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TOWARDS ALL-ORGANIC EMBEDDED SENSING SYSTEMS

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Abstract
In this work, organic electronics and polymeric transducers have been combined in order to design an embedded system with innovative materials. Two research backgrounds have been combined to realize an all-organic device able to transduce motion in electrical signals and vice versa. Moreover, a conditioning circuit for polymeric trasducers has been designed.

Key words
Organic electronics, organic trasducers, IP^2C

1 Introduction

In the last decades, organic materials have been tailored to obtain features to be applied in electronic device manufacturing. New molecules have been designed with enhanced properties like lifetime, environmental stability as well as solution processability and feasible charge mobility. Thanks to the improvements obtained in recent years, organic semiconductors exhibited charge mobility values comparable to amorphous silicon and polysilicon. Moreover, stamp-based imprinting processes have been adopted as lithographic techniques with tens of nanometers in scale and lower costs compared to conventional lithography. Imprinting techniques, combined with low-cost deposition processes like spin-coating and inkjet printing, have been adopted to realize multilayered structures of materials processed by solution like transistor, resistors and capacitors[Fortuna et al., 2008].

On the other hand, material scouting activities have developed a new class of motion transducers which presents several attractive features. Electro-active polymers (EAPs) showing motion electromechanical transduction features, such as IPMCs, have been widely investigated [Bonomo et al., 2006] [Bonomo et al., 2007].The typical structure of IPMCs consists of a fluorocarbon membrane containing sulfonate groups (usually Nafion® 115 or Nafion® 117), covered on both sides with a metal layer (platinum or gold), used as electrodes. Recently, an innovative class of EAPs with motion transduction capability, called Ionic Polymer-Polymer Composites (IP^2Cs), has been introduced [Di Pasquale et al., 2009] [Fortuna et al., 2009]. These organic trasducers are based on only organic materials: Nafion® membrane and organic conductor as electrodes.

The introduction of electro-active materials enables the growing of new applicative fields characterized by the low costs involved in the device manufacturing.

In section 2 polymeric trasducers are described from their manufacturing to their electrical characterization. An overview of the organic electronics is presented in section 3. In section 4, the design of a peak detector in organic technology is reported with simulation results. Section 5 draws the conclusions.

2 Organic Trasducers

IP^2Cs consist of a fluorocarbon membrane containing sulfonate groups (the thickness being hundreds of micrometers) covered on both sides with a thin organic conductor coating layer (few micrometers) used as electrically conductive surface electrodes. A typical IP^2C sample is a thin ionic polymeric membrane, the usual thickness being about 200 μm, covered on both sides by organic material layers, to form the electrodes. The polymeric bulk has been obtained from one sheet of Nafion® (perfluorosulfonate made by Dupont™). A film of PEDOT:PSS (from 5 μm to 10 μm) has been deposited over the Nafion® surface to realize the electrodes. Moreover, during transducers manufacturing Nafion® membrane absorbs an amount solvent that increases trasducers capabilities. Organic material for electrodes and solvent inside Nafion® membrane are significant element during manufacturing device for obtaining considerable performances. IP^2Cs exhibit both of actuators and sensors characteristics. Strips of these composites can undergo bending features and flapping displacement if an electric field is ap-

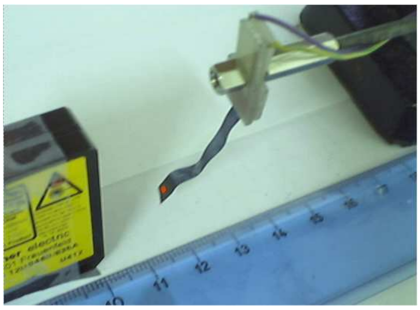

Figure 1. Photo of an IP^{2}C strip during an actuator measurement.

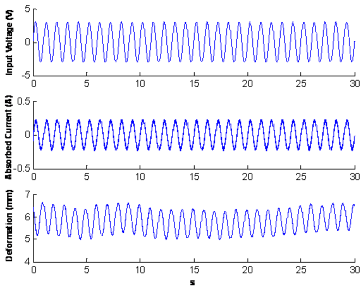

Figure 2. Actuating measurement of an IP^{2}C.

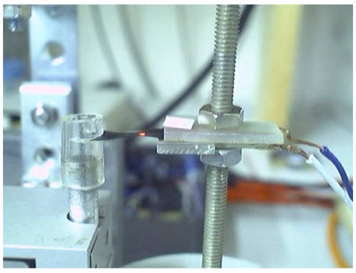

Figure 3. Photo of an IP^{2}C strip during an sensor measurement.

plied across their thickness(Figure 1). Through a conditioning circuit the signals reported in Figure 2 were obtained. The first graph shows the voltage signal applied to IP^{2}C, the second one is the absorbed current from membrane and the third signal is sample displacement.

On the other hand, a voltage is produced when composite strip is bended (Figure 3).

Figure4 shows obtained data through suitable experimental setup:applied displacement, measured blocking force and sensing current.

The IP^{2}C behaviour has been modelled suitably both as sensor and as actuator [Fortuna et al., 2009].

3 Organic Electronics

In the last decade, research on the electrical properties of organic materials has revealed conductive and semiconductive behaviors of such polymers [Dimitrakopoulos and Mascaro, 2001]. A large number of physi-

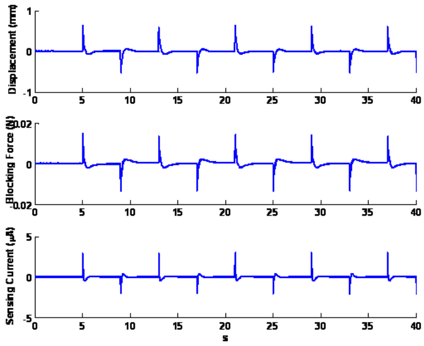

Figure 4. Experimental data: displacement, blocking force and sensing current.

cist, chemical and electronics engineers have been addressed these results towards the proposal of a new class of technology, called organic electronics [Fortuna et al., 2008]. This technology allows the realization of low cost polymeric devices (such as organic transistors resistors, capacitors and conductive lines) over glass or plastic substrates [Fortuna et al., 2009] . Moreover, this technology requires low-price manufacturing processes based on solution and imprinting techniques [La Rosa et al., 2007] . Over the last years, material engineers have synthesized a large number of new polymeric materials, designed ad-hoc in order to achieve the target application requirements. This growing interest for engineered polymers has encouraged chemical companies introducing to market innovative materials. Since the realization of the first Organic Thin Film Transistor (OTFT) in 1983 [Ebisawa, Kurokawa and Nara, 1983] , an intense research effort has been dedicated to both the improvement of organic materials and the development of innovative deposition and manufacturing techniques for low cost electronics assessment. Up to now OTFTs have been investigated for applications in different fields from electronic backplanes in organic light-emitting diodes (OLED), rollable displays, to chemical and bio-FET sensors, to simple logic circuits to be associated with radio-frequency identification (RFID) tags, as well as with thin- film batteries and e-paper in new multi-functional systems [Hoppe and Sariciftci, 2004] [Torsi and Dodabalapur, 2005] [Jang].

4 Design of an embedded organic system

The research activities presented in this work combined polymeric transducers with organic circuits to realize an all-plastic device. Therefore, electronic circuits can be integrated into the transducer system during the manufacturing flow without the need of supplementary assembly processes. The adoption of organic materials, to realize an all-organic device, allows realizing electronic devices of the desired shape and size, over large areas, easily and with a low processing cost.

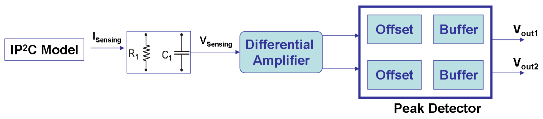

Figure 5. Block diagram of the organic peak detection circuit.

Moreover, thanks to their flexibility new applications can be envisaged in different fields ranging from bio-medical to aerospace industry. An all-organic embedded system, composed of both organic circuitry and all-organic electromechanical devices (IP^{2}C) is proposed with the signal generation, the power supply and the conditioning circuits. In order to develop novel smart applications the electromechanical transducers have been characterized and its behavior has been modeled [Fortuna et al., 2008] [Bonomo et al., 2007] [Di Pasquale et al., 2009] [Fortuna et al., 2009]. The polymeric composite sensing device has been modeled by defining the dynamical system that transforms the applied mechanical stimulus into the sensor electric reaction. A model has been implemented in CADENCE® environment to design a system that includes both the IP^{2}C sensor model and the organic peak detector schematic able to sense the deformation of the system. The IP^{2}C sensor model follows the equation 1, extracted by cantilever model of Eulero-Bernoulli [Bonomo et al., 2006], that allows to obtain sensing current from sample displacement.

$$\frac{i(s)}{\delta(s)} = s \cdot \frac{3t_h wY}{4L_S} \cdot d(s) \tag{1}$$

With suitable parameters values both IPMC and IP^{2}C sensor behaviour can be modeled through the equation 1. In Figure 5 the block diagram is reported which explains each component of designed circuit. The IP^{2}C model is the first block that generates sensing current. Through RC block sensing voltage is obtained and put in input at differential amplifier. The last circuit allows to obtain output signals for detection of direction peak.

The entire circuit has been simulated by means of Mentor Graphics ELDO and all components are shown in Figure 6, 7 and 8.

The organic device is composed of a differential amplifier with a current mirror and a set of source common amplifiers with only p-type organic thin film transistors.

4.1 Simulation Results

The simulation, reported in Figure 9 and Figure 10, shows that when the membrane is subjected to impulsive displacement (Delta), it produces a current slope which flows through the RC block. A sequence of two opposite voltage peak is detected by the differential amplifier producing two opposite output signal.

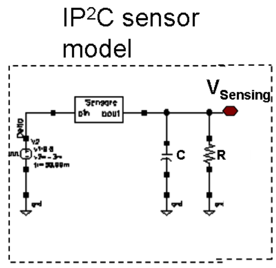

Figure 6. Schematic of the IPMC model block.

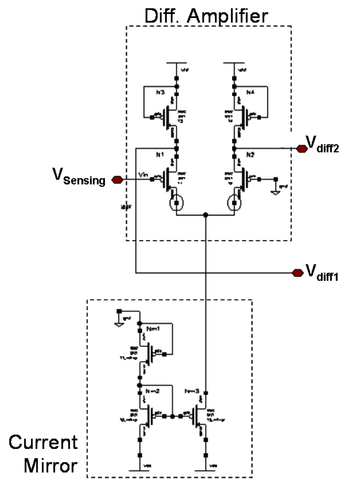

Figure 7. Schematic of the organic differential amplifier.

The output signals are amplified by two amplification stages producing two delayed output voltage pulses. If a negative displacement is applied the pulse produced in the second output is delayed respect the first output; when the membrane is subjected to a positive displacement a delayed pulse is observed in the first output. The produced signals are well-matched with organic digital circuits which can compute the information developed by the peak detection circuit in order to obtain complex sensing information. For example, a set of IP^{2}C or IPMC, each coupled with its peak detection unit, can be used to obtain organic complex motion sensing systems, such as organic forward/backward incremental encoders.

5 Conclusions

Organic electronics and polymeric transducers have been combined in order to design an embedded system with innovative materials. All-organic peak detector have been designed and simulated in CADENCE® environment with an IP^{2}C sensor model.

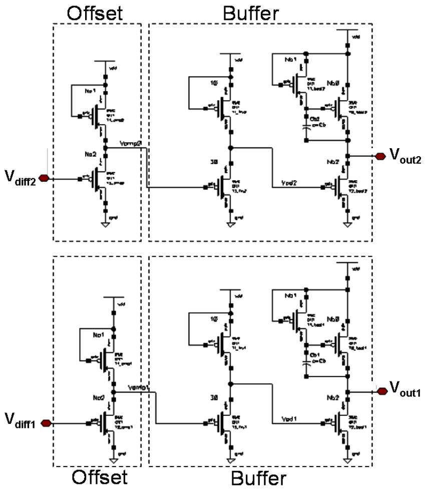

Figure 8. Schematic of the organic peak detection circuit.

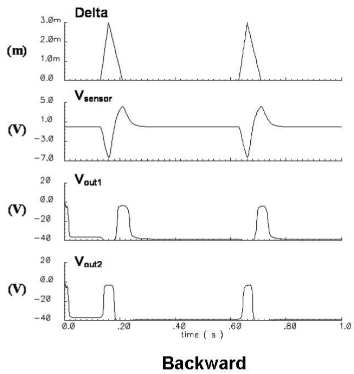

Figure 9. Simulation results of the organic peak detector applying a positive displacement.

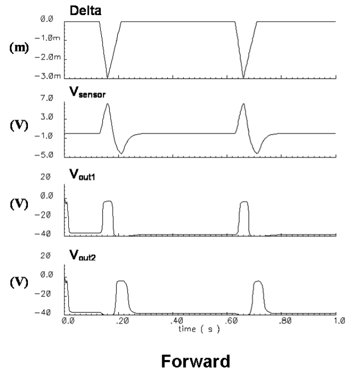

Figure 10. Simulation results of the organic peak detector applying a negative displacement.

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