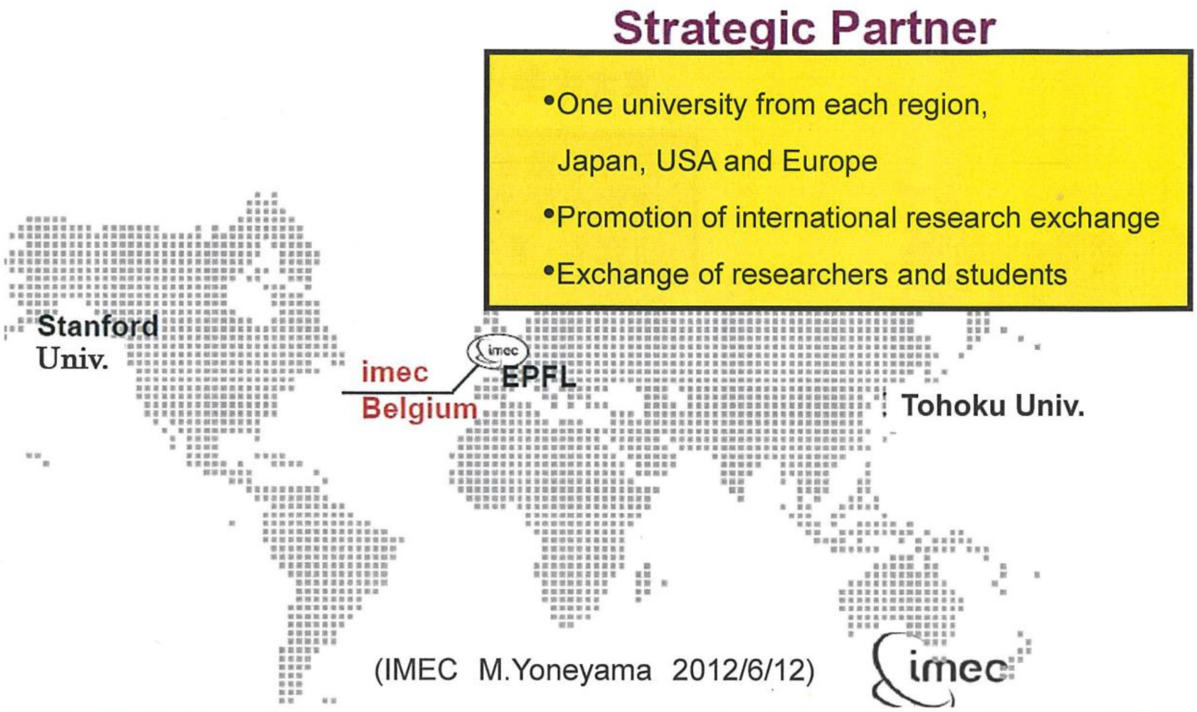
Tohoku Univ. and Belgium IMEC (Interuniversity Micro Electronics Center)



←Hiroshi Kazui (Director, Tohoku Univ.) and Luc Van Den Hove (IMEC president)

Signing ceremony (2012/6/11) →

Joint Seminar in IMEC (2012/6/21) Alternative annual meeting in IMEC and Tohoku University

H2 Poly-SiGe for MEMS sensor applications

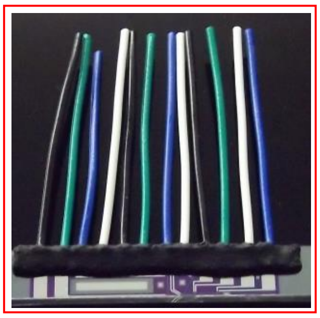


Exhibit #1: Sample to determine the piezoresistivity of a poly-SiGe layer by measuring the resistance changes during 4-point bending tests.

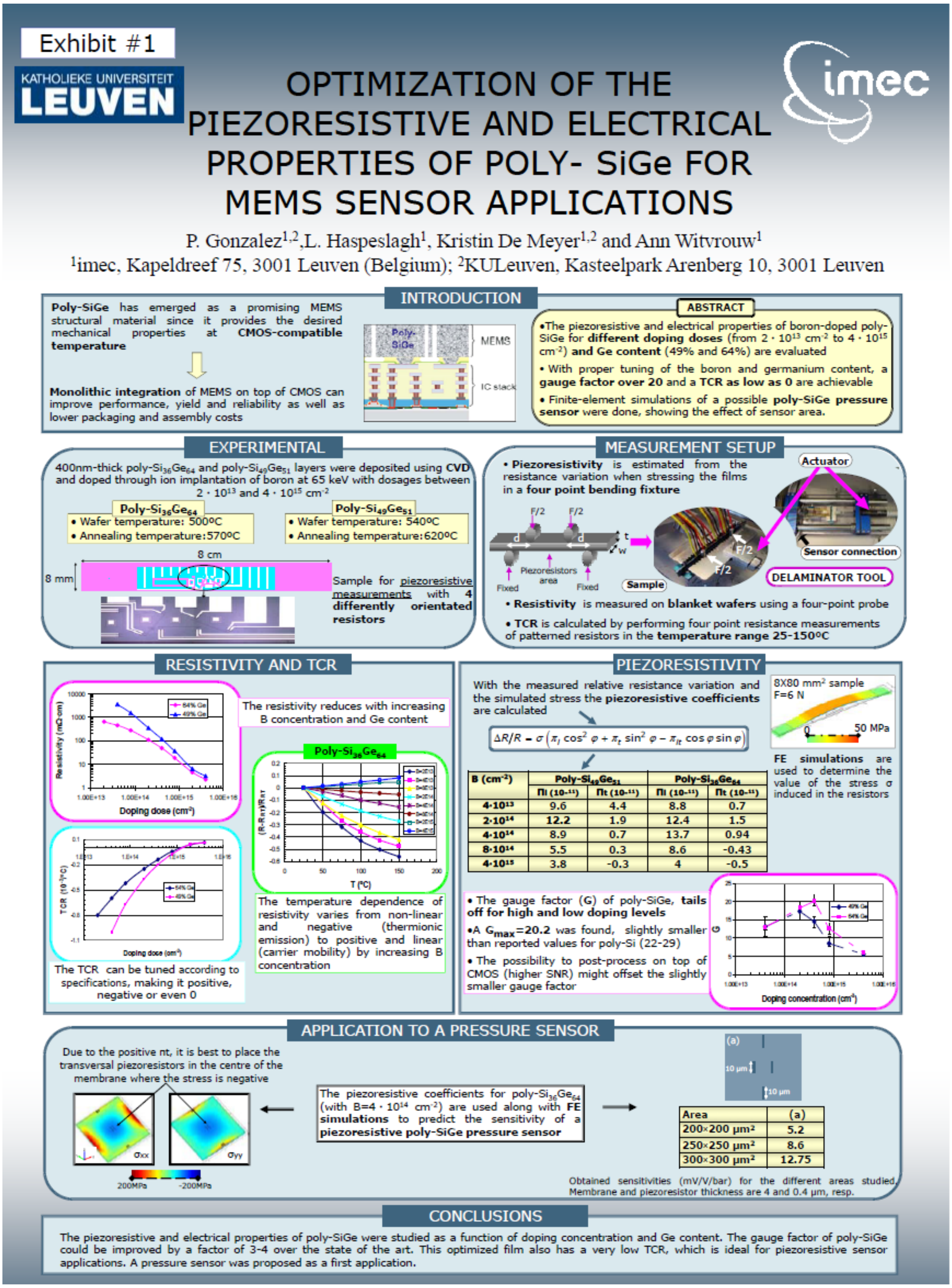


Exhibit #1

KATHOLIEKE UNIVERSITEIT LEUVEN

imec

OPTIMIZATION OF THE PIEZORESISTIVE AND ELECTRICAL PROPERTIES OF POLY- SiGe FOR MEMS SENSOR APPLICATIONS

P. Gonzalez[1,2], L. Haspeslagh[1], Kristin De Meyer[1,2] and Ann Witvrouw[1]
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INTRODUCTION

Poly-SiGe has emerged as a promising MEMS structural material since it provides the desired mechanical properties at **CMOS-compatible temperature**

Monolithic integration of MEMS on top of CMOS can improve performance, yield and reliability as well as lower packaging and assembly costs

ABSTRACT

- The piezoresistive and electrical properties of boron-doped poly-SiGe for **different doping doses** (from $2 \cdot 10^{13}$ cm^{-2} to $4 \cdot 10^{15}$ cm^{-2}) **and Ge content** (49% and 64%) are evaluated
- With proper tuning of the boron and germanium content, a **gauge factor over 20** and a **TCR as low as 0** are achievable
- Finite-element simulations of a possible **poly-SiGe pressure sensor** were done, showing the effect of sensor area.

EXPERIMENTAL

400nm-thick poly-$Si_{36}Ge_{64}$ and poly-$Si_{49}Ge_{51}$ layers were deposited using **CVD** and doped through ion implantation of boron at 65 keV with dosages between $2 \cdot 10^{13}$ and $4 \cdot 10^{15}$ cm^{-2}

Poly-$Si_{36}Ge_{64}$
- Wafer temperature: 500ºC
- Annealing temperature: 570ºC

Poly-$Si_{49}Ge_{51}$
- Wafer temperature: 540ºC
- Annealing temperature: 620ºC

Sample for piezoresistive measurements with 4 **differently orientated resistors**

MEASUREMENT SETUP

- **Piezoresistivity** is estimated from the resistance variation when stressing the films in a **four point bending fixture**
- **Resistivity** is measured on **blanket wafers** using a four-point probe
- **TCR** is calculated by performing four point resistance measurements of patterned resistors in the **temperature range 25-150ºC**

RESISTIVITY AND TCR

The resistivity reduces with increasing B concentration and Ge content

The temperature dependence of resistivity varies from non-linear and negative (thermionic emission) to positive and linear (carrier mobility) by increasing B concentration

The TCR can be tuned according to specifications, making it positive, negative or even 0

PIEZORESISTIVITY

With the measured relative resistance variation and the simulated stress the **piezoresistive coefficients** are calculated

$$\Delta R/R = \sigma\left(\pi_l \cos^2\varphi + \pi_t \sin^2\varphi - \pi_{lt}\cos\varphi\sin\varphi\right)$$

B (cm^{-2})	Poly-$Si_{49}Ge_{51}$		Poly-$Si_{36}Ge_{64}$	
	Π_l (10^{-11})	Π_t (10^{-11})	Π_l (10^{-11})	Π_t (10^{-11})
$4 \cdot 10^{13}$	9.6	4.4	8.8	0.7
$2 \cdot 10^{14}$	12.2	1.9	12.4	1.5
$4 \cdot 10^{14}$	8.9	0.7	13.7	0.94
$8 \cdot 10^{14}$	5.5	0.3	8.6	-0.43
$4 \cdot 10^{15}$	3.8	-0.3	4	-0.5

8X80 mm^2 sample, F=6 N

FE simulations are used to determine the value of the stress σ induced in the resistors

- The gauge factor (G) of poly-SiGe, **tails off for high and low doping levels**
- A G_{max}=**20.2** was found, slightly smaller than reported values for poly-Si (22-29)
- The possibility to post-process on top of CMOS (higher SNR) might offset the slightly smaller gauge factor

APPLICATION TO A PRESSURE SENSOR

Due to the positive πt, it is best to place the transversal piezoresistors in the centre of the membrane where the stress is negative

The piezoresistive coefficients for poly-$Si_{36}Ge_{64}$ (with $B=4 \cdot 10^{14}$ cm^{-2}) are used along with **FE simulations** to predict the sensitivity of a **piezoresistive poly-SiGe pressure sensor**

Area	(a)
200×200 μm^2	5.2
250×250 μm^2	8.6
300×300 μm^2	12.75

Obtained sensitivities (mV/V/bar) for the different areas studied. Membrane and piezoresistor thickness are 4 and 0.4 µm, resp.

CONCLUSIONS

The piezoresistive and electrical properties of poly-SiGe were studied as a function of doping concentration and Ge content. The gauge factor of poly-SiGe could be improved by a factor of 3-4 over the state of the art. This optimized film also has a very low TCR, which is ideal for piezoresistive sensor applications. A pressure sensor was proposed as a first application.

H3 MEMS gyroscope on CMOSIC using poly-SiGe

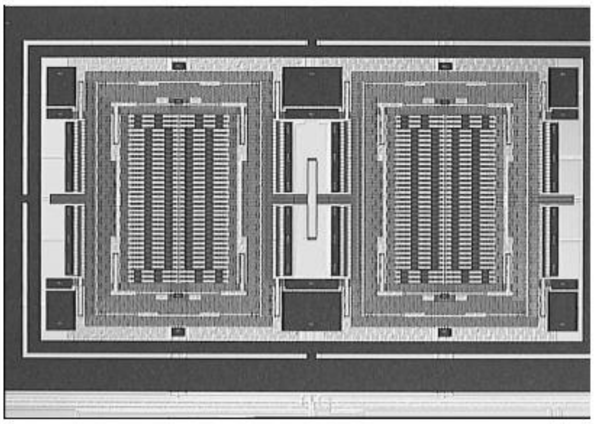
ISSCC 2005 / SESSION 4 / TD: MIXED-DOMAIN SYSTEMS

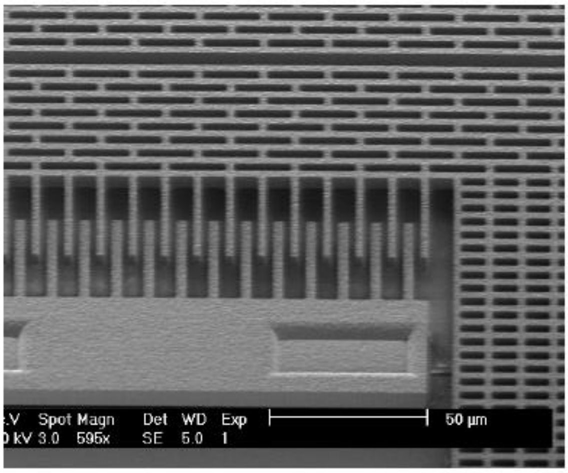
4.7 Processing of MEMS Gyroscopes on Top of CMOS ICs

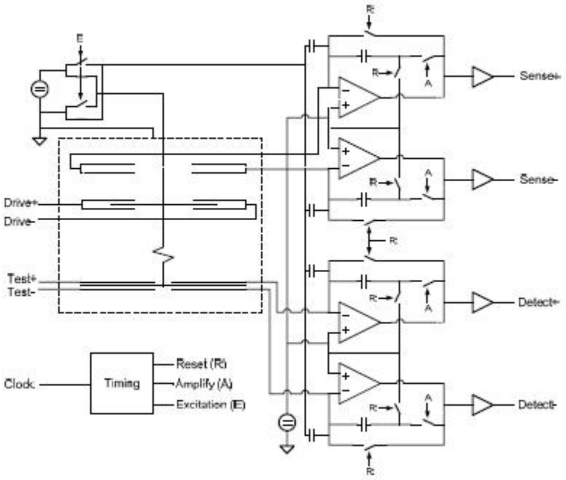
A. Witvrouw[1], A. Mehta[1], A. Verbist[1], B. Du Bois[1], S. Van Aerde[2], J. Ramos-Martos[3], J. Ceballos[3], A. Ragel[3], J. M. Mora[3], M.A. Lagos[3], A. Arias[3], J. M. Hinojosa[3], J. Spengler[4], C. Leinenbach[5], T. Fuchs[5], S. Kronmüller[5]

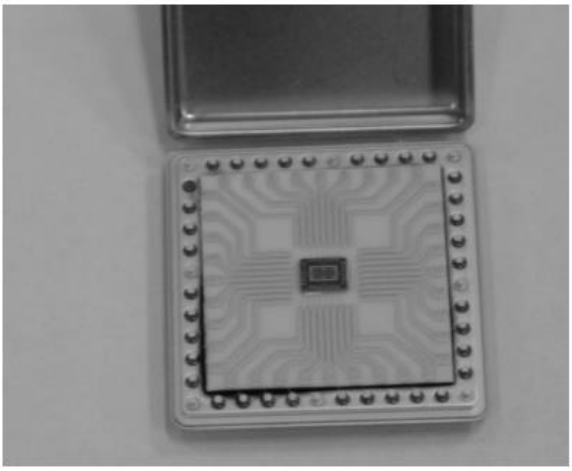
[1]IMEC, Leuven, Belgium, [2]ASM, Leuven, Belgium, [3]IMSE-CNM, Sevilla, Spain, [4]Philips, Böblingen, Germany, [5]Bosch, Gerlingen-Schillerhöhe, Germany

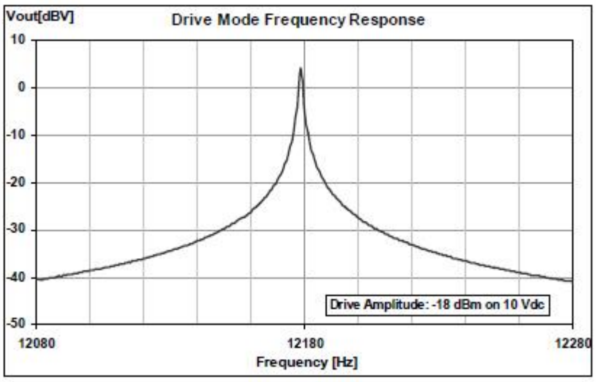
Exhibit #2: First poly-SiGe above-CMOS integrated gyroscope. The CMOS technology used is a standard 0.35 μm technology with 5 interconnect levels.

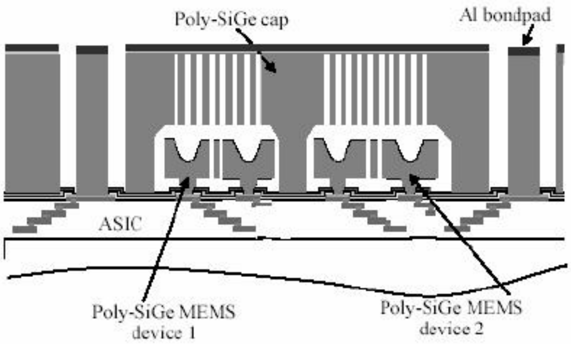








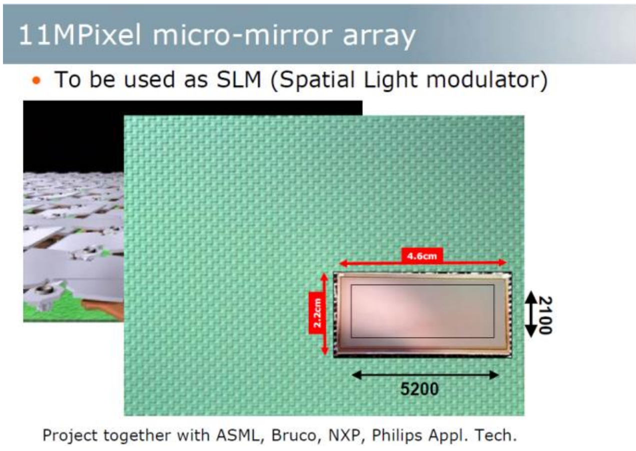


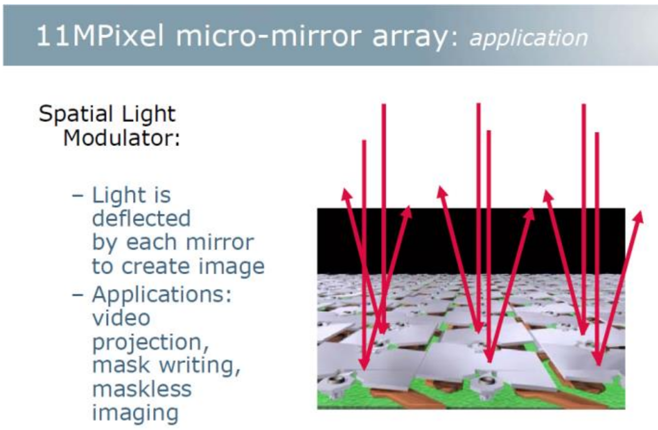


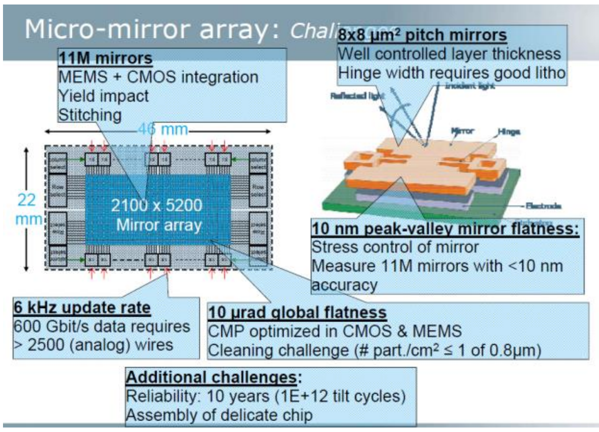
H4 # SiGe micro-mirror array on CMOS IC

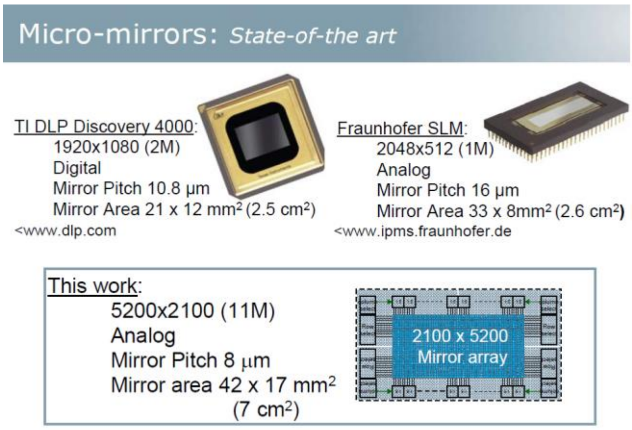
Ann Witvrouw

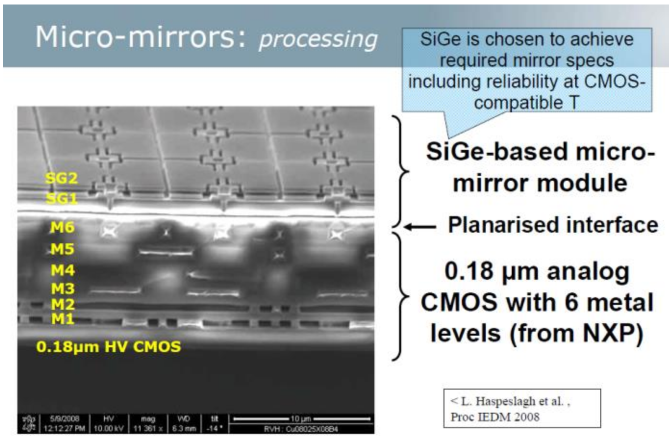
Exhibit #3: 11 megapixel micro-mirror array with 8 µm pitch made in poly-SiGe above standard 0.18µm analog-CMOS wafers fabricated by NXP, featuring 6 interconnect levels.

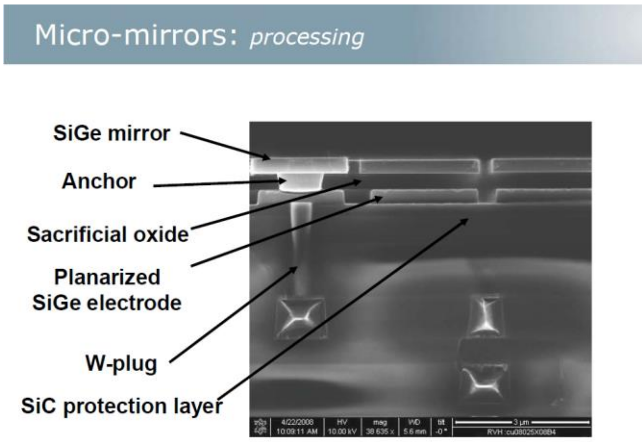


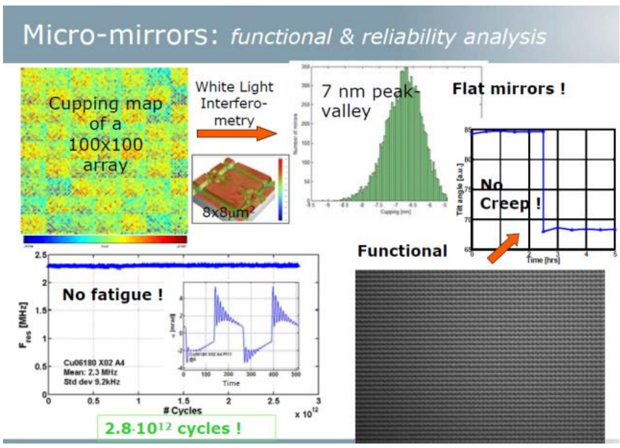


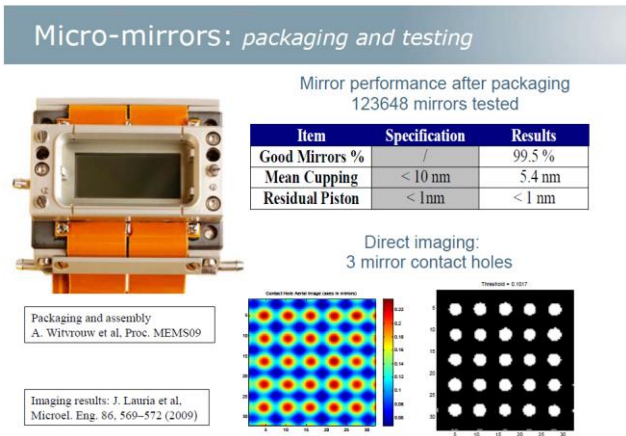












H5 CMORE SiGeMEMS mluti project wafer

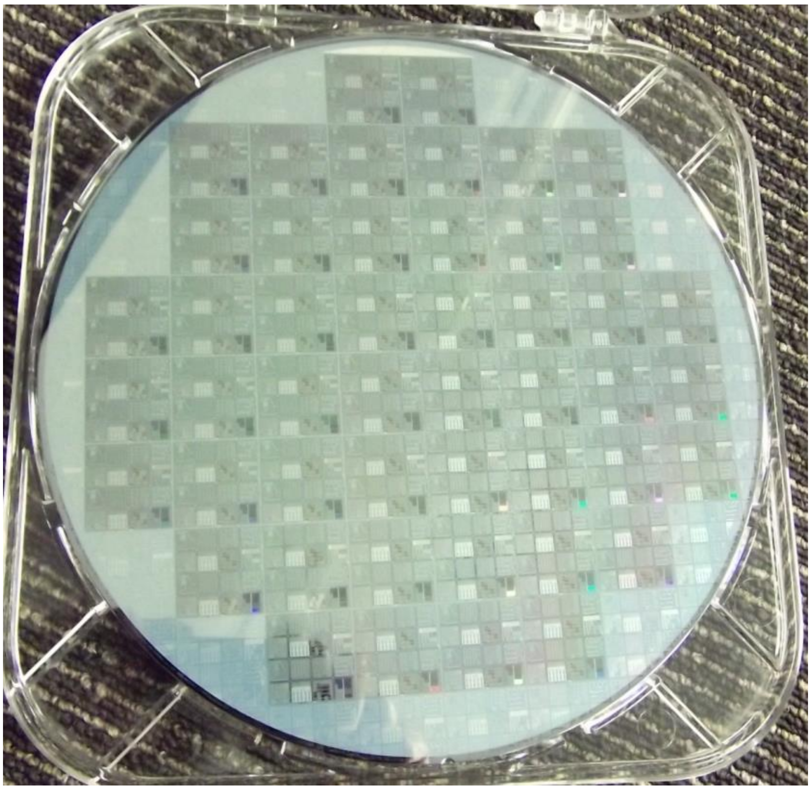


Exhibit #4: Poly-SiGe MEMS MultiProject Wafer (MPW) from the first SiGeMEMS MPW run organized by Europractice in 2011.

EUROPRACTICE IC SERVICE

imec

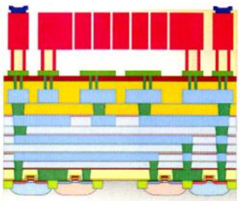
imec CMORE SiGeMEMS MPW

EUROPRACTICE IC Service offers Multi-Project Wafer Services in imec's CMORE SiGeMEMS standalone and SiGeMEMS/CMOS integrated technology:

Imec's **CMORE** **Si**licon **Ge**rmanium **MEMS** platform technology, referred to as **SiGeMEMS**, is developed to enable monolithic integration of CMOS and MEMS. Systems integrating MEMS devices with the driving and readout electronics on the same die lead to better performances in terms of signal to noise ratio through reduced interconnect parasitic resistance and capacitance, allow for smaller die size and package, and also for lower power consumption. SiGeMEMS is based on a MEMS-last approach which allows state-of-the-art CMOS foundries to be employed.

Technology

The SiGeMEMS process, belonging to imec's CMORE service platform, is very versatile. Thanks to its flexible and modular approach, allowing application-specific tuning and optimization, it addresses a large number of applications like gyro's, switches, μmicrophones, μspeakers, CMUTs, T-sensors, P-sensors, ... and array type devices like μmirrors, probe-based memories, and arrays for μfluidics and μpower generation...



EUROPRACTICE now offers a fixed baseline SiGeMEMS process in a Multi-Project Wafer Service. This unique baseline process consists of MEMS structures defined by an electrode layer and a 4μm-thick SiGe-mechanical layer on top of a TSMC 0.18um CMOS wafer. Nanogaps of 500nm will allow fabrication of extremely small features. A standalone MEMS version, identical but processed on a wafer with a single metal layer, will be available for initial prototyping.

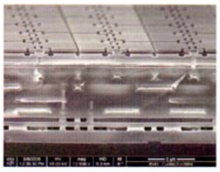
Europractice-imec SiGeMEMS MPW runs in 2012

imec CMORE	2012											
	J	F	M	A	M	J	J	A	S	O	N	D
SiGeMEMS MEMS-only								20				
SiGeMEMS/TSMC 0.18μm CMOS (CV018LD 1.8/3.3/32V)						10				25 [1]		

Note: 1) This run is preliminary and can be updated during 2012

Price

Technology Version	Standard Price	EU-Discounted Price
MEMS-only	4250 €	4000 €
CMOS integrated	28500 €	27000 €



EU-Discounted Price only applies to EUROPRACTICE registered (who paid their annual full membership fee) Academic and Research Members from all 27 EU countries and Norway, Iceland, Liechtenstein, Israel, Croatia, Serbia, Macedonia, Albania, Montenegro, Bosnia&Herzegovina, Switzerland, Turkey who submit designs for *educational or publicly funded research use only.*

Standard Price normal price for universities and research institutes not belonging to previous category. (Companies should contact imec CMORE at www.imec.be/cmore to take advantage of additional extensions and services.

Prices and conditions may change at any time without prior notice

For more information : epmems@imec.be www.europractice-ic.com

EUROPRACTICE IC SERVICE

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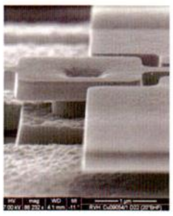
imec CMORE SiGeMEMS MPW

Principle

Imec's CMORE SiGeMEMS technology offered through the EUROPRACTICE IC MPW service is aimed at creating, characterizing and evaluating test structures prior to further specific development and production projects. By gathering the designs of multiple customers on the same masks set, MPWs allow to fabricate test structures and prototypes of devices at a low cost.



Advantages of SiGeMEMS

Monolithic integration with IC :

- Very compact
- Best solution for applications that are very sensitive to parasitics
- High intrinsic system reliability: less components, less interconnections.

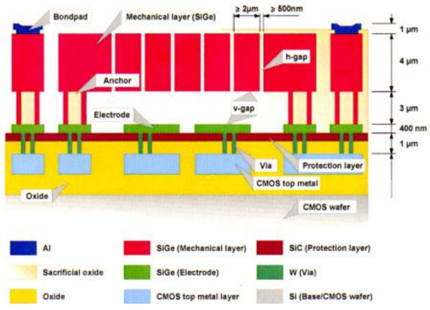
MEMS last above CMOS :

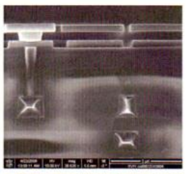
- Most flexible with respect to choice of CMOS technology
- Extremely well suited for MEMS array applications
  - very high-density and massively parallel interconnections possible
    → large arrays of MEMS (e.g. μmirror arrays)

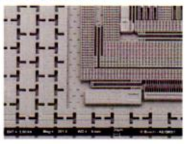
Poly-SiGe :

- High performance: low parasitics
- Good mechanical properties & reliability
  - better than Al: higher strength and Q factor
  - better than Al: less creep and fatigue

Summary of SiGeMEMS main features and dimensions







General conditions :

EUROPRACTICE SiGeMEMS MPW Service is accessible for universities and research institutes. (EUROPRACTICE registered members)
→ more info at www.europractice-ic.com

Companies can have additional extensions to take advantage of the versatile, flexible and modular technology:

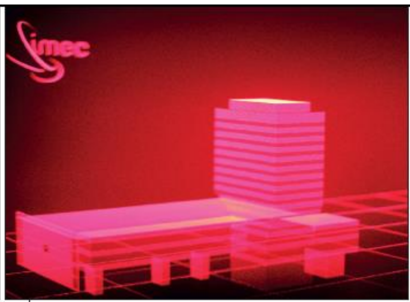
- Variable layer thicknesses
- Application-specific optimization of layer & material properties
- Application-specific functional add-on layers

Companies should contact imec CMORE at www.imec.be/cmore

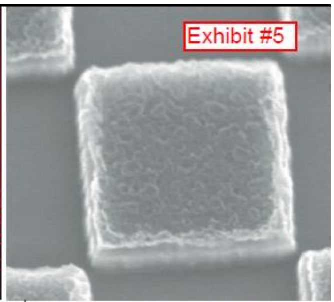
For more information : epmems@imec.be www.europractice-ic.com

H6 Holographic displays

Set-up for holographic display technology.



Holographic image demonstrator.



SEM-image of sub-wavelength binary holographic pixel.

DIGITAL DIFFRACTIVE OPTICS

PATH TO HIGH-QUALITY HOLOGRAPHIC DISPLAYS

Vision

Imagine having a meeting. You and your guests sit around the table arguing, discussing or presenting data. Just like any meeting you have today, only for one detail: some of the people around the table are 3D images – dynamic holograms – of people sitting in an office thousands of miles away. You will look them in the eye, feel their hesitations, and see their body language. Unlike with today's displays, you won't miss a cue.

Holographic visualization promises to offer a natural 3D experience for multiple viewers, without the undesirable side-effects of current 3D stereoscopic visualization (uncomfortable glasses, strained eyes, fatiguing experience). Imec's vision is to design the ultimate 3D display: a holographic display with wide viewing angle and a high-definition visual experience.

Challenges

Building a high-quality, real-time holographic display requires several breakthroughs from today's holographic prototypes. The challenges are threefold:

– To achieve high image quality, millions of light-diffracting elements are needed. These must all be individually controlled.

– To achieve a wide viewing angle, the light-diffracting elements should be sized close to or below the wavelength of the visible light, i.e. as small as a few hundred nanometers.

– To achieve real-time imaging, massive computing power is needed.

Technology

Imec is scaling its MEMS technology to meet these challenging demands. Our prototypes show promising results, setting the path to high-quality displays.

Imec aims for system-level solutions utilizing a unique combination of its multi-disciplinary teams with strong competences in:

- Advanced lithography
- Silicon processing
- SiGe MEMS processing platform
- MEMS design & prototyping
- Computational holography
- Holographic (lens-less) imaging
- Sub-wavelength diffractive optics
- Embedded system design
- Parallel computing platforms

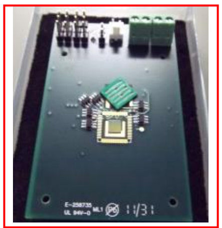
Our longer-term goal is to create a display system for computer-generated holography with billions of sub-wavelength diffractive elements, delivering high-definition 3D visual experience.

imec

www.imec.be

H7 MEMS for energy harvesters & electronic noise

Imec, The Netherlands



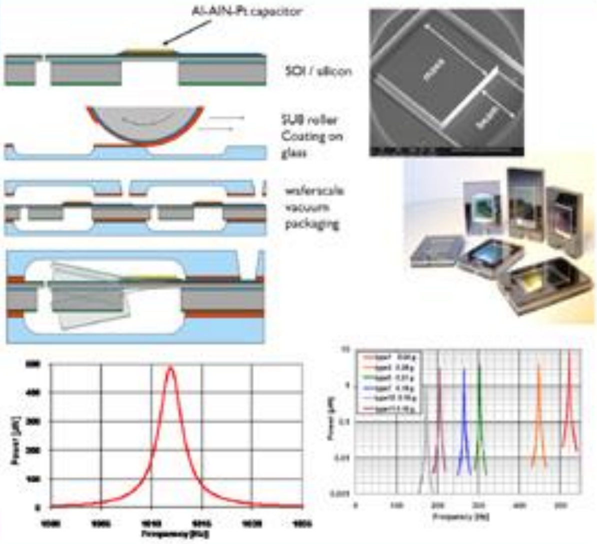
MEMS FOR ENERGY HARVESTERS & ELECTRONIC NOSE

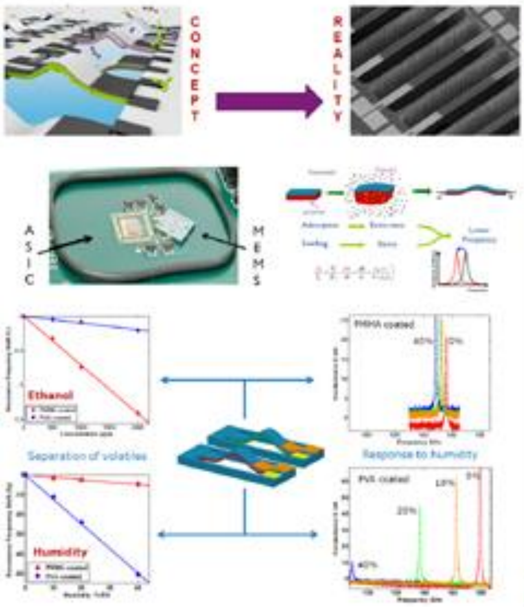
Background

Wireless sensor nodes are able to operate autonomously, for extended periods of time, provided they are equipped with Ultra Low Power components, and their energy is supplied by energy harvesters. For both the sensors as well as the harvesters, MEMS fabrication by bulk machining is an enabling technology.

Energy Harvesting

The **Piezo Vibration Harvester** is processed on SOI wafers. An Al-AlN-Pt is deposited and subsequently the beam and mass are defined using DRIE. The devices are vacuum packaged with two glass wafers with a cavity. Roller coating is used for this process. Several devices have been designed, each with their own resonance frequency (between 200Hz and 1 kHz). The maximum power output has been 489μW at an input acceleration of 4.5g.





Ultra Low Power Electronic Nose

MEMS cantilevers are traditionally used for mass based (bio-)sensing as the resonance frequency shifts when molecules adsorb.

Here, an electronic nose based on the response of an array of MEMS resonators is developed, where each resonator is coated with a different polymer and thus reacts differently when exposed to the environment. This approach, where swelling of the polymers gives a stress induced resonance shift, is significantly more sensitive (~300x compared to mass based sensing), thus enabling detection of low-mass volatiles with a scalable MEMS array. Additionally, a dedicated ASIC is developed that actuates the device through a piezo-electric patch, and tracks the resonance frequency.

Holst Centre