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Flip-chip packaging of piezoresistive pressure sensors

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Abstract

A packaging technology for piezoresistive silicon pressure sensors is presented which is based on the use of standard flip-chip bonding of the sensor die on a printed circuit board. The assessment of the packaging proposal has been carried out by using low-range, high-sensitivity relative pressure sensors. The characterization of the fabricated devices has shown the feasibility of the proposal in terms of stability and sensitivity although a higher dependence of the sensitivity on temperature than in the case of standard packaging. Since this drawback can readily be compensated for by the signal conditioning circuitry, the proposed packaging scheme can be of interest for cost-limited applications.

Keywords: Pressure sensor; Flip-chip; Packaging; Piezoresistive

1. Introduction

Much attention has been paid to the packaging of piezoresistive silicon pressure sensors since the performance and reliability of the device is greatly influenced by the encapsulation materials and packaging scheme used [1–3]. In addition, the need for a direct interaction between the silicon sensor and the medium makes protection against aggressive media compulsory [4]. All these constraints can lead to sensors in which the packaging represents more than half the cost of the device.

Among the different approaches proposed to tackle the packaging problem of microelectromechanical systems, flip-chip assembly has been considered of interest in terms of miniaturisation, reliability and cost [5,6]. This assembly technique has already been used in the case of accelerometers [7] and very recently for absolute silicon pressure sensors bonded to flexible substrates using conductive polymer bumps [8] or using anisotropic conductive films and stud bumping for the interconnects [9].

In this work a packaging technology based on the use of standard flip-chip assembly of piezoresistive silicon pressure sensors on common printed circuit boards is presented. The packaging proposal has been applied to low range, high-sensitivity relative pressure sensors with the aim of enhancing the effects that flip-chip soldering will certainly induce in the performance of the devices. The final purpose of this work is the assessment of an assembly and packaging proposal to fabricate hybrid pressure sensor systems of reduced dimensions for cost-limited applications.

2. Pressure sensor description

The piezoresistive pressure sensors used in this study have been in-house fabricated by means of a BESOI-based technology [10]. The sensor dice have a squared silicon diaphragm with a thickness of 15 μm and the chip dimensions are 5.38 mm × 5.88 mm. Two types of sensors have been used, their diaphragm dimensions being 1.46 mm × 1.46 mm and 2 mm × 2 mm, labelled Sensor S and Sensor L, respectively. In the standard fabrication technology the electrical connection pads are squares of 400 μm × 400 μm and made of aluminium. This metal, however, is not suitable for the flip-chip soldering process so an additional process module has been included in the fabrication technology in order to have the right metallization. This module, as described in [7], gives rise to a final metallization with gold and represents an additional lithographic mask in the technology. This specially designed mask leads to eight octagonal bump pads with a side of 300 μm, four corresponding to the electrical connection pads of the Wheatstone bridge of piezoresistors and four dummy pads included in order to symmetrically distribute the mechanical stresses that the soldering

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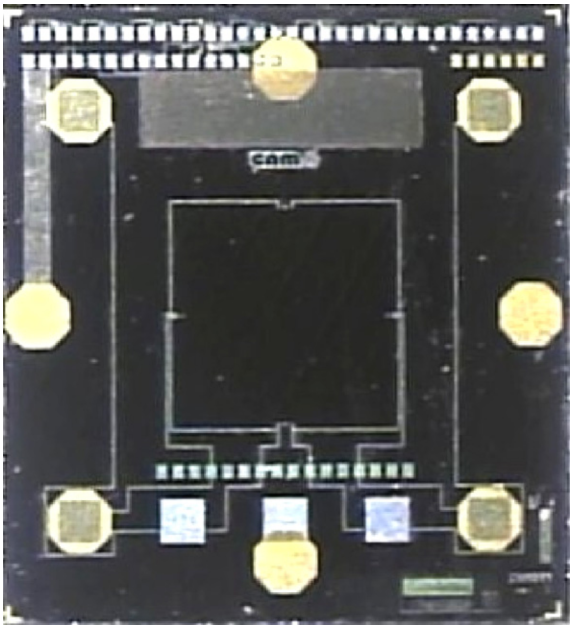

Fig. 1. Top view photograph of a type L pressure sensor showing the eight gold octagonal bump pads for flip-chip soldering.

process will certainly induce in the silicon diaphragm. The layout of the pads can be seen in Fig. 1.

After the complete wafer containing the pressure sensors is fabricated, a first-level packaging is made by anodically bonding a 1 mm-thick Pyrex#7740 glass wafer with the appropriate array of holes, for relative pressure measurement.

Some samples from the same batch were packaged on metal TO8 and using the standard wire-bonding technique. The characteristics of these pressure sensors will be used as a reference and will be compared with the results obtained when using the flip-chip packaging proposal. Measurement of the output voltage as a function of applied pressure has been carried out in the pressure range 0–50 mbar at different temperatures. The results obtained are shown in Fig. 2 for a temperature of 24 °C from which the sensitivities for each type of sensor are calculated, resulting in the following values: 347 (mV/bar)/V for Sensor L and 169 (mV/bar)/V for Sensor S. The dependence of the sensitivity on the temperature is shown in Fig. 3, indicating a linear dependence in the temperature range studied.

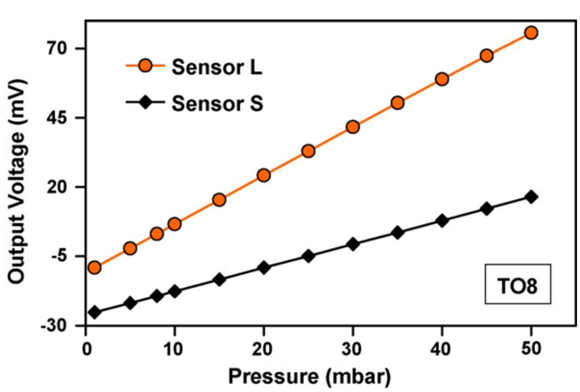

Fig. 2. Output voltage signal of TO8-packaged pressure sensors as a function of the applied pressure, at a temperature of 24 °C and with 5 V of supply voltage. The solid lines correspond to a linear fitting of the experimental results.

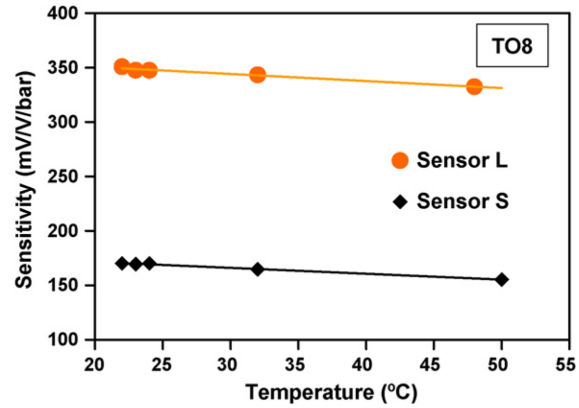

Fig. 3. Sensitivity of TO8-packaged pressure sensors as a function of the temperature.

3. Packaging process

The pressure sensor packaging proposal to be evaluated is schematically drawn in Fig. 4. It consists of a printed circuit board (PCB), with a central drilled hole, on which the sensor is to be soldered in flip-chip configuration. In the case of relative pressure sensors, once the pressure sensor chip is soldered onto the PCB, the assembly flow follows with the sealing of the gap between the chip and the PCB. Finally, the package is completed with the adhesion of a sensor cap on the opposite side of the PCB that will allow pressure application on the top side of the silicon diaphragm of the sensor die.

In the present work, the PCB has been designed with octagonal connection pads with similar dimensions as the ones on the pressure sensor and has been fabricated of laminated FR-4 and gold for the metal pads and connections. With respect to the flip-chip soldering process between the gold pads on the sensor and the gold pads on the PCB substrate, it starts with a screen-printing step using a 100 μm-thick steel stencil and Sn/Pb (63/37) solder paste performed in a DEK248 automatic machine. The sensors are then placed upside down by means of a manual pick-and-place machine. An ambient controlled hot plate is then used to perform a reflow process which melts down the solder paste and links the flip-chip to the FR-4 board.

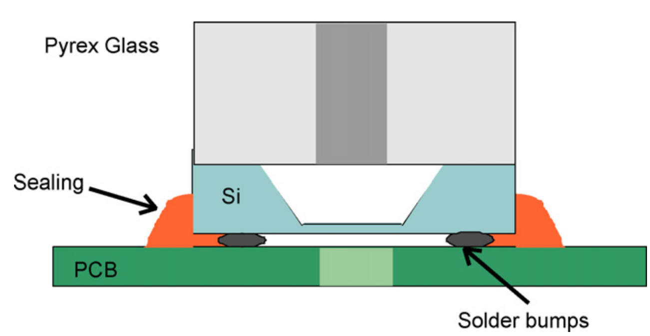

Fig. 4. Cross-sectional drawing of a flip-chip soldered piezoresistive pressure sensor.