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POSFET Tactile Sensing Arrays using CMOS Technology

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Abstract

This work presents fabrication and evaluation of novel POSFET (Piezoelectric Oxide Semiconductor Field Effect Transistor) devices based tactile sensing chip. In the newer version presented here, the tactile sensing chip has been fabricated using CMOS (Complementary Metal Oxide Semiconductor) technology. The chip consists of 4 x 4 POSFET touch sensing devices (or taxels) and both, the individual taxels and the array are designed to match spatio-temporal performance of the human fingertips**.** To detect contact events, the taxels utilize the contact forces induced change in the polarization level of piezoelectric polymer (and hence change in the induced channel current of MOS). The POSFET device on the chip have linear response in the tested dynamic contact forces range of 0.01–3 N and the sensitivity (without amplification) is 102.4 mV/N.

"Keywords: POSFET, CMOS, Tactile Sensing, Extended Gate, PVDF"

1. Introduction

Touch sensing plays an important role in various application domains such as robotics, electrotextiles and medical prosthesis. A large amount of efforts has been devoted on the development of tactile sensors and over the years, touch sensing technology has improved. Many new touch sensors using different materials and transduction methods, viz: Resistive, Piezoresistive, Quantum Tunneling, Capacitive, Optical, Ultrasonic, Magnetic, Piezoelectric etc. have been developed [1, 2]. Suitability of these sensors to a particular application depends on number of constraints, which include size of the sensors, response time of the sensors, and physical features such as bendability or conformability etc. Many times the sensors are big in size and considering also the associated electronic circuitry, they are unsuitable for body sites like robot's fingertips, where large numbers of sensors with high density are needed. For this reason, MEMS (Microelectromechanical Systems) based miniaturized touch sensors with on-chip

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electronics have been explored [3]. MEMS based sensors are quite sensitive, with their usage limited to applications where strength of the contact forces (to be measured) is very small. The maximum contact forces (~ 0.25 *N*) that MEMS based sensors can detect lie in the lower range of the contact forces experienced by humans in a normal manipulative tasks (~ 0.15–0.9 *N*). The mechanically flexible OFETs (Organic Field Effect Transistors) have also been employed for measuring contact parameters [4]. Besides mechanical flexibility, OFETs have advantage of easy and economical fabrication. However, organic devices typically have short life, are less robust, and much slower in comparison with the devices developed using silicon technology. Best organics are known to have a mobility of about 1 cm^2/Vs versus 85 cm^2/Vs for silicon based MOS devices [5] - which limits their usage to measurement of slow varying contact events. On other hand, silicon technology allows us to have high performing and miniaturized sensors with possibility of having electronics on the chip (leading to a full tactile sensing system on chip). The touch sensing chip reported in this work is therefore developed using the silicon technology. For long, the major drawback of using silicon technology for applications like electronic skin has been the lack of bendability. Recent technological advances such as ultra thin chips [6, 7], and the Si-NW approach [8, 9], however, hold a great promise in the direction of having silicon based mechanically flexible systems.

This work presents the design, fabrication and evaluation of a new version of POSFET touch sensing device based tactile sensing chip. The 4 x 4 POSFET devices based tactile sensing chip has been implemented using CMOS technology. The CMOS implementation is useful as it allows implementation of on-chip electronics. In this regard, this work extends our previous work on the POSFET tactile sensing devices [10-12]. Previously the tactile sensing chips were developed with POSFET sensing device only. The POSFET devices in the new chip have been redesigned to have an aspect ratio (*W/L*) of 273. As shown later in the experiment section, the redesigned POSFET have improved sensitivity, which is more than two times that reported previously [10]. This paper is organized as follows: The concept and working of POSFET touch sensing device is briefly presented in section II. Section III presents the design, and fabrication of the POSFET tactile sensing array. The evaluation of new POSFET based tactile sensing chip is presented in section IV.

2. Working Principle of POSFET device

The structure of a POSFET touch sensing devices is shown in Fig.1. The piezoelectric polymer film is present over the gate area of the MOS device. The transducer material is thus an integral part of the device. The remanent polarization (P_r) of the polarized polymer and the principle of charge neutrality lead to the appearance of fixed charges $\pm Q$, as shown in Fig. 1. When external force is applied on the POSFET device, additional charges (proportional to the applied force) are generated in the piezoelectric polymer film. Because of charge neutrality requirements the additional charge (or the force variation) is reflected into the channel, thereby modulating the charges in the induced channel. In this way the (contact) force is directly reflected as the variation in channel current of the POSFET devices – which can be further processed by an electronic circuitry that may also be integrated on the same chip. Using semiconductor devices as sensor, as proposed here, enables true system integration as the integration of sensor and electronics begins right from the transducer level.

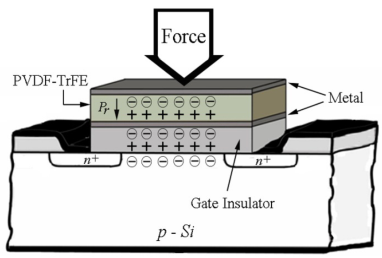

Fig 1. The structure and working of a POSFET device.

Similar approaches, but using extended gates, have been reported in the past for ultrasonic [13], pressure sensing [14]. In the extended gate approach, the gate terminal of a MOS device is connected to a large size electrode or the extended gate that is located elsewhere on the chip. Like POSFETs, the extended gate approach too brings the sensor and conditioning electronics closer and hence the overall response is better than the conventional approach - where the sensor and conditioning electronics are placed apart. However, extended gates introduce a large substrate capacitance (whose value depends on the substrate), which in turn, significantly attenuates the voltage available at the gate terminals of MOS transistors. Thus, benefits of closely located sensor and electronics are not fully exploited with extended gate approach. With piezoelectric polymer on the gate of the MOS itself, the POSFET touch sensing devices are relatively free from such issues. Further, unlike extended gate approach, the POSFETs occupy lesser area on the chip. The saved silicon area can be used to accommodate on–chip electronics and signal conditioning/processing circuitry.

3. Design and Fabrication

The POSFET devices have been designed to have an active area of 0.9 *mm* x 0.6 *mm* so as to obtain spatial acuity comparable to that of human fingertips (~1 *mm*). This design makes the POSFET chip suitable for applications such as robotic fingertips, where human like tactile spatio-temporal response is desired. For large transconductance, the n-MOS device in POSFET has been redesigned to have an aspect ratio (*W/L*) of about 273. The large value of channel width (*W)* is obtained by designing a serpentine like or interdigitated gate structure [12]. The fabrication process of POSFETs is similar to the one presented in [12]. It is based on a non-standard 4-μm CMOS technology with Al gate and nMOS transistors on p-well. As shown in Fig. 2, the fabrication starts with boron implant and diffusion to create deep p-wells to insulate the n-type devices. A Si_3N_4/SiO_2 double layer with equivalent thickness 45 nm is used as gate dielectric. The double layer dielectric is inherited from the template technology, originally developed for integrated chemical sensors. A 500nm-thick layer of LPCVD LTO (*Low Temperature Oxide*) silicon oxide is deposited for electrical insulation, followed by contact hole realization and patterning of Al wires. Then, the FET section of the device is completed with the deposition of a second layer of 300nm of LPCVD LTO to insulate Al wires, with openings for electrical contacts. Then, a 2.5 *μm* thick P(VDF-TrFE) piezoelectric film is spin coated on the wafer and top metal (Cr/Au) is then deposited by e-gun evaporation and further defined over the gate area of POSFET only. The metal is also used as mask during subsequent plasma etching of the polymer. The fabrication steps related to deposition and processing of piezoelectric polymer film are similar to those reported in [15].

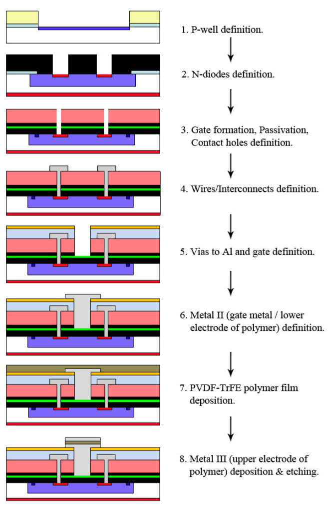

Figure 2: Schematic process flow of chip fabrication

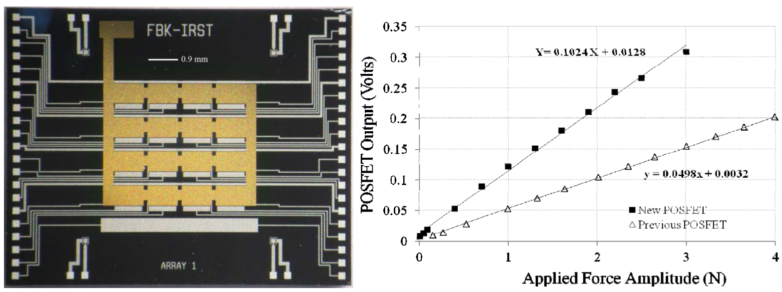

Fig. 3: (left) The POSFET tactile sensing array after fabrication. (right) Comparison of POSFET response with previosus version.

4. Results

The fabricated 4 x 4 POSFET tactile sensing array is shown in Fig. 3. The POSFET device was tested by applying normal dynamic force in the range 0.01-3 *N*. In operative conditions the FET gate is floating and the top contact (over polymer) is short-circuited to drain. The chosen source-follower configuration does not provide amplification. Nonetheless, this configuration provides higher output robustness to gain mismatches between different devices on the array. The sensitivity of POSFET device is 102.4 mV/N (Fig 3), which is more than twice the value reported earlier [2, 3].

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