

**PMUT / CMUT SOLUTIONS:  
ULTRASONIC TRANSDUCERS FOR OPENING NEW MARKET OPPORTUNITIES**

Leti MEMS Workshop | FAIN Bruno | June 20, 2017



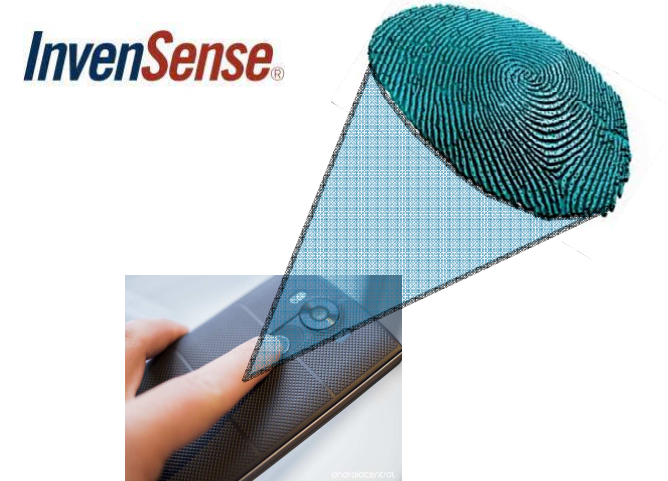
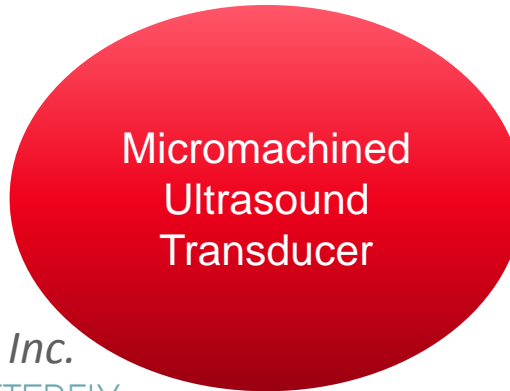


# ULTRASONIC TRANSDUCERS : APPLICATIONS

Non-destructive testing



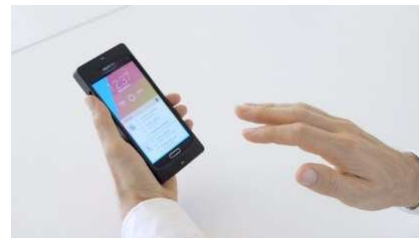
Medical applications



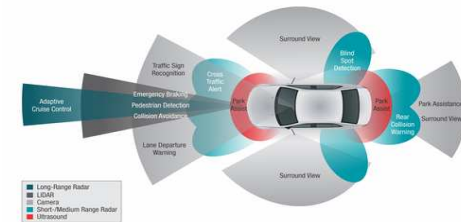
Fingerprint sensor



Smart home, IOT, AR / VR,



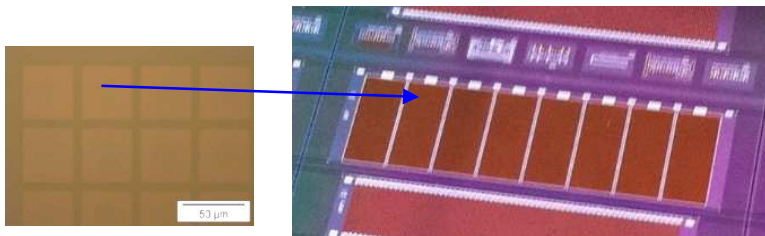
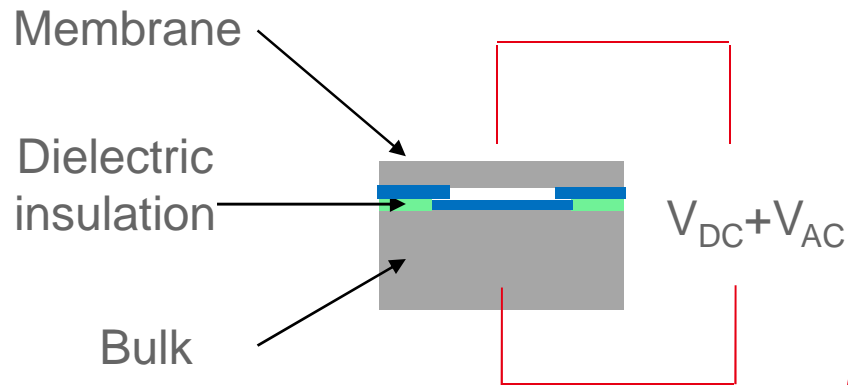
Ranging / HMI



Driverless car

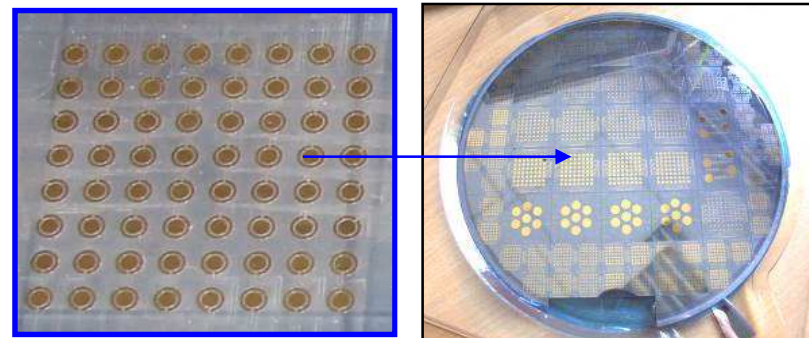
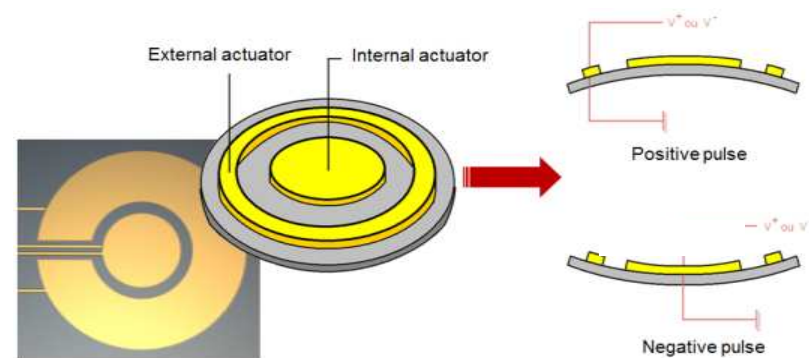
# CAPACITIVE VS PIEZOELECTRIC MICROMACHINED ULTRASONIC TRANSDUCER

## CMUT



- Sacrificial release / wafer bonding process

## PMUT



- AlN / PZT / ... -based PMUT



# CAPACITIVE VS PIEZOELECTRIC MICROMACHINED ULTRASONIC TRANSDUCER

**CMUT**

**PMUT**

**DC bias**

~ 100 V

No DC bias required



# CAPACITIVE VS PIEZOELECTRIC MICROMACHINED ULTRASONIC TRANSDUCER

## CMUT

## PMUT

DC bias

~ 100 V

No DC bias required

Frequency range

> 200 kHz

> 1 kHz



# CAPACITIVE VS PIEZOELECTRIC MICROMACHINED ULTRASONIC TRANSDUCER

## CMUT

## PMUT

DC bias

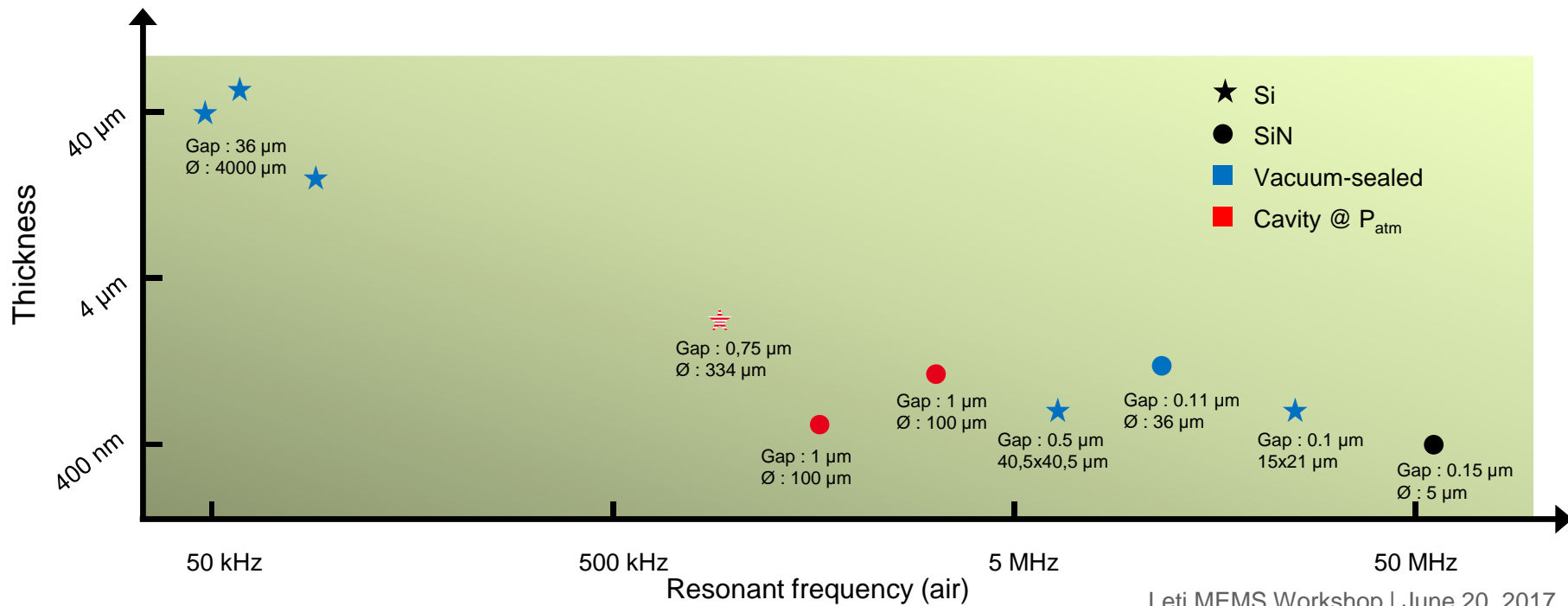
~ 100 V

No DC bias required

Frequency range

> 200 kHz

> 1 kHz





# CAPACITIVE VS PIEZOELECTRIC MICROMACHINED ULTRASONIC TRANSDUCER

## CMUT

## PMUT

DC bias

~ 100 V

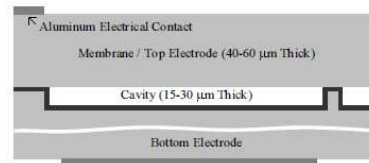
No DC bias required

Frequency range

> 200 kHz

> 1 kHz

CMUT @ 50 kHz



Wygant et al.,  
IEEE Ultrasonics  
Symposium, 2007

Diameter : > 4 mm  
 $V_{DC} = 200 V$   
Thickness = 40  $\mu m$

CMUT @ 180 kHz



Na et al., IEEE Ultrasonics  
Symposium, 2016

Diameter : > 2 mm  
 $V_{DC} = 200 V$   
Thickness = 18.3  $\mu m$



# CAPACITIVE VS PIEZOELECTRIC MICROMACHINED ULTRASONIC TRANSDUCER

## CMUT

## PMUT

**DC bias**

~ 100 V

No DC bias required

**Frequency range**

> 200 kHz

> 1 kHz

**Interconnexion**

→ TSV

→ Flip-chip



# CAPACITIVE VS PIEZOELECTRIC MICROMACHINED ULTRASONIC TRANSDUCER

## CMUT

## PMUT

DC bias

~ 100 V

No DC bias required

Frequency range

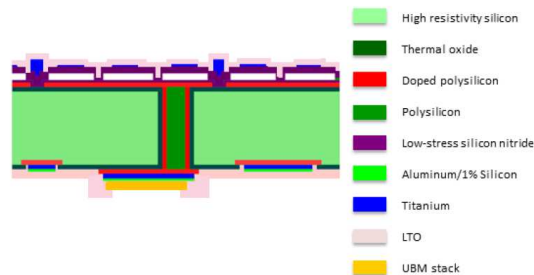
> 200 kHz

> 1 kHz

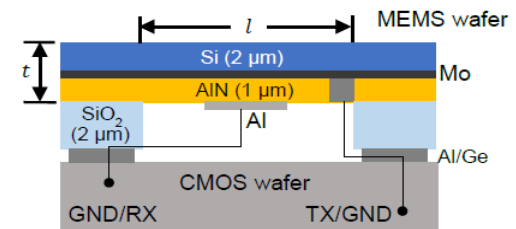
Interconnexion

→ TSV

→ Flip-chip



Moini *et al.*,  
2016 IEEE International Ultrasonics  
Symposium Proceedings



Horsley *et al.*,  
2016 IEEE International Ultrasonics  
Symposium Proceedings



# CAPACITIVE VS PIEZOELECTRIC MICROMACHINED ULTRASONIC TRANSDUCER

	CMUT	PMUT
DC bias	~ 100 V	No DC bias required
Frequency range	> 200 kHz	> 1 kHz
Interconnexion	→ TSV	→ Flip-chip
Electromechanical coupling	Typ. 50 %	<< 50%



# CAPACITIVE VS PIEZOELECTRIC MICROMACHINED ULTRASONIC TRANSDUCER

	CMUT	PMUT
DC bias	~ 100 V	No DC bias required
Frequency range	> 200 kHz	> 1 kHz
Interconnexion	→ TSV	→ Flip-chip
Electromechanical coupling	Typ. 50 %	<< 50%
Technology	Good control	Piezo. Material deposition

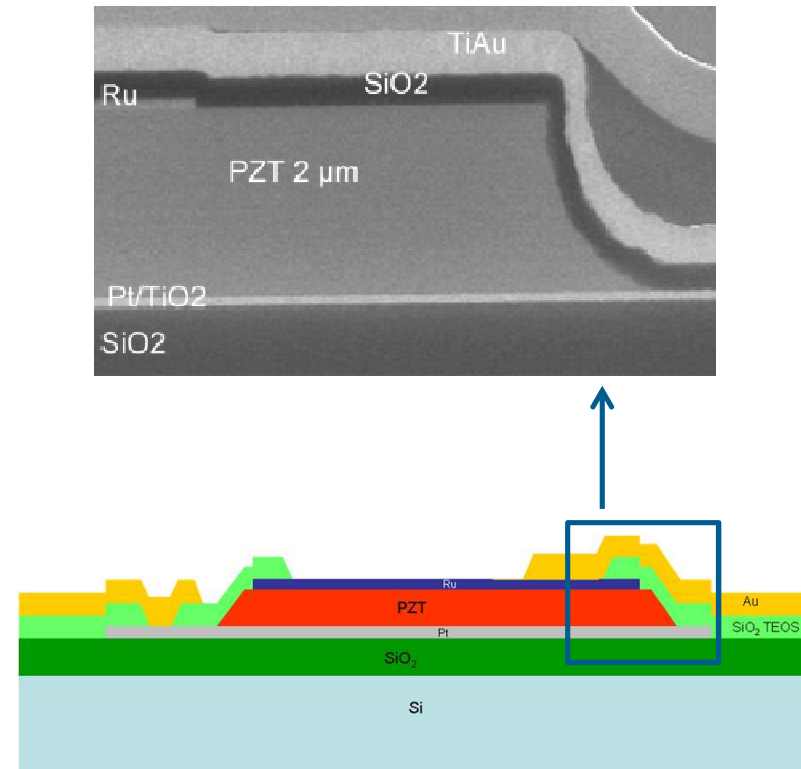
## ALN-BASED VS PZT-BASED PMUT

	PZT	AlN
E (Gpa)	82	330
$\nu$	0.24	0.39
$\rho$ (kg/m <sup>3</sup> )	7500	3255
$\epsilon_r$	1400	10
$ e_{31,eff} $ (C/m <sup>2</sup> )	22	0.9
Breakdown field (V/ $\mu$ m)	90	390
	Ferroelectric material	-
Technology	<i>Sol-gel deposition</i>	<i>Sputtering</i>

- ✓ PZT offers unique properties for actuators (high  $e_{31,eff}$ )
- ✓ AlN presents advantages for sensors (low  $\epsilon_r$ )

# PIEZOELECTRIC MATERIAL FOR PMUT @ LETI

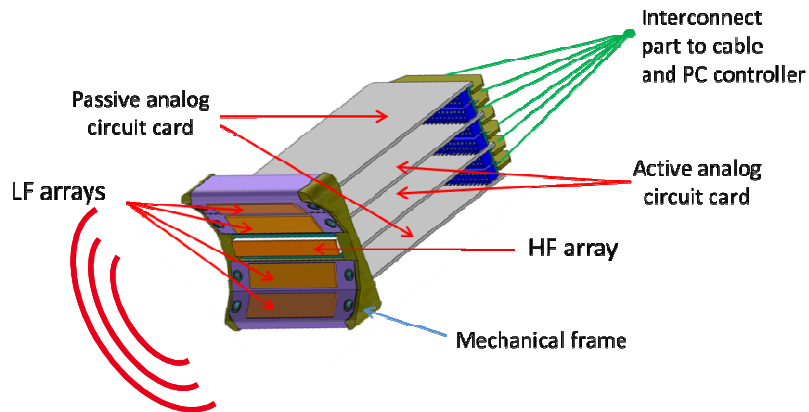
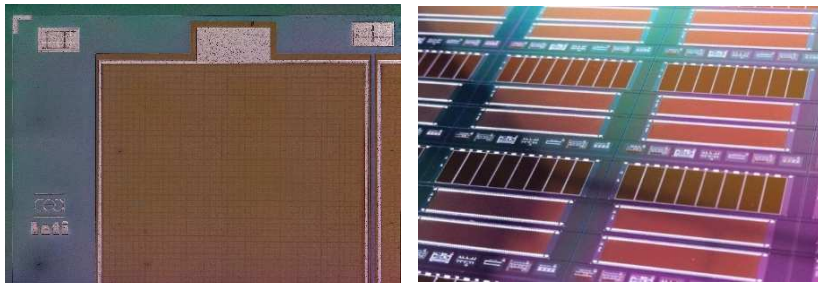
	PZT LETI
$\epsilon_r$	< 1600
$ e_{31,eff} $ (C/m <sup>2</sup> )	18
Breakdown field (V/m)	110
Electric losses (tan $\delta$ )	$3,5 \cdot 10^{-2}$
Technology	Sol-gel deposition



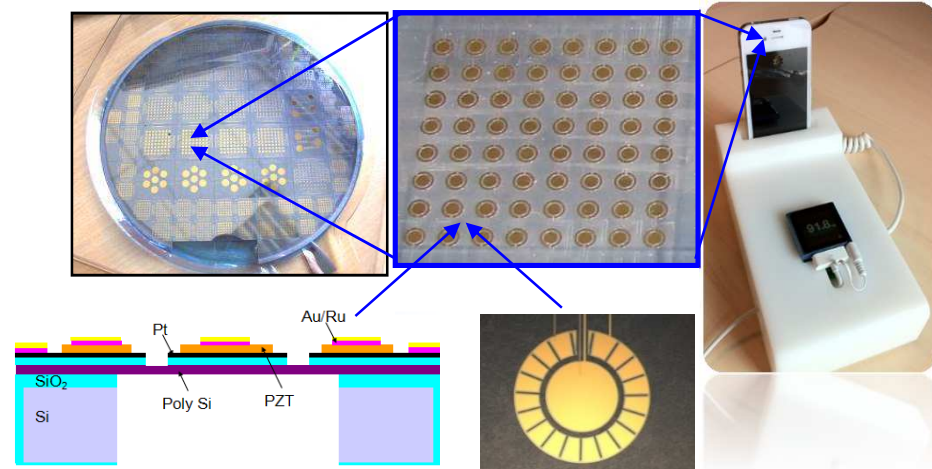


# RECENT ACHIEVEMENTS

## CMUT-based dual-mode probe for theranostics



## Piezo-actuators for acoustics @ 25 kHz



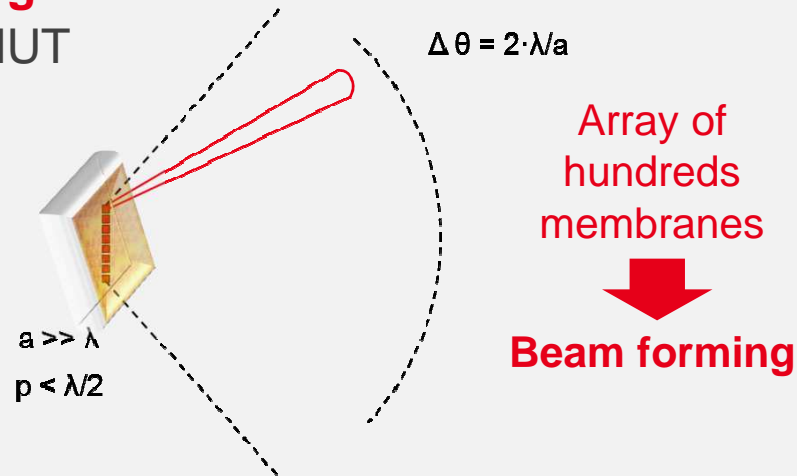
Actuation voltage < 30 V

Thickness < 1mm , size 1 x 1cm<sup>2</sup>



## Under Development : pMUT « Acoustic imaging »

pMUT



Distance	> 5 m
Field of view	120°
Angular resolution	10°
Time Response	30 ms



## CONCLUSION

- ✓ **Complementary pMUT and cMUT technologies for different applications**
- ✓ **Design and modelling of the whole system @ LETI :from acoustics to electrical signal through electro-mechanical transduction**
- ✓ **8” piezo-MEMS pilot line (PZT, AIN, ...) @ LETI**
- ✓ **Piezoelectric material at the state of the art**
  
- ✓ **MUT will benefit from co-design of MEMS / ASIC / software including beamforming strategies**