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Optimization of the Piezoresistive and Electrical Properties of poly-SiGe for MEMS Sensor Applications

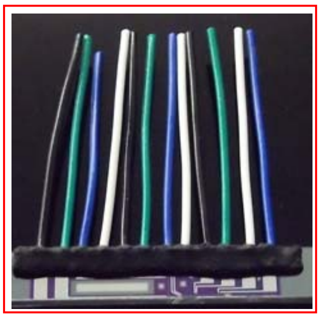

Exhibit #1: Sample to determine the piezoresistivity of a poly-SiGe layer by measuring the resistance changes during 4-point bending tests.

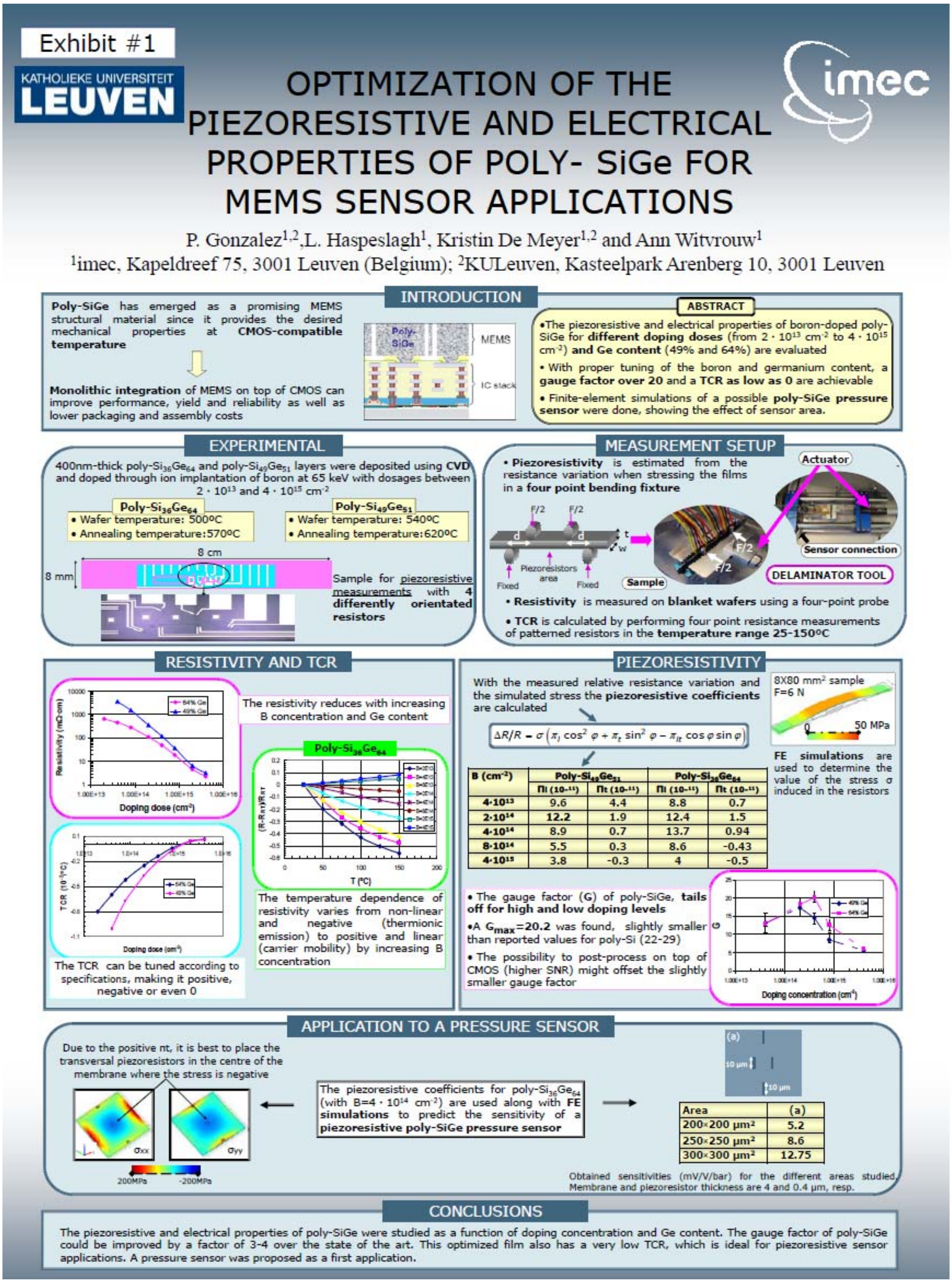

Exhibit #1

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

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

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

PIEZORESISTIVITY

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

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

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

B (cm^{-2})	Poly-$Si_{49}Ge_{51}$		Poly-$Si_{36}Ge_{64}$	
	Πl (10^{-11})	Πt (10^{-11})	Πl (10^{-11})	Πt (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

- 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 µm²	5.2
250×250 µm²	8.6
300×300 µm²	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.