A Low Cost CMOS Compatible MEMS based Fingerprint Sensor Design

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Abstract: In this paper, a novel design of a fingerprint sensor composed of a 2D array of piezo resistive micro beams has been presented. When the user presses the sensor array with a finger, the ridges and valleys that compose the fingerprint induce corresponding deflections in the micro beams. These deflections can be detected by means of a resistivity change, which when used with appropriate signal processing circuits, convert the deflections into an equivalent voltage signal. The design also includes post processing circuits comprising of A/D converter, needed to digitalize the amplified signal. The digitalized outputs from individual micro beams represent the pixels of the final fingerprint image. A sample data resulting from a sensor array of (224 x 256) micro beams, each of dimensions 50µm x 50µm, has been successfully used to reconstruct an image of the fingerprint using MATLAB. COMSOL Multiphysics was used to simulate the microbeams.

Keywords: Fingerprint, CMOS, MEMS, Piezoresistivity, Micro Beams

1. Introduction

User identification by fingerprint in practical situations is required for better security. As a key device in small and thin fingerprint identification systems, semiconductor capacitive sensors have been developed [1-2]. The first successful implementation of a MEMS based fingerprint sensor was by M. Tartagni and R. Guemeri[2] who used a capacitive sensor. In this case, each pixel has got a capacitive sensor surrounded by the grounded walls in order to polarize the users' finger surface and to ensure ESD tolerance [8]. These walls are generally obtained by gold electroplating so as to overcome oxidation. In spite of these grounded walls, electrostatic discharges can cause serious chip degradation. Another kind of fingerprint sensor was developed, which uses a layer of pyroelectric material above a VLSI circuit [4]. In this case, this layer is to measure the temperature difference induced by the ridges of the finger in contact with the chip surface. These integrated sensors present different disadvantages as the need of specific technology and the medium range operating temperature. Parrain, Charlot, Galy and Courtois[9] designed a new type of fingerprint sensor based on resistivity change. In this paper, the design of fingerprint sensor using piezo-resitive sensors is presented.

When a finger touches a piezo-resistive sensor, the sensor detects piezo-resistance of the micro beams. The piezo-resistance of the micro beams is translated into a fingerprint image. This type of sensor is sensitive to finger surface conditions and humidity in the atmosphere and it is sometimes difficult to obtain clear fingerprint images. This also restricts applications of fingerprint sensors.

To solve this problem, a MEMS fingerprint sensor with novel cavity structures has been proposed. Mechanical deformation of this structure is related to only the topographic information of a finger surface. Therefore, the MEMS fingerprint sensor can obtain surface topography of any finger independent of the finger surface conditions. This means that clear fingerprint images of even dry or wet fingers can be obtained, which widens applications for practical use.

2. Design of Micro beams and FEM Simulations:

In order to determine the behavior of the micro beams, FEM mechanical analysis performed using COMSOL Multiphysics 4.2a software. This FEM software can manage several physical phenomenons nevertheless it does not seem to consider the piezo-resistivity easily. As a remedy, the stress variations with respect to finger force were found.

We have designed two models for the micro beams and analysed the same. Based on the results, as shown in the figures 1b and 2b, for the same force on the sensor, the strain in the circular beam is larger compared to that in the rectangular beam. Hence, we have used the circular micro beams for the use.

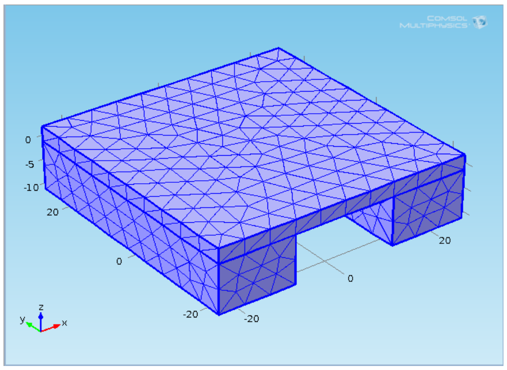

Figure 1a: Geometry

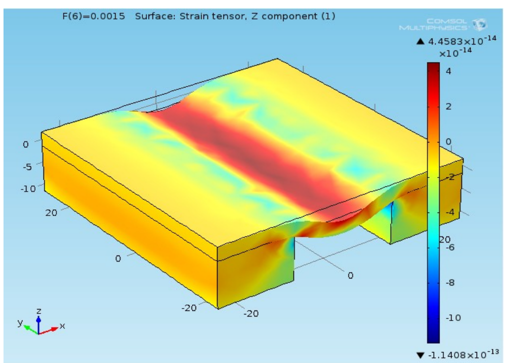

Figure 1b: Strain

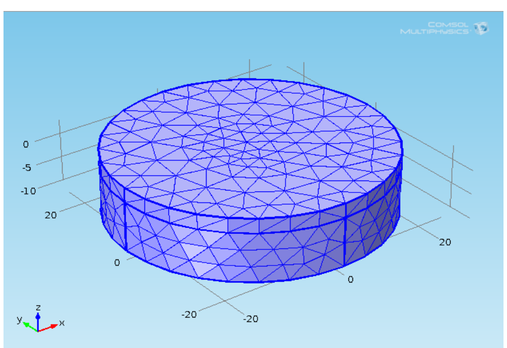

Figure 2a: Geometry

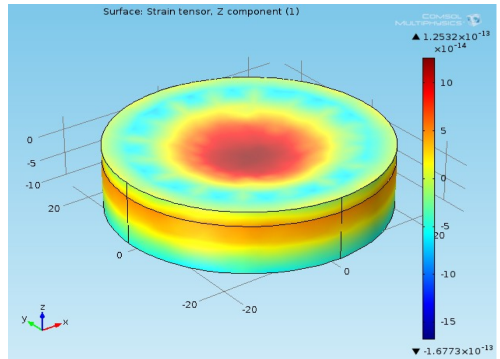

Figure 2b: Strain

The upper limit of the finger pressure in practical use was measured to be 0.6 MPa[5]. Therefore, the upper limit of the force that the finger can exert is 0.6 MPa times the area of the micro beam. From the geometry as shown in the figure 2a, the area of the micro beam is 1.9634e-9 m2. Thus, the upper limit of the force is approximately, 1.178 mN. The strain in the micro beams were found for the different values of finger force upto 1.5 mN and the corresponding values were plotted as shown in the figure 3.

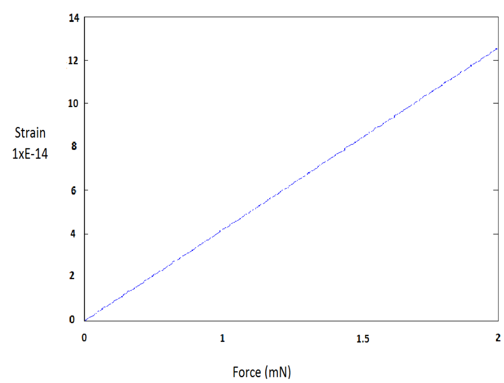

Figure 3: Strain Vs Force

The resistance change in metals is only due to the change of geometry resulting from applied mechanical stress and can be calculated using the simple resistance equation derived from [ohm's law](ohm's law) :

$$R = \rho L/A$$

where L= Conductor length [m] A= Cross Sectional Area of Current flow [m2]

Differentiating this equation, we get

$$\frac{\Delta R}{R} = \varepsilon(1+2\upsilon) + \frac{\Delta\rho}{\rho}$$

The relative change in resistivity is given by

$$\frac{\Delta\rho_{ij}}{\rho} = \sum_{k,l} \pi_{ijkl} T_{kl}$$

Where π = piezoresistivity coefficient and it is ~0 for metals

The gauge factor is given by

$$GF = \frac{\Delta R/R}{\varepsilon} = (1+2\nu) + \frac{\Delta\rho}{\varepsilon\rho}$$

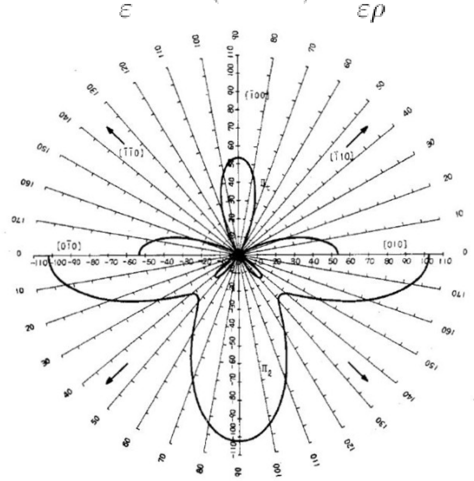

Figure 4: Room Temperature piezoresistance Coefficients in (001) plane of n-Si (in 10-12 cm2/dyne)

Figure 4 shows that the maximum value of piezoresistive coefficients π of n-doped silicon along the direction of <100> is πl =102 *10-11 Pa-1 at the room temperature [12].

The Young's Modulus of Silicon is 162 GPa [11].

Using these values, the gauge factor was found and is given by

$$GF = \frac{\Delta R/R}{\varepsilon} = E\pi_L \approx 165$$

Taking the slope as the Gauge factor, relative change in the resistance ΔR/R was plotted against the strain as shown in the figure 5.

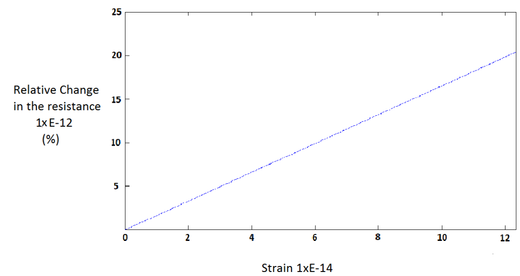

Figure 5: relative change in the resistance vs strain

3. MEMS structure and sensing mechanism:

The MEMS fingerprint sensor has a large number of arrayed small pixels. Each pixel, representing a micro beam, is connected to the Wheatstone bridge circuit, which in turn, is coupled to the amplifier and then to the A/D converter.

As the finger presses the sensor, the stress will be applied on the micro beams. There will be a piezo-resistance in the beams due to this stress. The piezo-resistance in the beams due to ridges will be more than that due to valleys. This relationship Rr > Rv is translated into digitized signal levels. With this sensing, the detected signals from all the pixels generate one fingerprint image.

4. Electronic Control:

The microbeam which acts as a piezo-resistor forms a branch of Wheatstone bridge circuit as shown in the figure 6. The output Vb is passed as an input to the amplifier. The schematic of the amplifier used is as shown in the figure 7, whose output Vout is fed to an 8-bit ADC as shown in figure 8 and is represented by 256 gray scales.

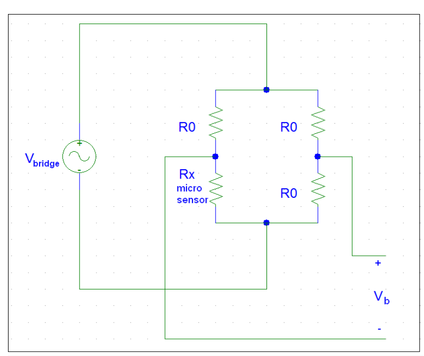

Figure 6: Wheatstone Bridge Circuit

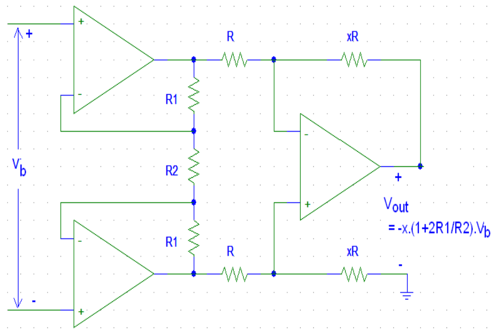

Figure 7: Amplifier

The Schematic of the sensor is shown in the figure 6.

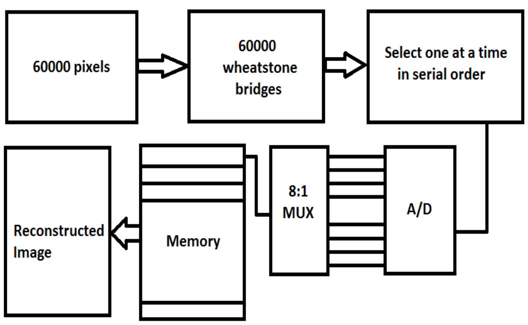

Figure 8: The Schematic of the fingerprint sensor

With an array of 224 x 256 microsensors, and each element connected to one arm of a Wheatstone bridge circuit, use of a multiplexer logic circuit allows one to select one of the outputs at a time. The output from the multiplexer is passed through an A/D converter. The resulting output in the range 0-255, from the A/D converter is stored in the memory, one at a time. The stored data is used to reconstruct the image.

5. Results and Discussion:

The chip is designed with 224x256 pixels in the die size of 15mm x15 mm. Each pixel is a 50-µm square, leading to a good resolution. Based on the FEM simulations, the relative change in resistance increases with the applied force. Therefore, with maximum force, we can get darker and clearer image.

A sample data resulting from an array of 17x13 microbeams located within the image boundary is as shown in the figure 10. The data collected from the 2 types of sensor namely circular microsensor and rectangular microsensor were used to plot the image in MATLAB. The results are shown in the figures 9a and 9b.

Figure 9a: The fingerprint image generated by circular microsensor

Figure 9b: The fingerprint image generated by rectangular microsensor

The results clearly show that, for the same amount of force, the fingerprint sensor with circular microbeam produces image with the better contrast, than the ones with rectangular microbeam.

26	71	94	178	252	239	173	83	11	0	13	68	144
0	1	0	70	173	236	242	175	75	2	0	7	100
68	67	8	7	76	190	247	234	178	80	3	1	84
226	189	83	11	0	56	192	249	248	164	66	11	13
248	255	192	99	22	6	61	188	253	244	182	69	2
148	245	250	181	88	12	0	77	172	254	251	174	126
32	166	245	255	196	80	28	0	63	191	235	250	255
40	36	174	244	245	206	74	18	7	61	185	244	247
152	30	47	148	243	254	205	81	11	7	67	185	252
247	140	49	55	156	234	252	200	91	0	10	161	251
246	226	139	32	50	153	154	219	190	90	26	110	203
197	230	244	111	5	23	41	143	237	201	35	9	103
37	60	187	128	16	0	0	147	255	220	75	0	20
17	27	200	200	117	36	8	161	241	217	170	53	1
78	28	190	252	217	93	26	87	188	255	243	89	14
191	32	151	228	254	220	48	14	93	249	230	120	40
207	47	22	146	253	203	55	0	81	228	255	224	130

Figure 10: Sample data from the sensors

6. Conclusion:

This paper has described the work about the design of two types of CMOS compatible MEMS based fingerprint sensor, one with circular microbeam and the other with rectangular microbeam. The fingerprint images simulated using both the designs when analysed, shows that the fingerprint sensor using circular microbeams, gives an image with better contrast due to the better sensitivity. This sensor has the potential to widen the application of fingerprint identification in various environments. Future work will be on the integration of the sensor into more complex SoC device including MEMS part and analog and digital signal processing unit. This highly integrated fingerprint recognition system will make the processes such as scanning, image processing, signature extraction and matching done using a single chip.

7. Acknowledgements:

The authors are grateful to Birla Institute of Technology and Science, Pilani for providing institutional support to carry out the research.

8. References:

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