Thinned CMOS Pressure Sensors for Applications in Tactile Sensing

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In order to allow for a dexterous handling of objects, the skin of a human hand is covered with mechanoreceptors, which exhibit a great dynamic range. Not only can they detect the light touch of a feather but also the weight of carrying a heavy object. At the fingertips the spatial resolution, at which touch can be sensed, lies in the millimeter range. Additionally, sensing of other physical properties like temperature is possible. Mimicking these skin properties is of great scientific interest. Some of the promising application areas are those of humanoid robots and prosthetics.

Developing a technical equivalent to the human skin is of great scientific interest. A system equipped with such a skin will be able to mimic the human ability to handle objects of different sizes and shapes and to adapt to new previously unknown objects. Humanoid robots, for example, shall one day be able to perform tasks in unstructured scenarios like acting as household service robots. So at least their hands have to be equipped with sensors to measure the contact forces. Equipping the whole body of a robot with tactile sensors will be beneficial as this allows for detecting accidental contacts, which is an important safety feature to protect nearby humans from injuries.

Another possible application for a technical skin is to enhance prostheses. A variety of hand prostheses have been developed: from simple grippers to more sophisticated myo-electric anthropomorphic hands [1] that can be controlled by muscle activity in the residual limb. However, these prostheses don't provide touch sense feedback. Without feedback gripping and moving objects requires constant visual supervision. Consequently, means of providing such a feedback are under active development. Approaches range from tactile displays [2] to stimulating afferent nerves [3].

The commonly used passive arrays based on capacitive [4] or resistive [5] measurements provide a resolution that is comparable to that of a human hand but cannot measure additional parameters like temperature. Therefore, we suggest using active CMOS based sensors to develop an artificial skin. They can measure a multitude of physical quantities and the integration of analog and digital electronics allows transmitting the measured values over a digital network. Employing the network approach greatly reduces the required wiring effort compared to connecting each sensor individually. Additionally, on chip self tests, redundancy and sleep functions can easily be integrated. If the thickness of silicon is reduced to below 50 µm the normally brittle material becomes flexible and the sensors can be applied to curved surfaces.

The flexible tactile sensor array is developed in two steps. Firstly, the system is developed using sensors with normal thicknesses on a rigid substrate to evaluate the suitability of the sensors to measure tactile events. This is shown in Fig. 1. The sensor which has been used is a CMOS integrated capacitive pressure and temperature sensor similar to the one presented in [6]. It is 5.5 mm long, 0.55 mm wide and 0.73 mm thick. The sensors are glued on top of a custom printed circuit board. Electrical connections are made via wire bonding and the bond wires are protected by epoxy. For tactile measurements the pressure sensors are covered with a layer of silicone. Different loads were applied and one

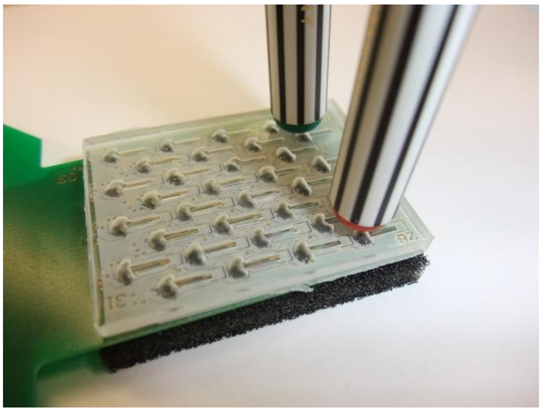

Fig. 1: *Applying a load to a rigid tactile sensor array.*

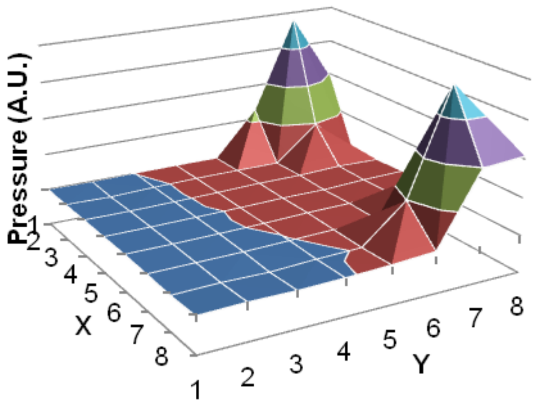

Fig. 2*: Measured values for the load case shown in Fig. 1.*

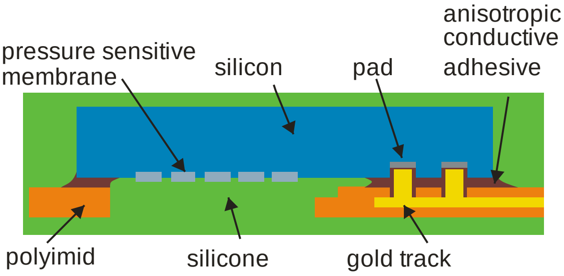

Fig. 3: *Thin pressure sensor chip mounted on polyimide foil.*

example is presented in Fig. 2. It can be clearly seen that the CMOS integrated pressure sensors can be used for a tactile sensor array when embedded in silicone.

For a flexible system every part that is used has to be flexible as well. Therefore, a thin polyimide film has been chosen as the carrier. Fig. 3 shows the design. The silicon sensor chip is glued onto the polyimide foil with an anisotropic conductive adhesive that also provides the electrical connection between the chip's pads and the gold conductors. The membranes may not be covered with epoxy glues as they stiffen the membranes and lead to sensor failure. Below the pressure membranes there is an opening in the polyimide foil to allow for unhindered pressure transmission. For tactile measurements the sensors will be embedded in silicone for mechanical protection.

The sensors are thinned after being glued to the polyimide foil. Therefore, the foil is fabricated on a 3 mm thick glass substrate that is four inch in diameter. The glass substrate is stable enough to be mounted to the lapping jig later in the process. First, an aluminum sacrificial layer is evaporated onto the glass substrate. After that, polyimide is spin coated and patterned. Chromium and gold are evaporated as a plating base and pads and conductors are made by electroplating gold. A layer of polyimide, another layer of gold and a final layer of polyimide follow. An anisotropic conductive adhesive is dispensed at the sites specified in Fig. 3 and the sensor chip is flip chip bonded to the polyimide foil (Fig. 4). Subsequently, the adhesive is cured. To avoid chip breakage during lapping the chips are embedded in a photoresist. After lapping the protecting resist is dissolved and the chip is covered by a resist prior to etching the sacrificial layer. As a last step the resist is dissolved in acetone.

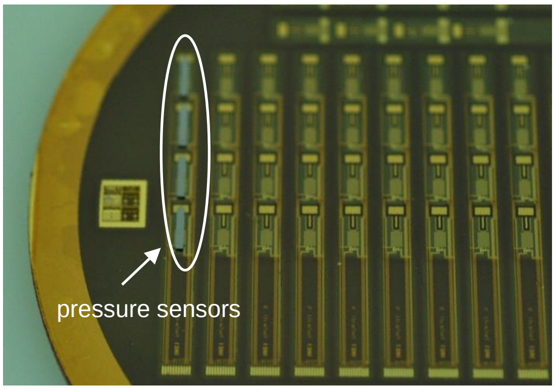

Fig. 4: *Flip chip bonded pressure sensors before lapping*

The membranes of the sensors were visually inspected after lapping down to 55 µm and no damage was observed. The correct function of the thinned sensor was evaluated in a pressure chamber in which the air pressure was varied between 1000 mbar and 1400 mbar. From Fig. 5 it can be clearly seen that the sensor still works when thinned down to 55 µm.

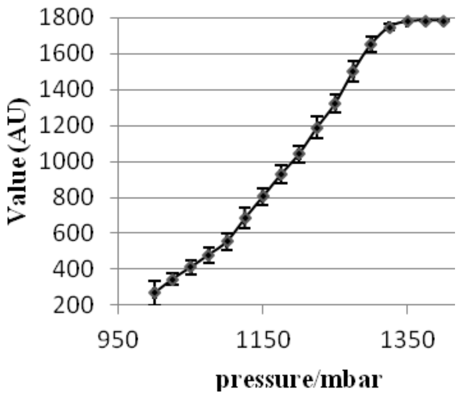

Fig. 5: *Result of sensor characterization*

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