International Journal of Applied Engineering Research ISSN 0973-4562 Volume 10, Number 17 (2015) pp 38102-38104

Matrix Of MEMS Pressure Transducers For Tactile Diagnostics Devices

D.V.Gusev, R.S.Litvinenko, V.S.Sukhanov

SPC “Technological center”, Moscow, Zelenograd, Georgievskiyproezd, bld.5

Abstract
The article presents the design of a silicon crystal matrix of piezoresistive pressure sensing elements MIPD-32 for tactile diagnostics devices. The principle of operation is described, and experimental data of the pressure transducers sensitivity is shown.

Keywords: Minimally invasive surgery (MIS), MEMS, tactile sensor.

1. INTRODUCTION
Currently methods of minimally invasive surgery (MIS), where operations on the internal organs are held through small (2 cm) incisions, are actively developing. These methods allow the operator (surgeon) not to enter into direct contact with the internal organs of the patient [1].
Although MIS has a lot of advantages, for example, less tissue damage, less blood loss, faster recovery period, less postoperative complications, shorter hospital stay, improved cosmetic results, it is also characterized by several disadvantages, including: the lack of haptic feedback, the need to increase technical expertise, longer duration of surgery and the difficulty of removal of the bulky organs. Among these problems the most serious is the loss of tactile functions [2].
The surgeon uses the sense of touch to get the basic information about the state of the examined tissue. For example, if the tumor is hidden in the depths of the healthy tissue, it is almost impossibleto detect it visually. In open surgery the surgeon has a free access to organs and tissues and can manipulate them. However, during laparoscopic operations the direct palpation of internal organs and tissues is impossible. This is the major obstacle to the development of MIS methods. In this regard, for further development of MIS it is necessary to create tools to obtain tactile information.

2. THEORETICAL PART
Tactile sensorstechnologies are rapidly evolving, and the interest in them is growing steadily. The main constraint in this area is not a limitation on computing power of the processors used, it is the lack of technologies that can convert volumetric haptic interaction into an electrical signal.
The main trend in the field of tactile sensors is reproducing the haptic properties of human skin. Matrix tactile devices match this requirement in the best way, since each cell of the matrix, which represents a microelectronic strength sensor, gives specific information, while together they form a complete view of the form of the object [3]. Known attempts to use most types of sensors (capacitive, magnetic, optical, piezoelectric, etc.) as artificial receptors. Most of them have significant drawbacks that either make it impossible to use them in practical applications, or impose significant limitations [4].
Silicon tensoresistive pressure transducersare the most suitable for creating tactile sensors. This statement is reinforced by the global experience [5], which shows that the process of creating arrays with a high density of sensing elements is joined with silicon technology, including MEMS devices. One of the key benefits of silicon MEMS devices is the ability to create sensitive elements on production lines for CMOS circuits. Silicon bulk micromachining technology is well studied and allows to produce crystals with high (more than 40 units/cm2) density of sensitive elements. Silicon also has a strong piezoresistive effect, almost ideal elastic characteristic, high mechanical strength and stable electrical characteristics for a long time.
Due to the high linearity of response and low hysteresis value high accuracy of the output signal of the transducer can be achieved. At the same time, the problem of temperature dependence can be solved by means of temperature compensation.
For the effective application of sensor matrixes in haptic diagnostics devices it is requiredto cover with sensors a surface space comparable to the phalanx of the surgeonsfinger. This means that the design of the matrix should allow to combine multiple chips into a single device. In such cases, the problemofa huge number of interconnects arises, which not only affects the overall reliability of the product, but also creates obstacles to miniaturization. The only solution is the integration of active devices directly into the crystal.

3. EXPERIMENTAL PART
Based on many years of experience [6] in the field of tactile transducers in SPC "Technological center" crystal MIPD-32 (Fig.1) was developed. Crystal, made by siliconbulk micromachining technology, is a matrix of 32 pressure sensitive elements with a membrane thickness of 17±3 μm. Sensitive elements of the matrix use tensoelectrical effect occurring in silicon under the action of external mechanical impact, and are designed for use in the pressure range 0÷100 kPa. The pressure is applied on the lower side of the crystal. The size and shape of the crystal due to the need to install it in the standard sized endoscope (10mm in diameter).

International Journal of Applied Engineering Research ISSN 0973-4562 Volume 10, Number 17 (2015) pp 38102-38104

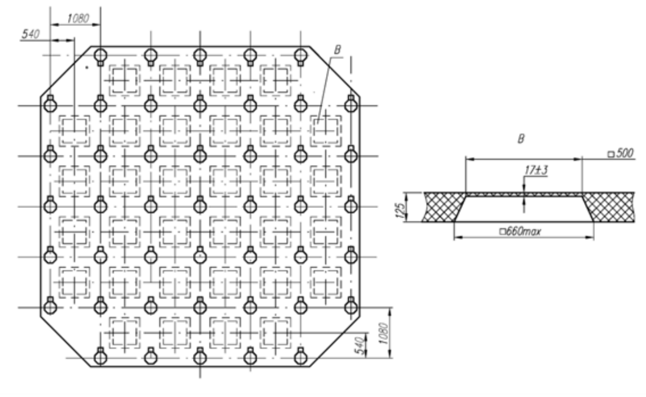

Fig.(1).- Design of MIPD-32

Besides 32 tensobridges the crystal contains a temperature sensor for temperature compensation and power supply monitor (Fig.2). Each sensitive element is sequentially queried using the 34-bit shift register scheme on static synchronous D-flip-flops, clocked by the signal level, and CMOS pass keys. Pass keys and shift register are integrated directly into the MIPD-32, which means combining MEMS and CMOS technologieson a single chip. Analog part (strain conversion devices, temperature sensor)supply voltage is +1.2...2.5 V. Digital part (the shift register and the keys) supply voltage is +2, 5...5, 5 V.

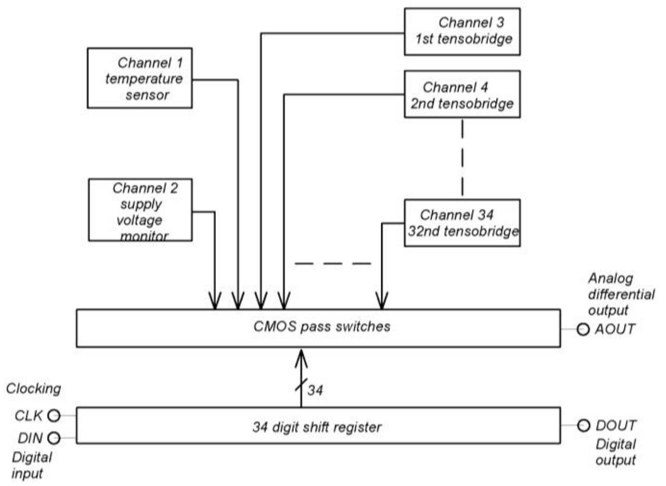

Fig.(2).- Structural scheme of MIPD-32

34-bit line of series-connected D-flip-flops is designed to enable the pass keys. The output DOUT is suitable for cascading the next crystal (Fig.3); thus the total bit width shift register will increase by 34 with each crystal connected in the cascade. Connecting the output DOUT of the last crystal to the microcontroller, it becomes possible to automatically determine the number of crystals in the cluster.

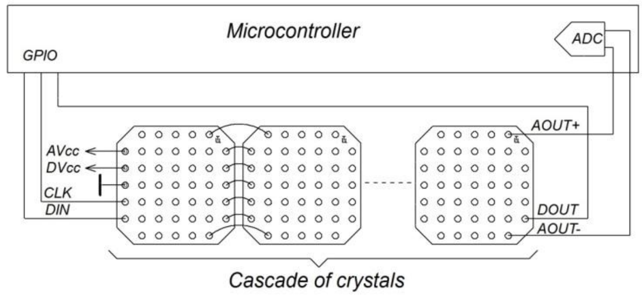

Fig.(3).- The scheme of inclusion crystals in cascade

Most of the pads are duplicated, except DIN and DOUT circuits. In case of wire welding itsimplifies the cascading of modules in clusters at the expense of the installation of wires directly from crystal to crystal.

The average value of the pressure sensitivity is 0.1 mV/[V*kPa]. According to experimental data, the variation of sensitivity is close to the normal distribution (Fig.4) and is ± 0, 033 mV/[V*kPa] (3σ level).

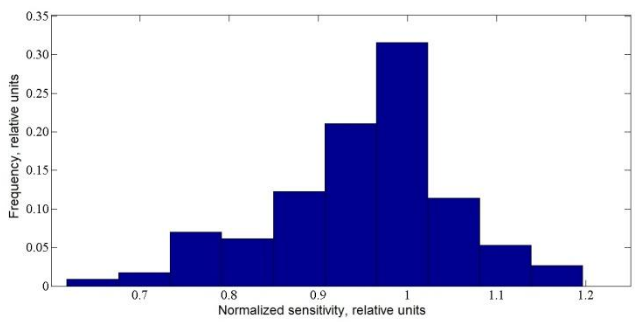

Fig.(4).- Distribution histogram of the normalized sensitivity

Following the formula of calculation of specific sensitivity [7], the variation of sensitivity in terms of the membrane thickness is ± 2, 9 µm.

$$S_{sp} = \frac{C}{d_m^2},\ C = 0{,}128\pi_{44}a_m^2(1-\mu),$$

where C - estimate index of the constructionsensitivity(constant for a particular crystal), π_{44} - main piezoresistive coefficient for tensoresistorsof p-type conductivity in silicon orientation (001), a_m - the distance between a pair of tensoresistors on the edges of the membrane, μ - the Poisson's ratio.

This leads to the conclusion that the main reason for the variation in sensitivity of individual transducers is associated with technological variation in the thickness of the membranes.

Theexperimental values of the parameters of the individual transducers are shown in table 1.

The design of MIPD-32 provides the possibility of using the technology of flip-chip mounting. Therefore, all contact pads are placed on the front side of the crystal, thus avoiding external influences on the interconnects during operation of the device.

Table (1). – Characteristics of MIPD-32

Parameter	Experimental value
Applied pressure range, kPa	0÷100
Density of the sesnisitive elements, cm^{-2}	69
Operating temperaturerange, °C	+5 ÷ +50
Operating range of supply voltage, V	Digital: 2, 7 ÷ 5, 5. Analog: 1, 2 ÷ 5, 5
Chip size, WxHxD, mm	6, 8x6, 8x0, 15
Nonlinearitycoefficientat +20°C, %	0, 07
Temperature coefficient of zero offset, %/10 °C	0, 11
Temperature coefficient of sensitivity, %/10 °C	0, 21

4. CONCLUSION

The developed silicon crystal MIPD-32 can be used in hapticdiagnostic devices as a sensor for obtaining tactile information. Combining MEMS and CMOS technologies it was managed to place 32 pressure transducers, temperature sensor, power supply monitor, and a shift register circuiton a single chip. This eliminates the necessity of using complicated and cumbersome external circuitry tocombine several crystals in a single device. The experimental studies of the sensitivity values of the pressure transducers are in good agreement with the calculated values.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

ACKNOWLEDGEMENTS

The work was financially supported by the Ministry of Education and Science of the Russian Federation within state contract No. 14.577.21.0112 (unique identifier applied research RFMEFI57714X0112). The work was carried out using the equipment of CCU “Functional testing and diagnostics of micro - and nanosystem technique" on the basis of SPC "Technological center".

REFERENCES

[1] Ravinder S. Dahiya, Giorgio Metta, Maurizio Valle, GiulioSandini Tactile Sensing – From Humans to Humanoids. // IEEE TRANSACTIONS ON ROBOTICS, 2010. - NO. 1. - VOL. 26. - P. 1-20.

[2] M. Ramezanifard, J. Dargahi, S. Najarian, and N. Narayanan Design, Modeling and Fabrication of a Tactile Sensor and Display System for Application in Laparoscopic Surgery. // World Academy of Science, Engineering and Technology, 2009. - Vol.3. - P. 170-174.

[3] Sadovnichij V.A., Sokolov M.E., Makarovec N.A., Budanov V.M., Podolskij V.E. Mechanoreceptor tactile diagnostics and tactile broadcast in endoscopic surgery. // MOSCOW. 2012. P. 127-149.

[4] Sokhanvar S., Dargahi J., Najarian S., Arbatani S. Tactile Sensing and Displays. // John Wiley & Sons Ltd. 2013. P. 23-34.

[5] Ravinder S. Dahiya, Maurizio ValleRobotic Tactile Sensing // Springer. London. 2013.P. 79-129.

[6] Amelichev V.V., Budanov V.M., Gusev D.V., MihajlovY.A., Sokolov M.E., Suhanov V.S., Tihonov R.D. Design and Technology of Creation of Matrixes of Pressure Converters for Tactile Endoscopy Sensors // Journal of NANO and MICROSYSTEM TECHNIQUE, 2012. - №11. - P. 27-30.

[7] Ignateva E. V., Mikhailov Yu. A., Timoshenkov S. P. On the Structural Design of Membrane with Solid Center of Silicon Pressure Strain Transducer in Range from 0, 025 to 25 MPa. // Journal of NANO and MICROSYSTEM TECHNIQUE, 2010. - №2.- P. 24-31.