ULTRA-SENSITIVE SHAPE SENSOR TEST STRUCTURES BASED ON PIEZO-RESISTIVE DOPED NANOCRYSTALLINE SILICON

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This paper describes the miniaturization of dense piezoresistive sensor arrays based on doped hydrogenated nanocrystalline silicon deposited on flexible substrates. The substrates are 125 µm-thick polymide (PI) or polyethylene naphthalate (PEN) foils that are rugged, flexible and bendable. The nc-Si:H films, with a thickness of the order of 100 nm are prepared by radio-frequency plasma-enhanced chemical vapor deposition under high-vacuum conditions. The doping level and crystalline fraction were optimized for maximal gauge factor (GF) values. Longitudinal gauge factors GF = -30 and +26 were obtained for n- and p-type nc-Si:H films, respectively.

A piezoresistive flexible sensor for later incorporation in sensing devices for medical applications has been fabricated and its strain sensing potential under laboratory working conditions was demonstrated. The outcome of the first biocompatibility tests shows that the material is not harmful for the tested cells (osteoblasts) but, more important, it favors cell proliferation. This could be exploited in future clinical devices. The sensors, used in a Wheatstone quarter-bridge configuration, show similar sensitivity (output voltage amplitude ~30 µV/nm) when used either in the parallel and transverse relative directions of current and strain, as shown in Fig. 1. This high sensitivity achieved indicates that bi-dimensional mapping of a growing biological tissue or analogous may be accomplished using piezoresistive sensing. Hence, the scale down limits to achieve such high spatial resolution is being developed.

In this paper we describe, in a first approach, the fabrication of test structures, by the use of optical lithographic processes. The test structures consist of piezoresistive rectangularly shaped elements, having lateral dimensions in the range 50 to 100 microns, defined by a reactive ion etching process on nc-Si:H. At the end of each element, two metallic pads, forming ohmic contacts to the sensing elements, are defined by a lift-off process. Electrically conductive leads connect to the electrical pads, allowing wiring to be done in a region far away from the sensors active region. In this way, and using a parallel voltage divider configuration, the piezoresistive sensors periodically distributed in a row, are addressed and read in real-time.

Since the sensing action of the elements consists of a change in their resistance, it is possible to perform their readout without switching elements (e.g. MOSFETs) inside the array, which simplifies the fabrication process. The readout technique is based on a two-port network, where either a current is applied to the device and the voltage at its terminals is measured, or a voltage is applied and the current is measured. Fig. 2 shows the readout circuit for a 4 × 4 sensor array, with the switches connected to read R11. Notice that since the impedance of the ammeter is very low, sensors R12, R13 and R14 are shunted and their currents are null.

The piezoresistive response of the test structures is analyzed in terms of reliability, sensitivity and linearity. Similar test structures being protected by an optimized encapsulating layer will have wear resistance and fracture toughness tested.

The spatial resolution of the sensors is addressed by bringing them into contact to surfaces having specific topographic feature distributions. The electromechanical experimental tests of the sensor assembly are described by theoretical Finite Element Modeling and compared to the experimental results.

Acknowledgements

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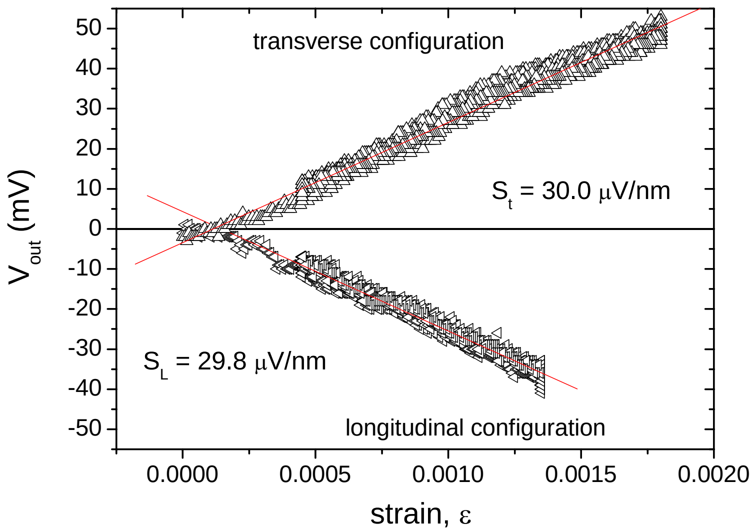

Fig.1 – Wheatstone bridge output voltage, V_{out}, (sensors in a quarter-bridge configuration) as a function of applied axial strain, ε, for two sensor orientations: (bottom) placed parallel to the strain axis, and (top) placed orthogonal to the strain axis.

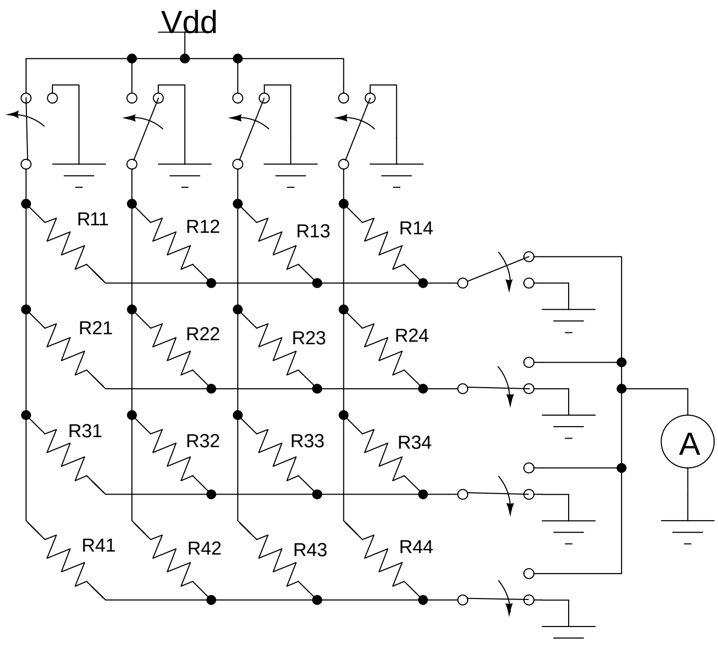

Fig. 2 - Readout circuit for a 4 × 4 sensor array, with the switches connected in the position to read R11. In this case, a voltage is applied to R11 and its current is measured. R12, R13 and R14 are shunted, so their currents are null.