Design and Fabrication of a PCB MEMS Module with Integrated Switches and Sensor Suite

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Abstract

We demonstrate the feasibility of integrating Kapton-based MEMS capacitive switches and a sensor suite onto a printed circuit board with minimal impact to existing manufacturing processes. Copper-cladded Kapton laminates were bonded onto rigid PCB substrates with a BCB film spacer. The Kapton was patterned using reactive ion etching to produce MEMS structures such as suspended membranes and flexures. Atomic layer deposited alumina coatings were applied as dielectric layers for the capacitive switches and tilt sensors/accelerometers. The copper cladding was also patterned by etching to function as electrical leads, resistors, and capacitive electrodes. In this way, MEMS switches, tilt/acceleration sensors, temperature sensors, humidity sensors, and vacuum/pressure sensors, were all fabricated monolithically onto a PCB in a single module in the same fabrication process. We describe the fabrication process and demonstrate the functionality of the various sensors and switches in the module.

Introduction

The advantages of fabricating Microelectromechanical Systems (MEMS) sensors and actuators using printed circuit board technology include low cost fabrication, low cost integration with electronics, and suitability for high volume manufacturing for large area applications [1-4]. We summarize our efforts to demonstrate a PCB MEMS module that contains mechanical switches, and sensors for pressure, temperature, tilt and humidity, all fabricated simultaneously and with minimal impact to existing PCB fabrication processes.

Fabrication

The fabrication process is similar to that reported in Ref [4]. The modules are assembled from pre-fabricated PCBs and copper-cladded Kapton films. All of the MEMS devices except the temperature sensors use capacitive sensing or actuation. (The temperature sensor is a resistive device.) The copper layer on the PCB is patterned to create the ground electrodes for these capacitive devices, as well as electrical traces and solder pads, see Figure 1a. The copper is 15-20 microns thick and the traces are 100 microns wide. A 1 – 2 micron-thick layer of benzocyclobutene (BCB) is applied over the copper as a dielectric layer. The Kapton film is processed separately. The Kapton is 50 microns thick, with 5 – 10 micron-thick copper cladding on both sides. The copper cladding on the bottom side is patterned to define the sensing/actuation electrodes for the capacitive devices, while the copper cladding on the top side is patterned to reduce film stress and prevent warping of the Kapton. The film is reactive ion etched to “cut out” shapes in the film corresponding to the MEMS structures, see Figure 1b. Finally, a patterned Kapton film is bonded to a PCB using 1 mil-thick Polyflon™ bonding film. The thickness of this bonding film defines the gap between each device’s ground electrode on the PCB and its sensing/actuation electrode on the underside of the Kapton. The BCB dielectric layer prevents shorting between the ground and movable electrodes. Finally, solder is used to electrically connect the sensing/actuation electrodes on the underside of the Kapton to their corresponding traces on the PCB. Figure 1c shows a typical PCB MEMS module after assembly. In addition, for some assemblies we also used atomic layer deposited (ALD) Al_2O_3 coatings as further protection for the BCB dielectric layer. Each module contains several designs of mechanical switches, and sensors for tilt/acceleration, temperature, pressure and humidity.

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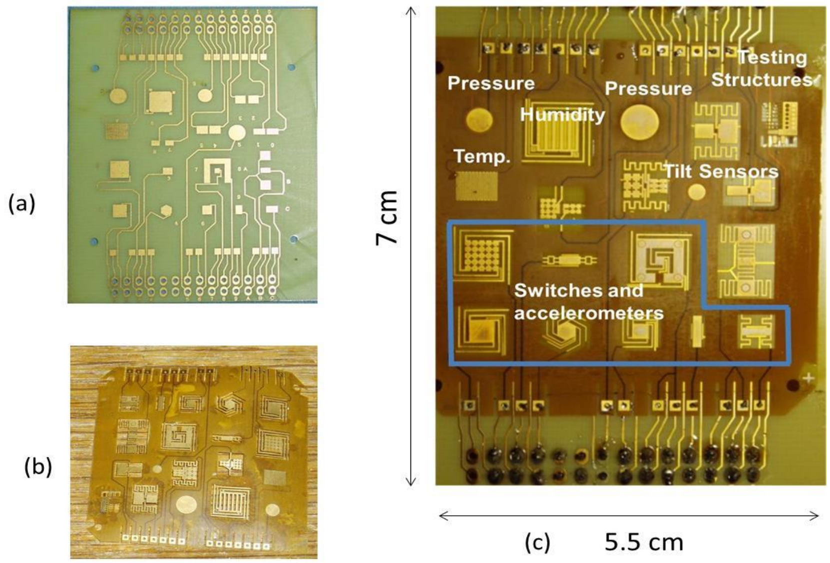


Figure 1. Photographs of (a) PCB with patterned ground electrodes (b) Copper-cladded Kapton film that has been reactive ion etched to create MEMS structures and with the copper cladding patterned on the underside as electrodes and on the top side to reduce film stress and warping. (c) Photograph of an assembled module containing switches and pressure-, temperature- , tilt- and humidity sensors.

Characterization

A. Switches. Figure 2 shows photographs of several designs of mechanical switches on the same module. They all consist of a movable plate (the Kapton) suspended over the ground electrode by tethers. The switch designs vary in the size and geometry of the plates and tethers. In addition, some switches consist of 2 pairs of electrodes mechanically connected to each other but electrically distinct. In these designs, one set of electrodes allows a bias voltage to be applied to partially lower the height of the second electrode, thus reducing the pull-in voltage of the second electrode.

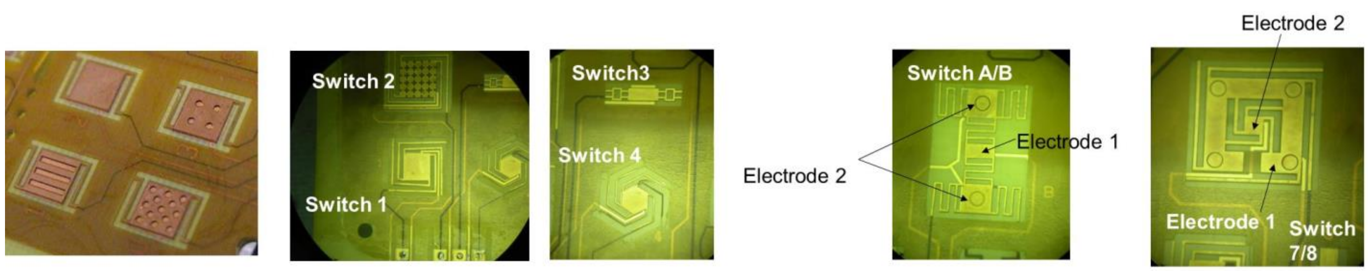


Figure 2. Photographs of several switch designs on one assembly. The plate dimensions range from 4 to 6 mm long

Static characterization consisted of finding the pull-in voltage of the switches, as determined by the voltage at which the plate snaps down and rests on the BCB dielectric layer. Snap-down was determined separately by using a LCR meter to measure the increase in capacitance, and using an optical interferometer to measure the plate's change in height. Figure 3a and 3b show typical measurements of pull-in voltage using these two measurement methods. Most of these switches had pull-in voltages of 80-100V. Dynamic characterization was done by use of a laser vibrometer while the switches were driven with a square wave. The plateaus at the top of Figure 3c indicate a stable "down" position of the plate during pull-in, while the plateaus at the bottom indicate that the plate has fully returned to its original "up" position. The maximum operating frequency was found by increasing the switching frequency until the plate did not have time to fully settle mechanically in either the "up" or "down" position, as shown in Figure 3d for a frequency of about 1.4 kHz.

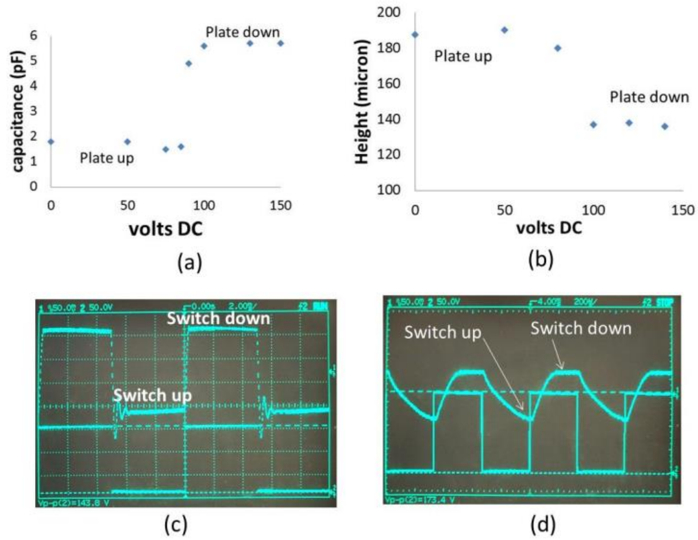


Figure 3. Static (a and b) and dynamic (c and d) performance of the switches. (a) and (b) show the snap-down of the plate at 80-100 V, as determined by the capacitance change (a) and by use of an optical interferometer to measure the change in the plate height (b). (c) Low-frequency behavior of the switch actuation as measured by a laser vibrometer. (d) Higher frequency (1.4 kHz) behavior of the switches, showing that this is the maximum operating frequency for this particular switch design.

B. Tilt Sensors. Figure 4a shows a photograph of the tilt sensors. Each sensor consists of two plates attached to a pivot beam, all suspended. Each plate has a ground electrode underneath it. A 200 mg solder ball is attached to one plate as a proof mass. When the PCB module is tilted, the tilt is detected by differential capacitance measurement between the two plates, as shown in Figure 4b and c. In addition, some of the switches can also be used as single-mode tilt sensors. Figure 4c shows the response of a switch when operated as a tilt sensor, when a 71 mg proof mass is attached to its plate.

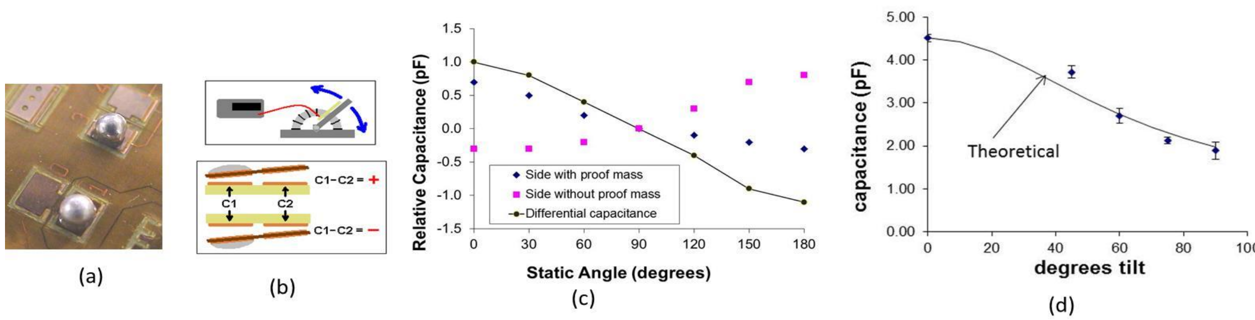


Figure 4. Tilt sensors. (a) Photograph of a tilt sensor with 200 mg solder ball as a proof mass. (b) Differential capacitance measurement of the tilt sensor. (c) Differential capacticance measurement as a function of tilt angle showing the change in capacitance of the side with and without the proof mass, and the differential capacitance (the sum of the latter). (d) Capacitance change of a switch when a 71 mg the device is used as a tilt sensor by attaching a 71 mg proof mass to the plate.

C. Humidity sensor. Figure 5a shows a photograph of a humidity sensor. It consists of a plate suspended above the BCB, with holes in the plate to allow moisture diffusion into the BCB, changing its dielectric constant. Figure 5b shows the test set up for varying the humidity of the chamber containing the PCB MEMS module. The relative humidity (RH) was measured with a commercial hygrometer. Figure 5c shows the PCB MEMS humidity sensor's response to humidity varying from 10-95%.

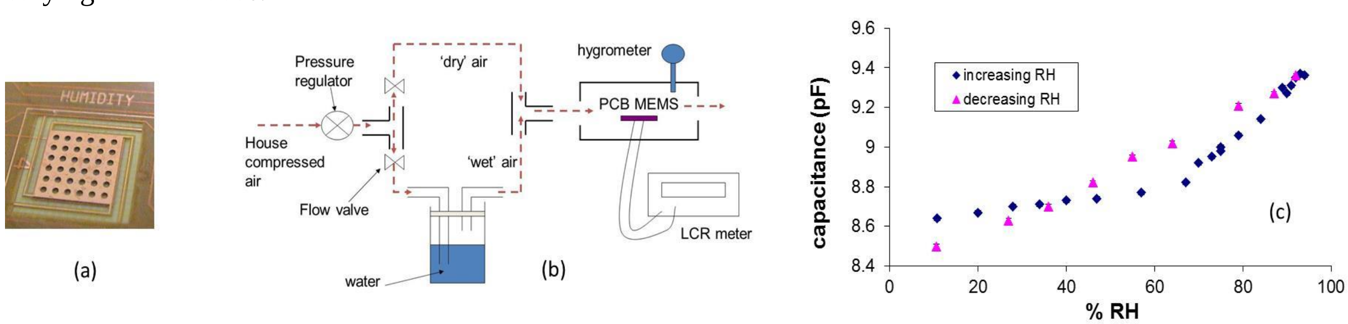
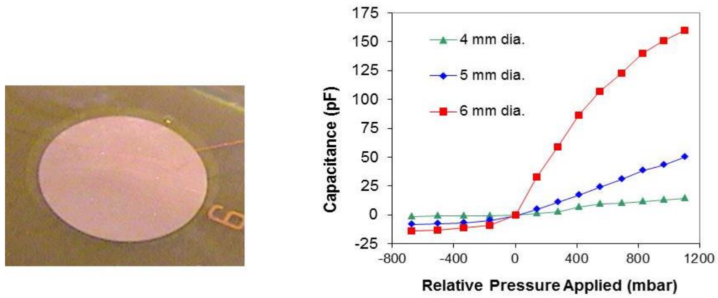


Figure 5. (a) Photograph of a humidity sensor. (b) Humidity sensor test set up. (c) Capacitance change of the humidity sensor with respect to relative humidity. The vertical error is +/- 0.01 pF and the horizontal error is +/- 0.5 % RH

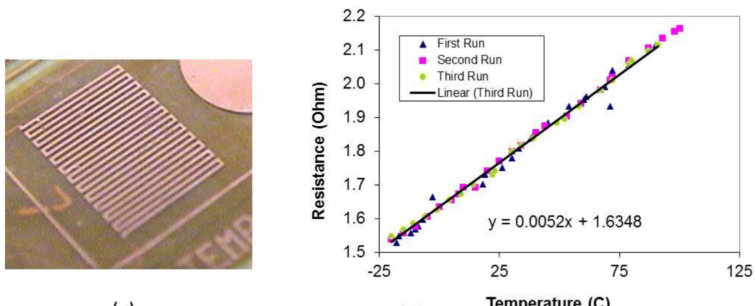
D. Pressure Sensor. Figure 6a shows a photograph of a pressure sensor. It is a circular plate suspended over the ground electrode. The plate is bonded around its perimeter with the bonding film, thus creating an enclosed cavity with 1 atm reference pressure. The PCB module was placed in a vacuum- and pressure chamber and the change in capacitance was measured over a range of pressures, see Figure 6b.



(a) (b)

Figure 6. (a) Photograph of a pressure/vacuum sensor. (b) Capacitance change of pressure sensors of various diameters, with respect to short term static pressure.

E. Temperature Sensor. Figure 7a shows a photograph of a temperature sensor. It is simply a resistor patterned from the copper on the PCB and/or the Kapton's copper cladding. The PCB module was placed in an environmental chamber, the temperature of the chamber was varied, and the temperature sensor's change in resistance was measured using the 4-probe technique. The resistance change is linear with respect to temperature, as expected, see Figure 7b.



(a) (b)

Figure 7. (a) Photograph of a temperature sensor. (b) Resistance of the temperature sensor with respect to temperature.

Conclusion

We summarized the fabrication and testing of an integrated PCB MEMS switch- and sensor suite made by bonding Kapton film etched into MEMS structures onto a PCB. The devices fabricated are mechanical switches and sensors for temperature, pressure, humidity and tilt.

References

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