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Development of Low Cost Piezoresistive Organic Cantilever Resonator

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Introduction

- We present the first piezoresistive transduced organic cantilevers in dynamic mode. The reported sensors have been fabricated using an innovative low-cost and environmentally friendly fabrication process.
- Electromechanical characterization of the organic cantilevers as a function of temperature has been performed validating this new concept.
- Finally, the organic MEMS has been used to extract mechanical properties of organic material.

1. Innovative fabrication process

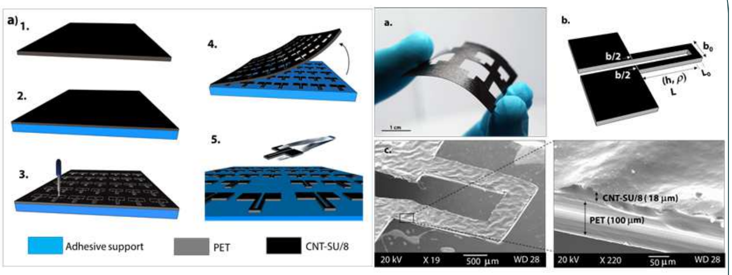

FIG 1a) Fabrication process flow of the U-shaped organic resonator, 1b) Optical image showing the flexibility of the bimorph nanocomposite + PET sheet after structures' patterning, 1c) Schematic of the U-shaped cantilever and 1d) SEM images of the U-shaped organic MEMS

- Extremely quick and low cost two steps fabrication process (FIG. 1a).
- Overall equipment cost estimation < 4,000 USD.
- Consequently, it could be applied to a wide range of polymers leading straightforward to the development of organic electronics.

2. Piezoresistive transduction

- The resonant frequencies (f_r) have been measured to be 3602 and 3597 Hz for optical and piezoresistive transduction respectively showing a good agreement between the two transduction methods (FIG. 2a).

- Quality factors: 21< Q < 23
- Good correlation with FEM simulations.
- f_r decreases with increasing temperature (inset FIG. 2b).
- Excellent linearity of the response (R=0.9975).
- Sensitivity = -0.33%/°C.
- LOD = 0.112°C.
- Comparable to commercial Pt100 temperature sensor.

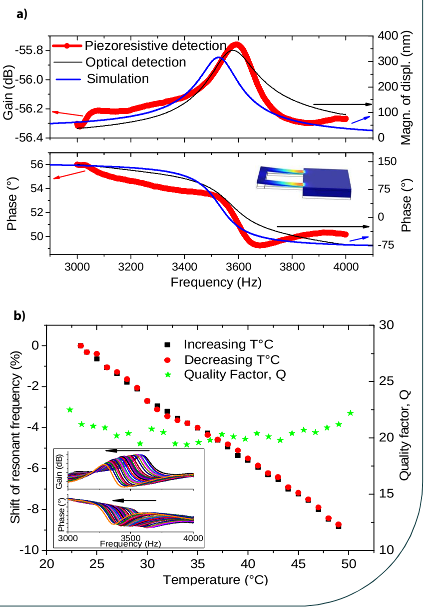

FIG. 2a) Comparison between SEM simulations optical and piezoresistive detection method for the 1st flexural mode of resonance and 2b) Shift of the resonant frequency and quality factor as a function of temperature changes obtained from electrical measurement of the piezoresistance; inset: Measured resonant frequency versus temperature where the arrows show the direction of the shift of the resonant frequency with increasing temperature

3. Possible applications

3.1 Temperature sensor

- The sensitivity of the thin film, U-shaped cantilever in static and dynamic modes to temperature have been measured to be -863, -976 and -3300 ppm/°C respectively (FIG. 3).

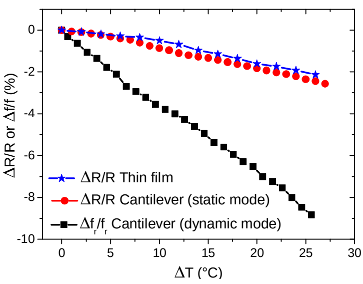

FIG. 3. Relative change of resistance or resonant frequencies for thin film and U-shaped cantilever in static and dynamic mode

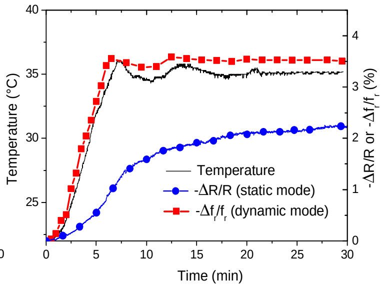

FIG. 4. Temperature control and real time responses of the MEMS in static and dynamic mode

- Quick response of the device in dynamic mode while a long delay in response to temperature can be seen due to the viscoelastic properties of the material in static mode (FIG. 4).
- Integrated piezoresistive transduction in dynamic mode clearly appears to be the method with optimal efficiency for temperature sensing.

3.2 Mechanical properties of organic material characterisation tool

- Determine accurately the variation of storage modulus (E') and tangent delta (tan δ) as a function of temperature of any organic material used as substrate in the MEMS structure.
- Excellent correlation of the E' and tan δ measured by DMA and MEMS resonator (Table 1 and FIG 5).

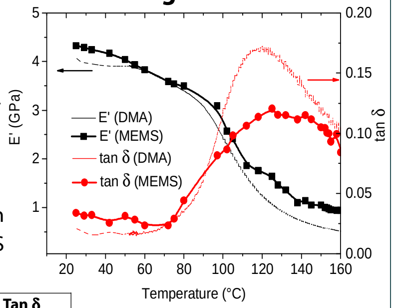

FIG. 5 Mechanical properties of the PET based U-shaped cantilever material as a function of temperature measured with the organic MEMS device and DMA

CNT-SU/8 on:	E' (GPa)		E"(MPa)		Tan δ	
	DMA	MEMS	DMA	MEMS	DMA	MEMS
PET	4.43	4.38	131	192	0.034	0.043
PEN	2.90	2.81	290	256	0.069	0.088
Paper	4.33	4.11	625	471	0.072	0.109

Table 1. Measured storage modulus of bimorph materials of CNT-SU/8 nanocomposite deposited on PET, PEN and paper substrates.

Conclusion

- Organic resonators have been fabricated using a quick, low-cost and environmentally friendly fabrication process. The developed fabrication method can be applied to a large panel of organic materials and can be seen as a considerable breakthrough for the development of low cost organic electronics devices.
- The quasi perfect correlation between FEM simulations, optical and piezoresistive responses convinced us to be the first piezoresistive transduction in organic MEMS resonators reported to date.
- Moreover, the MEMS resonators have also been converted from their initial purposes to determine the mechanical properties of organic materials. It has been shown that mechanical properties such as E' and tangent delta of organic material can be accurately extracted by recording the changes of resonant frequency of the fabricated MEMS.