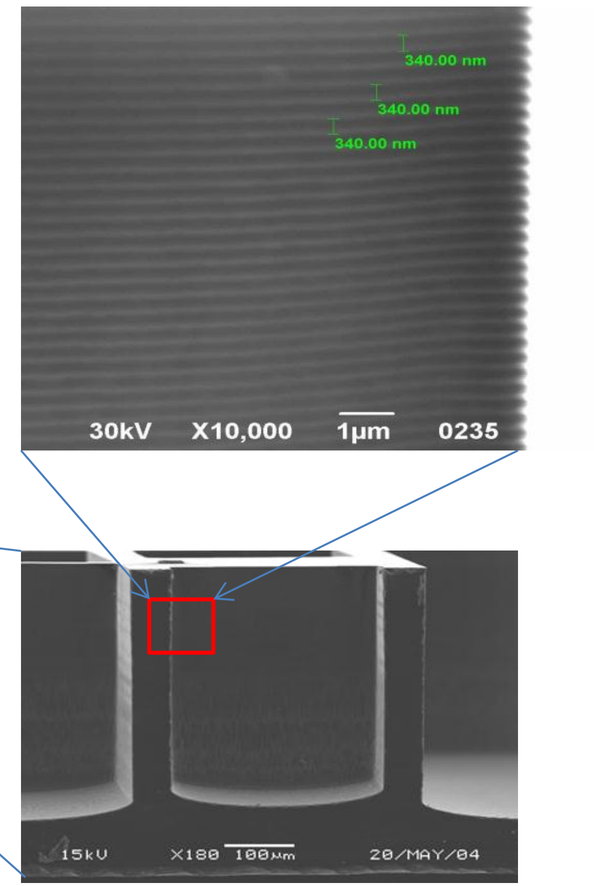
2) DRIE Etch for MEMS pressure sensor miniaturization

3) Automated Optical Inspection (AOI) for defect detection in MEMS Devices

PRESSURE SENSORS

Bosch Process





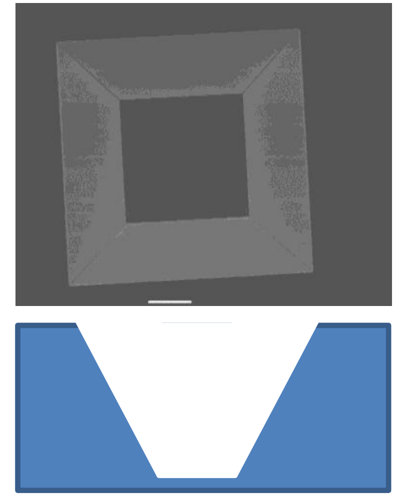
- Silicon anisotropic etching based on etch/deposition cycle by cycling SF6/C4F8
- Silicon etch in SF6 cycle
- Passivation of sidewalls with polymer in C4F8 cycle

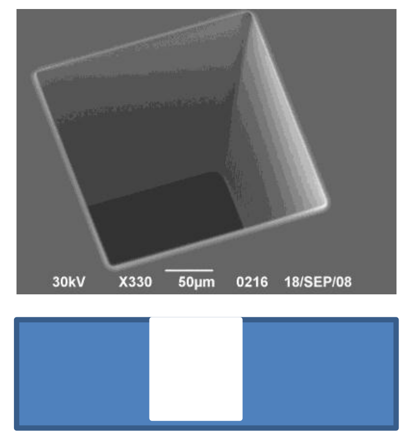
DRIE vs KOH Etch

Benefits for DRIE

- Precise control of membrane thickness
- Area reduction for sensors
- Bigger mounting surface, no constraint wafer necessary
- Better accuracy / repeatability

	KOH	DRIE
Membrane Thickness	Controlled by Etch rate / Etch stop	Defined by SOI starting material
Sensor Size	Bigger (with sidewall slope)	Smaller (vertical sidewall)
Mounting Area (% of die)	Smaller (with sidewall slope)	Bigger (vertical sidewall)
Accuracy/Repeatability	Worse (TTV, Etch rate variation)	Better (SOI material control)
Cost	Less expensive	More expensive (factor 3 x variable cost)
Throughput	Batch process (factor 2 x faster than DRIE)	Single wafer process


KOH



DRIE

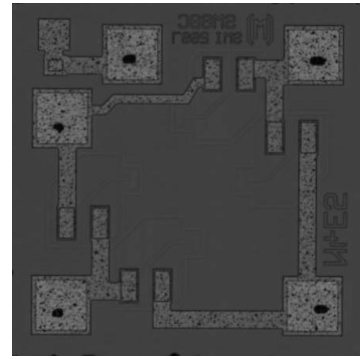
Products at SMI that benefit from DRIE

- Ultra small pressure sensors (SM68) for TPMS applications:

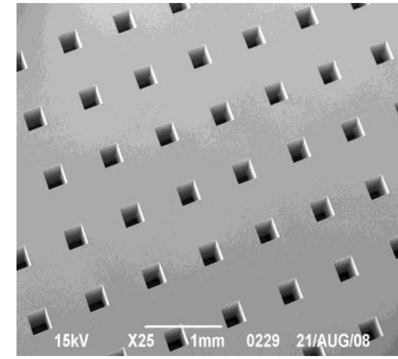
  -> Pressure range from 15 -150 psi

  -> DRIE formed cavity on backside enabling very small sensor design on SOI

  -> size reduction of about 60% compared to non DRIE etched sensors



SM68 sensor



SM68 sensor DRIE backside cavities

- Ultra Low pressure sensors (SM95) for medical and industrial applications

  -> Pressure range from 0.15 to 1.5psi

  -> Backside cavity and pressure range adjustment with DRIE process

SM95 wafer in front of a lamp showing semitransparent membranes formed by DRIE

- Covered under Patents US 7,111,518 and US 8,381,596 B2

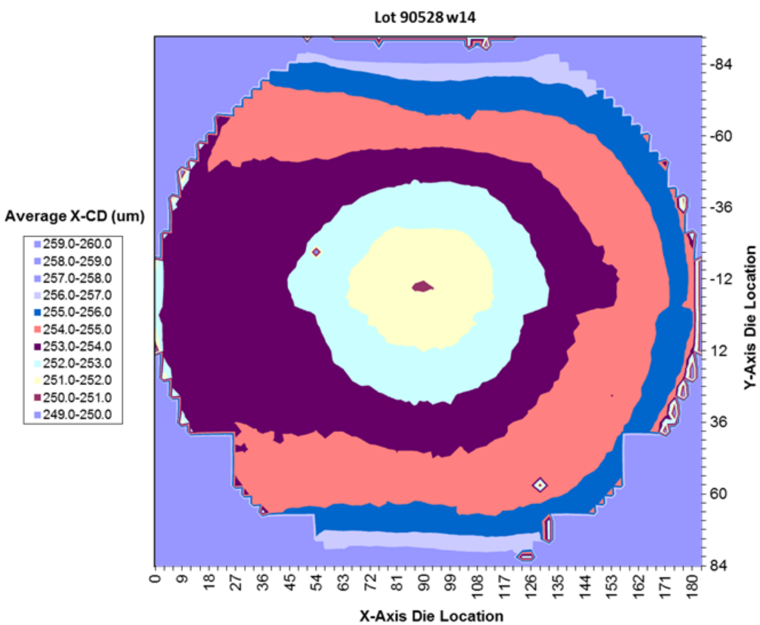
Compensation of DRIE non-uniformities

- CD / Overlay run-out towards the wafer edge

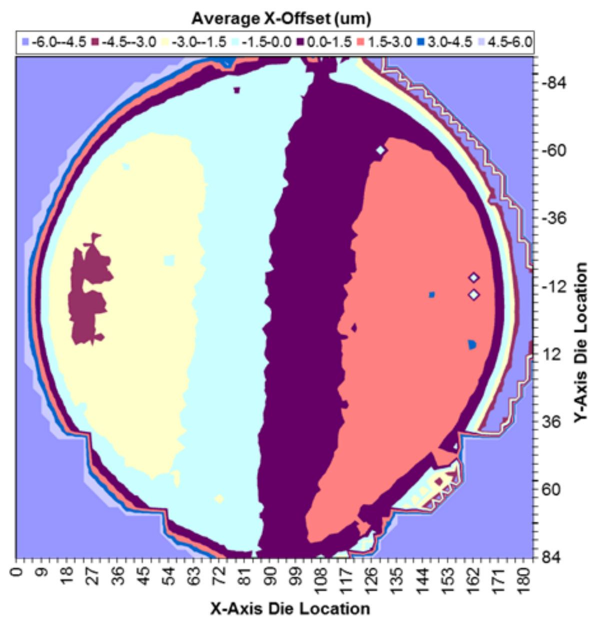
  -> DRIE CD gets bigger close to wafer edge due to loading effect

  -> Cavity shifts in the radial direction at wafer edge due to “outside effect ”

- Edge compensation in mask layout to improve CD/Overlay uniformity



Typical CD distribution in X-direction



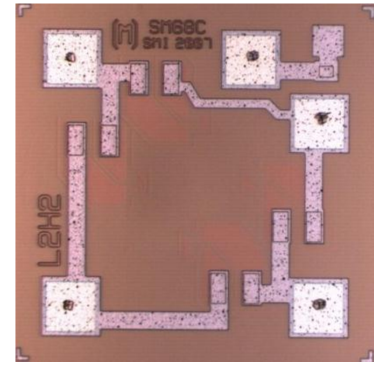
Typical cavity overlay distribution in X-direction

DRIE formed cavities for pressure sensors

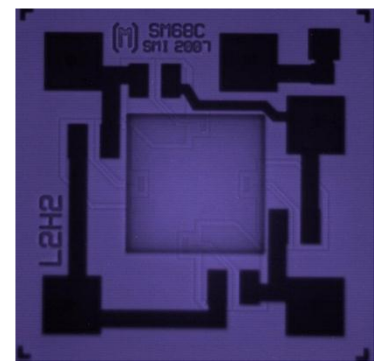
SMI PRESSURE SENSORS

Buried Cavity Technology --- DRIE reference cavity formed and buried in wafer before sensor /CMOS Foundry process

Comparison	Classic DRIE Approach	Buried Cavity Technology
Process sequence	Sensor foundry -> DRIE	DRIE -> Sensor foundry
Etch time	Long, through wafer etch low throughput	Short, shallow cavity etch high throughput
Cavity CD	Variation across wafer	Precise CD control
Cavity Overlay	Variation across wafer	Minimized Overlay error
Edge excl. Zone	Exclusion zone due to DRIE variance	Nearly no exclusion zone required
CMOS compatibility	Plasma Damage could impact CMOS circuits	Compatible



Optical Image



IR Image

Sensing bridge formed on pre-defined membrane

Content

1) SMICompany Overview

2) DRIE Etch for MEMS pressure sensor miniaturization

3) Automated Optical Inspection (AOI) for

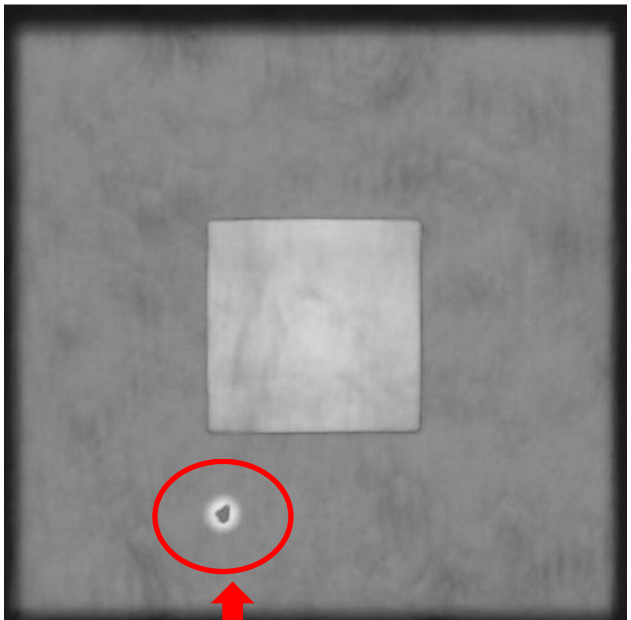
defect detection in MEMS Devices

Automated Optical Inspection (AOI)

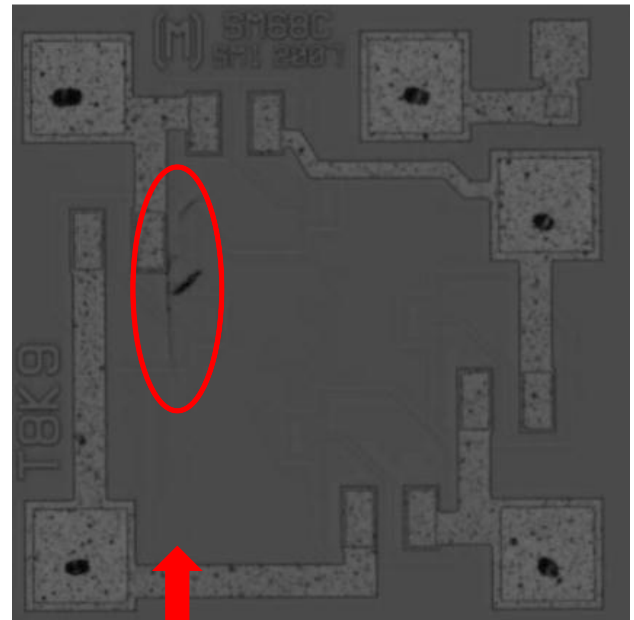
- Automated Optical Inspection (AOI) scans the wafer surface and automatically detects defects and classifies them
- ICOS, originating in Belgium and acquired in 2008 by KLA Tencor, built the equipment
- The system is equipped with one central loader and two inspection modules with high speed line cameras

Importance of visual inspection for MEMS devices

- Defects that cannot be caught by electrical tests and cause reliability / performance impacts



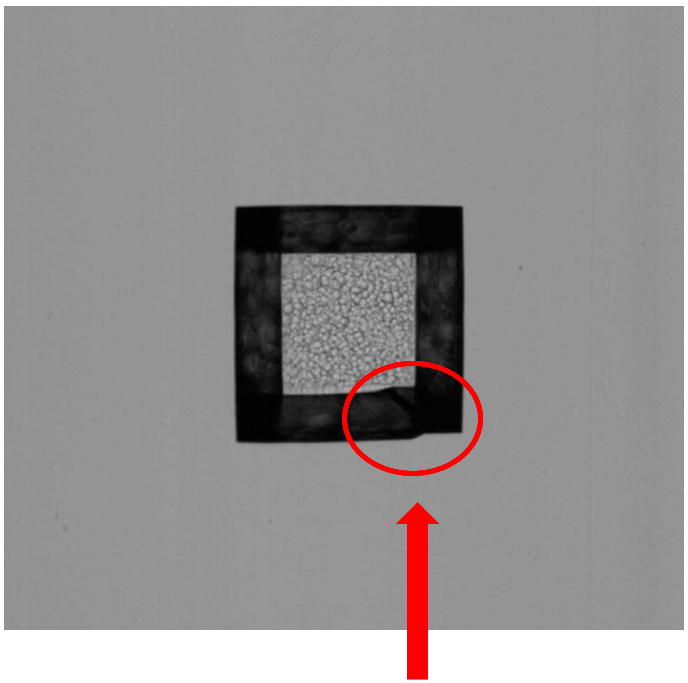
Bond Void on the backside
-> could cause a leak for
absolute pressure sensors



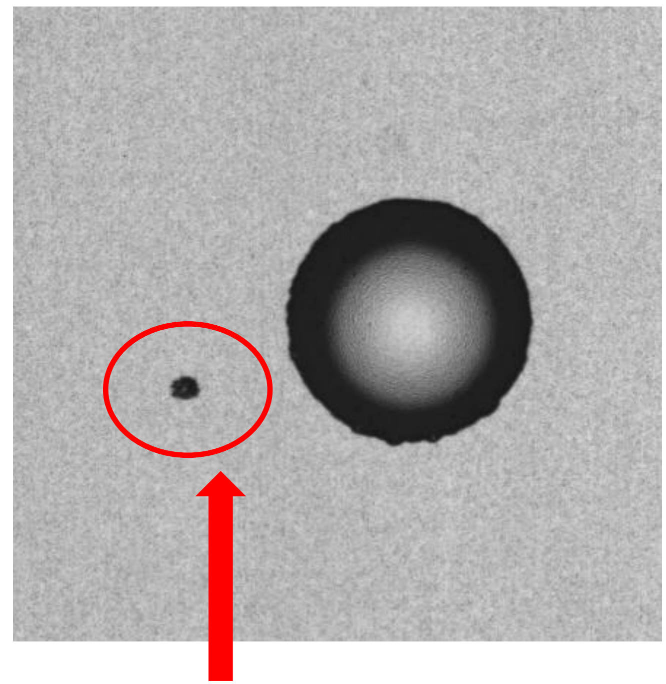
Cracks in Membrane
-> falsifies the pressure signal
-> reliability problem

Importance of visual inspection for MEMS devices

- Defects that cannot be caught by electrical tests and cause reliability / performance impacts

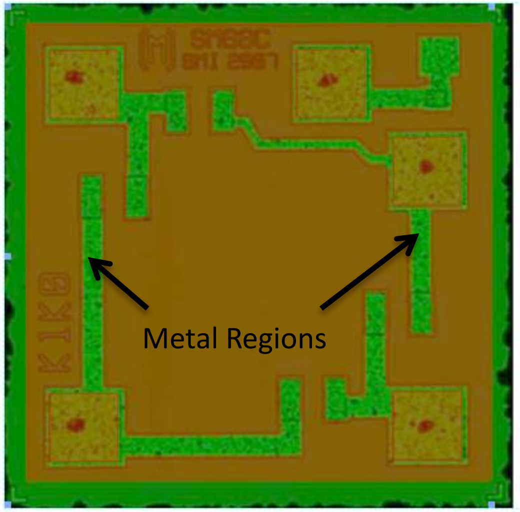


Mis-shaped cavity
-> influence on pressure non-linearity
-> modified sensitivity



Defects in backside metallization
-> could weaken eutectic bond
-> reliability problem

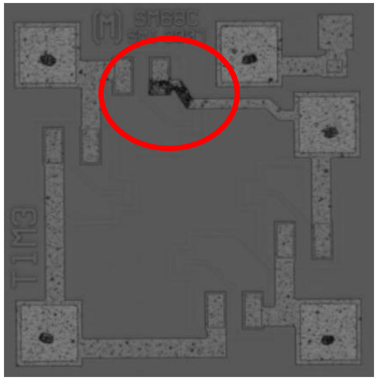
Criteria and methods to detect different defects Frontside Inspection

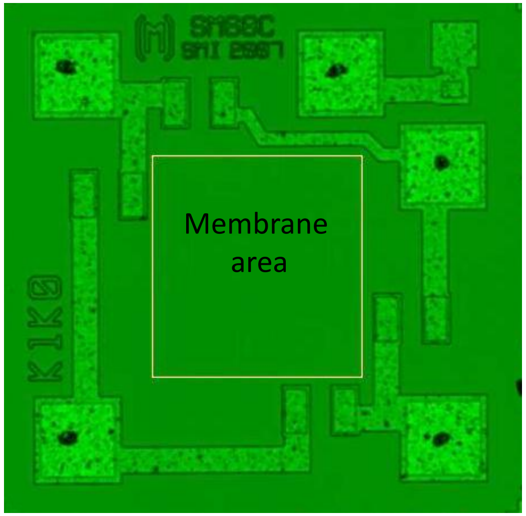


Metal Area

- Inspects for scratches and contamination in the metal region
- Example for the criteria used to detect the defect

Enable	Bin	Rule
☑	Metal	(Polarity IS Dark) AND(

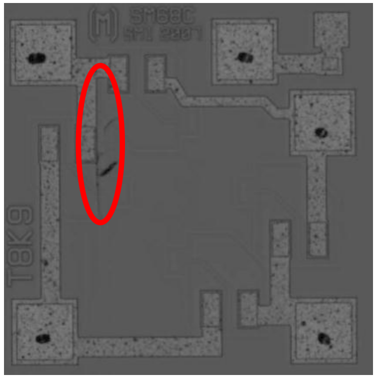




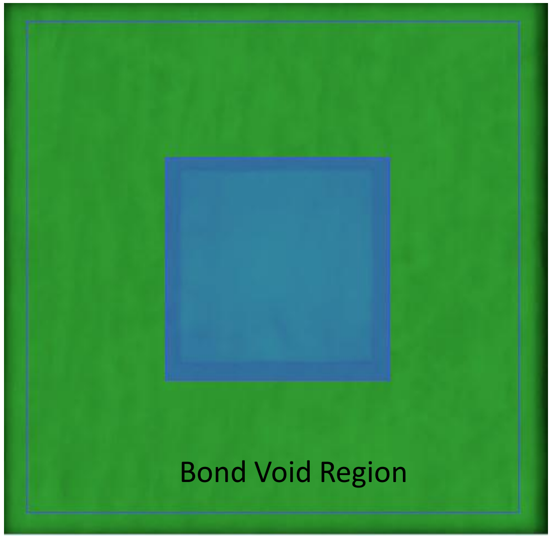
Membrane Area

- Inspects for fractures and contamination on the membrane
- Example

Enable	Bin	Rule
☑	Broken Cavity	(Length >=AND(Elongation >= 35)



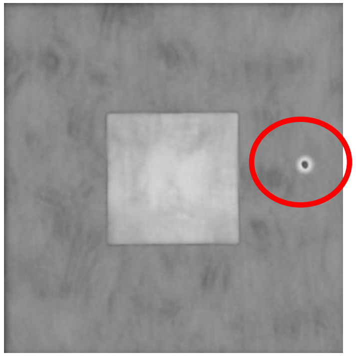
Criteria and methods to detect different defects
Backside Inspection



Bond Void Area

- Inspects for voids in the bond interface outside the cavity area
- Example

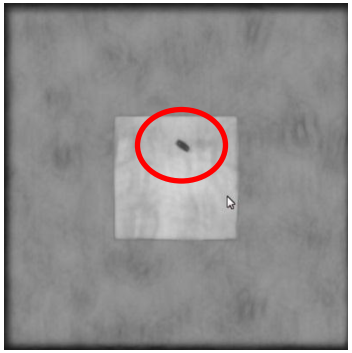
Enable	Bin	Rule
☑	Bond defects	(Area >AND(Roundness >= 30)



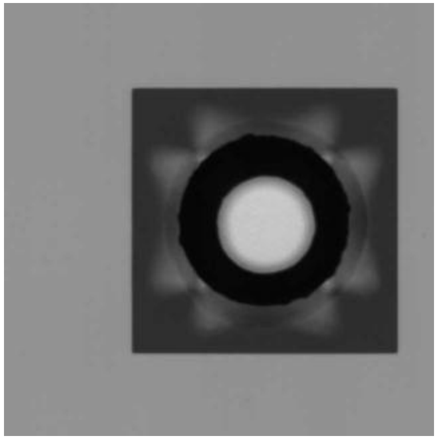
Diaphragm Area

- Inspects for cracks and contamination inside the diaphragm region
- Example

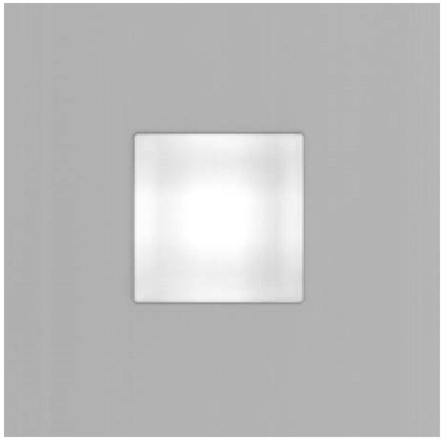
Defect Classificati...	Area(µm²)	Length	Width	Contrast(GV)
Cavity	570.8	36.2	20.7	85



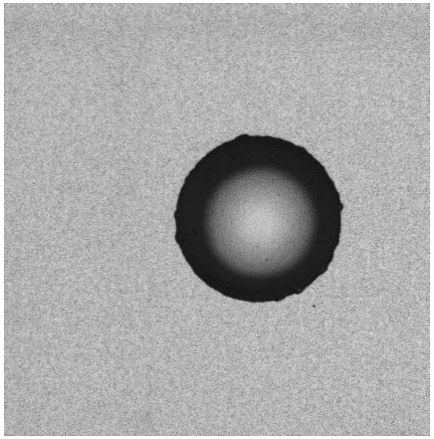
Inspection at different stages



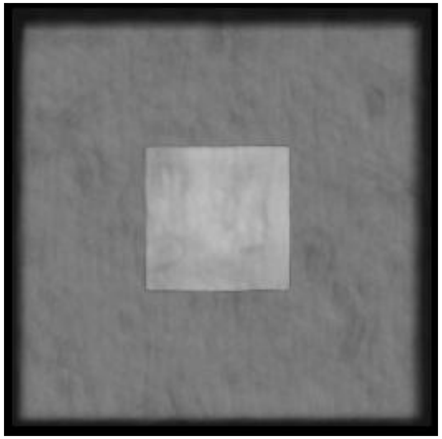
KOH etched Backside
Pre – Metal Inspection



DRIE etched Backside
before sawing



After Metal deposition
for Eutectic Bond

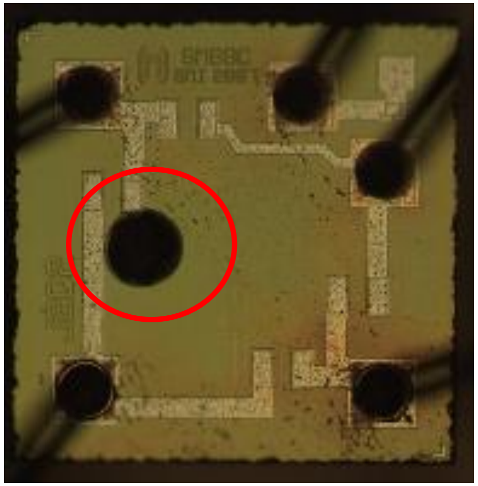


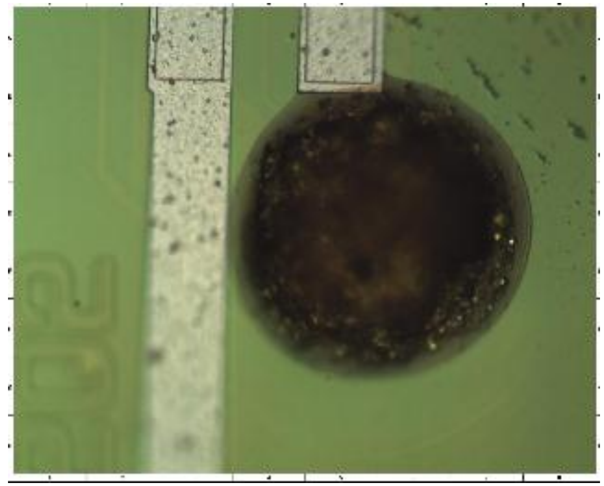
Backside after sawing
-> picture more blurry

Focus on specific defects in the different stages of the process

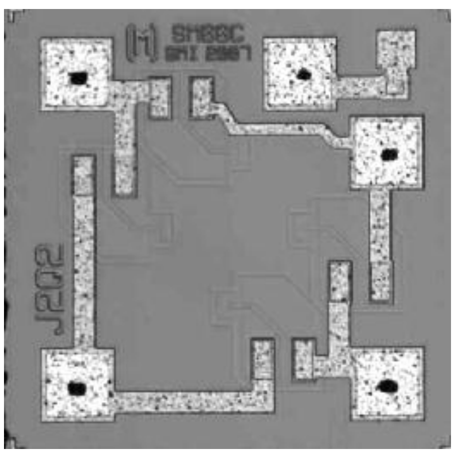
- Bond interface and membrane defects after bonding
- Defects in backside metal that influence eutectic bond
- Inspection after sawing for saw chipping and cracks

Inspection record to document quality





Sensor Image at Customer Site



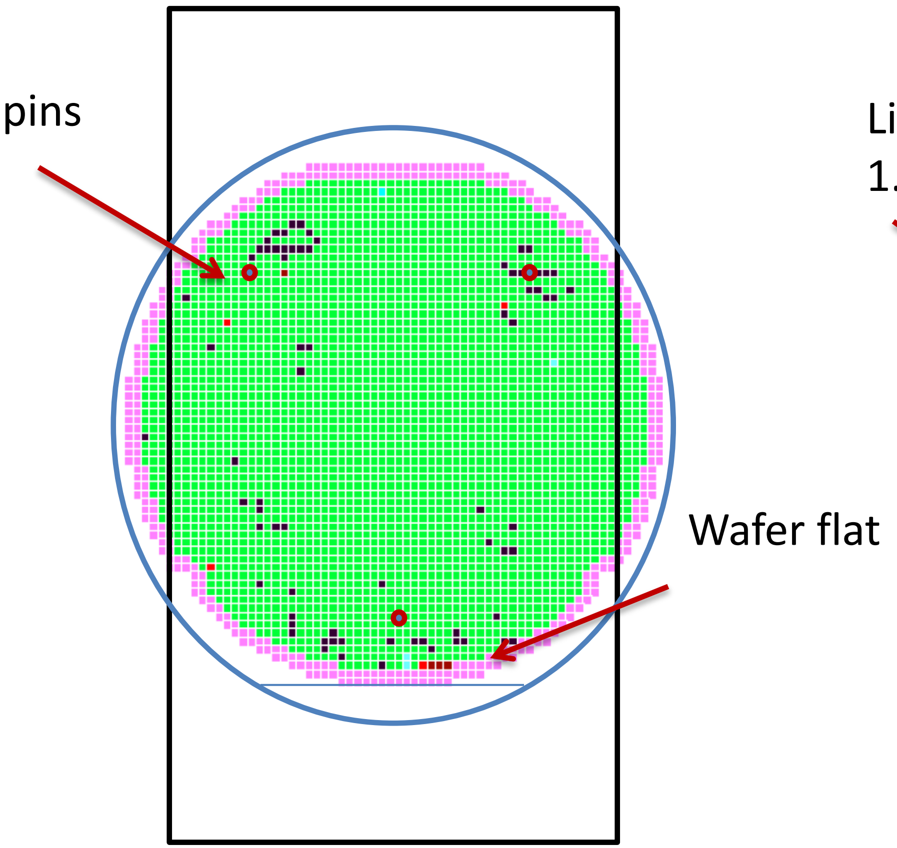
SM68 Sensor Image at SMI

- Defect was not on the Die at AOI
- Reassure customer of excellent quality

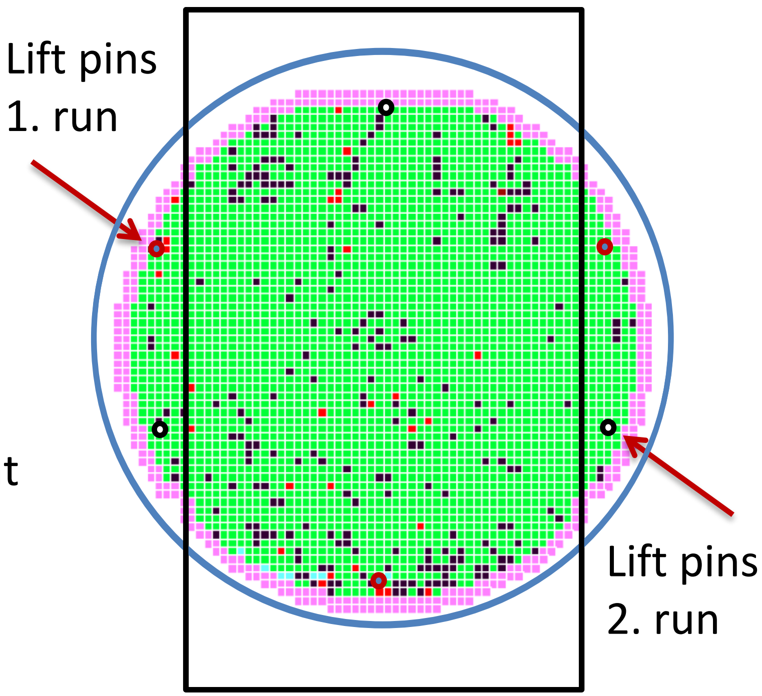
-> Defect must have occurred at customer site, finish with 5D report

Defect Reduction Program

- Screening with AOI after different steps in the process
- Correlation of defect to certain equipment used at that point



Novellus Paddle



Tegal Paddle

Classification and Yield Analysis using Pareto

Color	Name	Output code	Shortcut key
	To be inspected		
	Reject before		
	Pass		F1
	Invalid		
	Reference die		
	Reference die - Invalid		
	Reference die - Not Found		
	uneven cavity	62	Num 2
	saw chip/cracked die	63	Num 3
	back side scratch	64	Num 4
	back side contamination	65	Num 5
	broken diaphragm	68	Num 8
	probe reject	66	Num 6
	front side scratch	67	Num 7
	front side contamination	69	Num 9
	discolored field front side	70	/
	etch pit	71	Num *
	front side KOH, stained pad	72	Num -
	deep probe/ no probe marks	73	Num +
	FS litho defect, missing metal	74	Insert
	other/PCM/missing die	75	Home
	delamination/bond void	60	Num 0

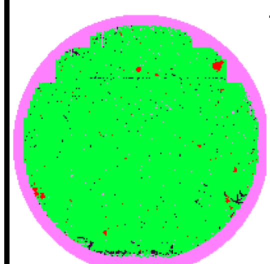
Reject Classification List

- Automated defect classification
  - type of defect
  - area where it is detected
- Shortcut keys for fast Operator reclassification during review
- Visual of a wafer map for quick overview for Operators / Engineers

Wafer ID:6 **Slot ID:0**

#Inspected: 25,665 #Reject: 614 **Yield**

#Pass: 25,051 #Invalid: 0 **97.61%**

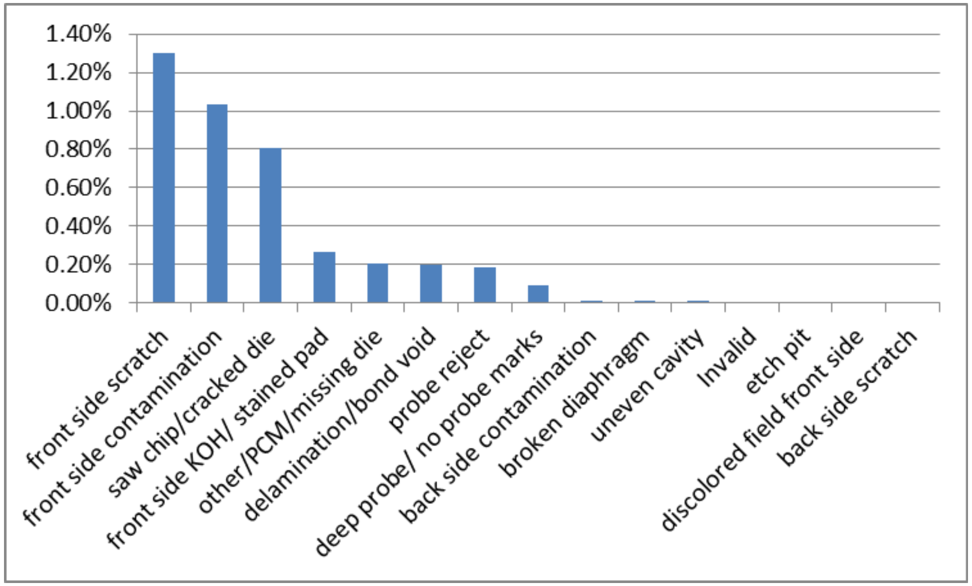


Name	Count	%
front side scratch	306	1
front side contamination	214	1
saw chip/cracked die	81	0
other/PCM/missing die	6	0
FS litho, metal	4	0
broken diaphragm	2	0
Other	1	0
Pass	25,051	98
Reject Before	5,315	

-> Basis for Pareto Analysis

Classification and Yield Analysis using Pareto

SMI PRESSURE SENSORS



Column1	Column2
front side scratch	1.30%
front side contamination	1.03%
saw chip/cracked die	0.81%
front side KOH/ stained pad	0.27%
other/PCM/missing die	0.21%
delamination/bond void	0.20%
probe reject	0.19%
deep probe/ no probe marks	0.09%
back side contamination	0.01%
broken diaphragm	0.01%
uneven cavity	0.01%
Invalid	0.00%
etch pit	0.00%
discolored field front side	0.00%
back side scratch	0.00%

- Pareto Analysis of Defect types improves the efficiency to increase Yield
- Wafer level Yield has been improved at SMI by 5% as an average over all products in the last 3 years by using Automated Optical Inspection (some products up to 10%)

Automated Classification to reduce time & cost

Comparison	Automated Optical Inspection	100% Operator Inspection
Front and Back Inspection on SM68 Sensor	~ 25 minutes machine time ~ 0 to 15min. Operator review time per wafer	~ 8 hours per wafer
Front and Back Inspection on SM95 Sensor	~ 10 minutes machine time ~ 5 to 15min. Operator review time per wafer	~ 2 hours per wafer

- The required throughput of > 40M sensors shipped per year would not have been possible without AOI and not sacrificing quality assurance
- The cost per wafer and the required Operators were reduced significantly
- Customers rely on SMI`s quality inspection using AOI as an essential part of the 0ppm automotive strategy

Acknowledgements

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SMI

PRESSURE SENSORS

Thank you !

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