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POTENTIALITY OF LTCC FOR SENSOR APPLICATIONS

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Технологія виготовлення кераміки, відпаленої при низькій температурі (НТК), дозволяє реалізувати різноманітні структури для їх застосування в сенсорах. Приклади сенсорів, які виготовлені на кафедрі гібридної мікроелектроніки факультету електроніки і інформатики Технічного Університету в Кошице, демонструють високу якість і можливість застосування НТК в різноманітних товстоплівкових сенсорах. Сенсори для іншого використання можуть бути реалізовані на основі спеціальних НТК багатошарових структур.

Potential of Low Temperature Cofired Ceramic (LTCC) multilayer technology allows to realize different structures for sensor applications. Examples of sensors realized at the Department of Hybrid Microelectronics Faculty of Electrical Engineering and Informatics Technical University in Košice have shown the quality of being potential or possibility of developing of LTCC for wide field of thick film sensor applications. Other sensor applications were realized on special shaped body based on LTCC multilayer.

1. INTRODUCTION

Low Temperature Cofired Ceramics (LTCC) technology offers great design flexibility over conventional thick film, thin film and high-temperature cofired technologies. LTCC technology is revolutionary in that it embeds all of this functionality onto one multi-layered ceramic module, thus marrying ceramic and silicon. Because of the difficulties of integrating passive components onto silicon, LTCC is the best way to move to higher levels of integration and miniaturization.

The introduction of LTCC into thick film technology (TFT) brings a new quality, which enables the production of 3D structures. It has an impact not only on the electronics applications but also much more on the non-conventional TFT applications in the field of sensors. LTCC as "high-tech" micro electronic material is often used for attractive flexibility of shape in conditions enabling multi-layered applications, which are far beyond the hybrid technology. The field of attention includes developments in the technology of substrates for microelectronics and the new multilayer 3D structures for sensors. This article presents an idea of unconventional application of LTCC in the development of some thick film sensors, which was realized on Du Pont DP951 Green Tape™. Presented results of investigations and simulations have been realised on the model of three types thick film sensors based on LTCC:

- On pressure sensor for vacuum sensing and on non-invasive pressure sensor for medical application, which measure the tissue pressure.
- On organometallic gas sensor. In article is presented multilayer heating system based on LTCC for shaping of temperature field distribution, where effects of number of resistors, their geometry as well as arrangement in the system on the temperature distribution have been analysed.

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Possibilities of creation the special sensor carriers based on LTCC for testing in high temperature operation is realised.

• Another idea presented in this article presents results of investigations and simulations that were realised on multilayer models of various shaped structures based on attractive flexibility of LTCC.

2. PRESSURE (VACUUM) SENSOR BASED ON LTCCC

The cylindrical configuration of the pressure (P) or vacuum sensor with the bridge system of the layer resistors is shown in Figure 1 [2].

The voltage U at a diagonal of the bridge is the output signal of the sensor. The characteristics of the sensor based on the piezoresistive effect are hysteresisless and shown linearity conversion of pressure into voltage (P/U). The sensitivity and a range of measurement of the pressure (force) are conditioned by material and dimensions of the membrane. The sensor is appropriated for measurements of vacuum (pressure) in the range of 0 ÷ 100...500 hPa (0 ÷ 100...500 mbar) with the sensitivity of 0.5...1 hPa/mV. It resulted from considerable technological difficulties with the realisation of the sensor (large diameter, small thickness of membrane, GTD 851AT and 951LT CDT etc.).

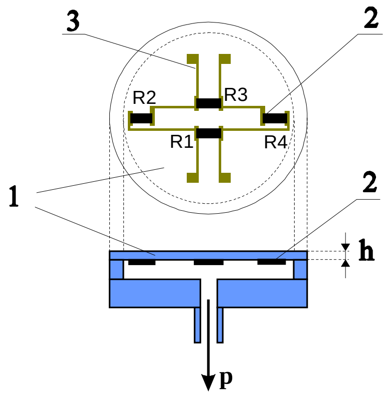

Fig. 1. Vacuum (pressure) sensor: 1– substrate, 2 – resistive layers, 3– conductive layers

The large operational stability of the sensor in relation to time and temperature has been confirmed by the results of the investigations. Perceptible changes of the shape of the characteristics were not observed after 1000 cycles of changes of pressure in the full measurement range. The sheet resistance of the compositions for manufacturing of the bridge resistors has been determined by a compromise between the bridge sensitivity and the immunity of the sensor in relation to interference signals.

An adequate hybrid microcircuit located on the surface of the multilayer LTCC substrate with a internal chamber of the pressure sensor is the essence of the integrated pressure/frequency converter (P/f). The structure of the converter system is shown in Figure 2. All resistors of the sensor bridge have been made with the use of the composition of sheet resistance $R_{\bullet}$ = 100 kΩ. It is the top limited value of the resistance taking into account the interference in the bridge system. The bridge output signal (in μV) is amplified by an instrumental amplifier.

The hybrid microcircuit includes: the instrumental amplifier, the voltage/frequency converter and the power supply circuit. In another version, the system can be provided with a specialised IC (e.g. AD 7710) for digital conversion of the bridge output signal into the standard voltage one.

In practical solution, the op-amp LM 6218 produced by National Semiconductor as an amplifier of the bridge voltage signal has been

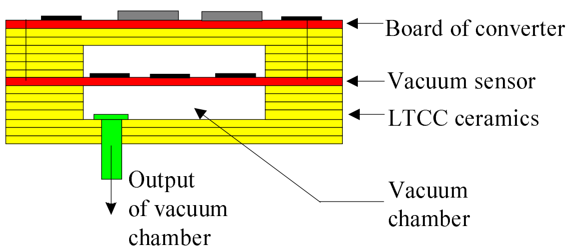

Fig. 2. Construction of converter as hybrid LTCC structure

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applied. Additionally, the amplifier plays the role of a low-pass filter and gives a possibility of the gain control, the temperature compensation of sensor characteristics, the resistance matching of the circuits and the correction of an offset voltage. The specialised integrated circuit AD 654 (Analog Devices) has been utilised as the voltage/frequency converter.

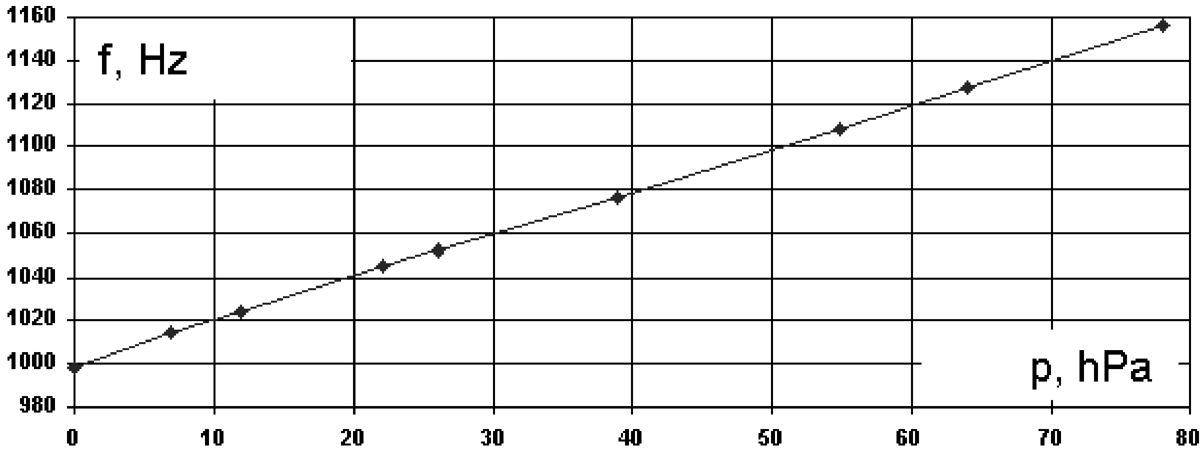

Fig. 3. Changes of output signal frequency of converter system vs vacuum pressure

The basic characteristics of the converter (Fig. 3.) shown a good linearity in the full assumed measurement range (0....100 hPa). Typical sensitivity of the elaborate system is equal to 2 Hz/hPa and 2 mV/hPa with the converter AD 7710.

3. NON-INVASIVE PRESSURE SENSOR FOR MEDICAL APPLICATION

An advantage of LTCC as an interconnect is its ability to construct various geometry by layer cut-outs. This capability of LTCC enables the constructing of thick film pressure hybrid multi-layer sensors which find application in the area of medicine for measurement of “compartment syndrom“ sensors as well as formation of other types of thick film sensors. Activities are oriented on the analysis of stability characteristics of non/conventionally shaped multi-layer modules and determination of their marginal condition, tenzometrical determination of residual tensile and pressure strain in compact and hole status, investigation of the internal multilayer conductive interconnections.

Compartment syndrome (CS) is a condition, witch by the increase of interstitial tissue pressure in enclosed, relatively rigid space is leading to both blood circulation and function in compartment disorder. Diagnostic difficulties may appear if compartment syndrome was not examined or if it was not brought into account. The main and typical CS subjective symptom is a rapid and intensifying acute pain accompanied by spasmodic attacks, which are localized not only in affected muscle groups but also peripherally in the area of a sensitive nerve. Subjective establishing of the smooth tissue rigidity depends on the personal experience of the doctor. That's why there is a natural effort to objectively quantify the stiffness of the soft tissue of the affected compartment. On the basis of requirements of the medical practice, we have developed a non-invasive sensor for the measurement of the tissue pressure based on LTCC ceramics, which was used and tested at the clinics of injury surgery [3].

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The construction of the pressure sensor (Fig. 4.) is based on previous experimental measurements regarding the requirements of the praxis, i.e. the dimensions of the membrane, the range of measurable pressure, sensor encapsulation etc., with the possibility of data processing and interpretation using a computer.

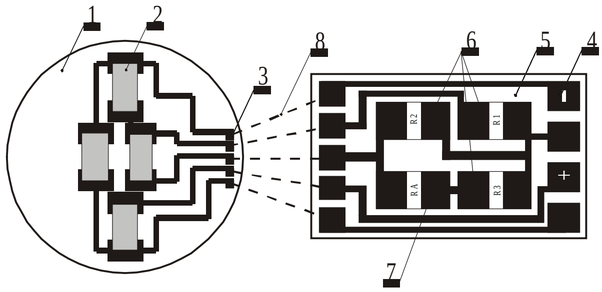

Fig. 4,a. Topology of tissue pressurethick film sensor

The pressure sensor consists of membrane 1 (LTCC) with diameter □ = 18 mm, thickness 200 □m after firing, on which four thick-film resistors 2 are deposited by means of screen-printing using resistive paste R = 100 k□□ The terminals 3 of the Wheathstone bridge are situated on the edge of the membrane, two terminals are for bias voltage □1□V and two are for output signal from the bridge. Thin conductors with the conductive surface 4 on the ceramic plate 5, on which serially parallel resistors 6 are embedded, connect the terminals 3, in the second ramification is the resistor 7 in form SMD. Their resistivity is calculated from the value of the output non-zero voltage with zero pressure. Resistors 6 and 7 provide stable zero output voltage with zero pressure. Circular membrane 1 with the ceramic plate 5 are placed in a metal container 9, witch consists of two parts and is connected by screws 10.

From hardware point of view the data acquisition from the pressure sensor is realized by means of IEC 1625 interface. Considering the purpose of the measurement, the developed software provides these functions: adjustment of the referential pressure levels, pressure measurement in automatic mode with adjustable time interval of measurement, pressure measurement in manual mode by pressing a key, displaying the measured data and reference level on display in graphical and numeric form, storing of the measured data and referential levels on files on hard disk, displaying the measured data in graphical form, setting the data about patient and their actualization during measurement.

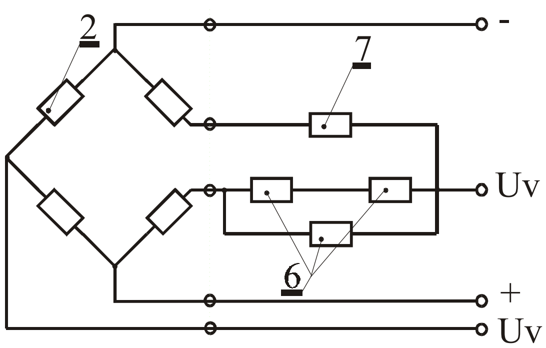

Fig. 4,b. Scheme of tissue pressure thick film medical sensor

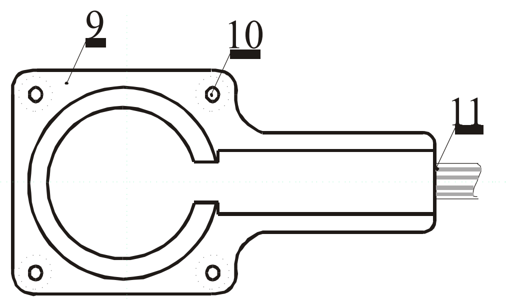

Fig. 4,c. Metal container of the medical sensor

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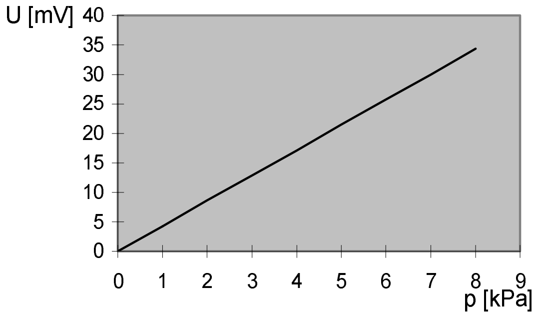

Fig. 4,d. Change of output signal voltage of medical sensor vs, tissue pressure in non-invasive measurement

During the measurement, the function of the display is to show besides the measured data also the name of the patient, his birth number, date and current time. From this state it is possible to adjust the referential pressure level and filling in the data about the patient anytime. The command for stopping the measurement is entered from the keyboard.

Fig. 4,d shows the graphical output from non-invasive measurement of tissue pressure. The output depicts two pressure levels, 1 and 2. The above-mentioned pain of burning character appears during pressure level 2. In that case it is necessary to open the plaster, which will prevent much more serious problems.

4. UNCONVENTIONAL UTILISATION OF LTCC IN THICK FILM GAS SENSOR

One of the important features of LTCC technology is the possibility of fabricating 3D structures using multiple layers of LTCC tapes. In this article we show the potential of ceramic tape technology for implementation of gas sensors, for multilayer heating systems based on LTCC with the aim of shaping of temperature fields distribution and for unconventional utilisation based on its attractive flexibility.

4.1. Multilayer heating structure based on LTTC

Generally the heater has an important role in organometallic gas sensors because the working temperature for methane is relatively high – in the range from 420 to 470°C. The distribution of heating field on the substrate surface is for exact sensors sensitivity very important factor, too. The results of temperature field distribution by the computer simulation made for the multilayer structure with one additional heating resistor placed on the top of whole heating system based on LTCC is in the Fig. 5.

The presented examples of simulations confirm the correctness of a proposed idea of using the multilayer systems for manufacturing different heating systems with a given temperature field distribution. However, these constructions require very precise selection of the shape of particular heating elements, values of dissipated powers as well as theirs mutual arrangement inside the men-

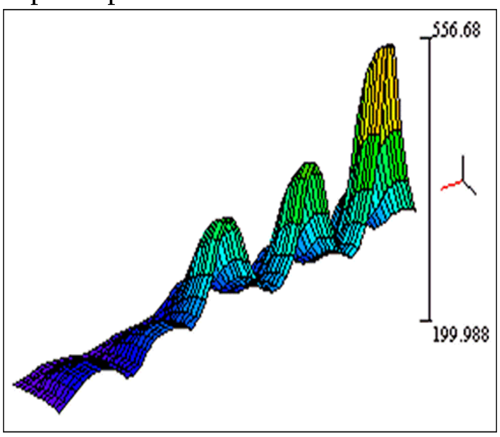

Fig. 5. Temperature field distribution in multilayer structure.
Heat conductivity λ = 2,3 W/mK, substrate thicknessz = $220 \cdot 10^{-6}$ m

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tioned structure. The applied simulation method based on multilayer LTCC allows to obtain fast and relative accurate results which could be employ in some other models, where stabile distribution of temperature field is needed.

4.2. Special Sensor Carrier System for Testing and Measurement Based on LTCC

The special sensor carrier system for testing and measurement of the thick film gas sensor based on the LTCC was developed. The sensor carrier frame made of the LTCC tape enables to create a necessary shape including the open window for sensor unit assembly using standard wire bonding technology. Moreover it enables to use the standard thick film technology for the realisation of a necessary conductive layout for power supply, for the ASIC assembly and/or for realisation of electrical interconnections with another signal processing (i.e. computerised numerical control). This assembly solution eliminates the temperature loss and secondary solves the need for regular electrical connections with additional electronics devices or equipments (ASIC or its computer simulation). The ceramic gas sensor units were mechanically fixed by standard wire bonding technology in special sensor carrier system.

5. ADDITIONAL POSSIBILITIES OF LTCC APPLICATIONS

Other sensor applications demand a special shaped body of LTCC multilayer. Unfired LTCC multilayer could be transformed by bending, pressing or deep drawing. The following chapter should give an overview about some additional possibilities for the realization of sensor structures by LTCC technology with modified materials and three-dimensional shaped set-up.

A mechanical bending process could be utilized for special shaped multilayer sensor. The lamination of common bending LTCC tape allows also the realization of different shaped multilayer as well as multilayer with toplayer or innerlayer structures. The realization of bending structures demands two or more lamination steps for the different multilayer parts and is fabricating under angle of dip from 0 to 90°. But notice, the quality of the transforming process depends on the behavior of the unfired laminate, especially elasticity, plasticity and tensibility. A higher transforming temperature about the lamination temperature is advantageous by the most materials. The application of such a transforming process requires the possibility of a cofiring of all thick film pattern on the multilayer and the ceramic.

The applications of these methods are to be found in liquid sensors, flow sensors, microfluidic elements, sensor carriers [6].

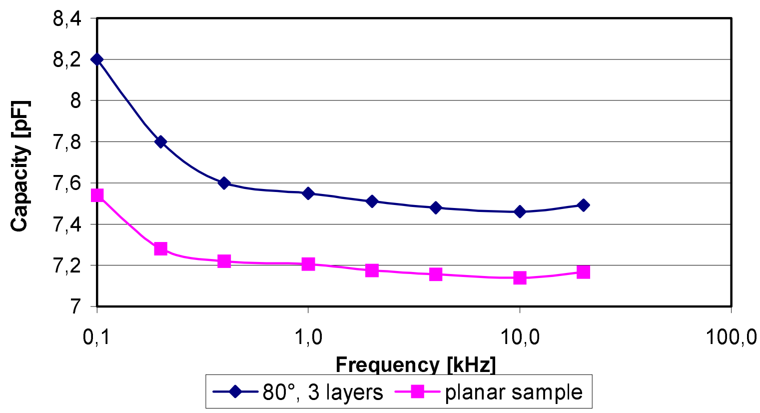

Fig. 6. Dependence of capacity vs frequency in the plane and in the bending structure

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Changes of output signal of conductivity vs frequency represents a small difference between plane and bending structure which contains 8 tape layers. The most noticeable results are evident from the Fig. 6. where is comparison of the dependence capacity on frequency in the plane and in the bending layer multilyer (8 layers) structure based on LTCC. Dependence of voltage cross talk signal vs frequency in the plane and in the bending structure (8 layers) are in the Fig. 7.

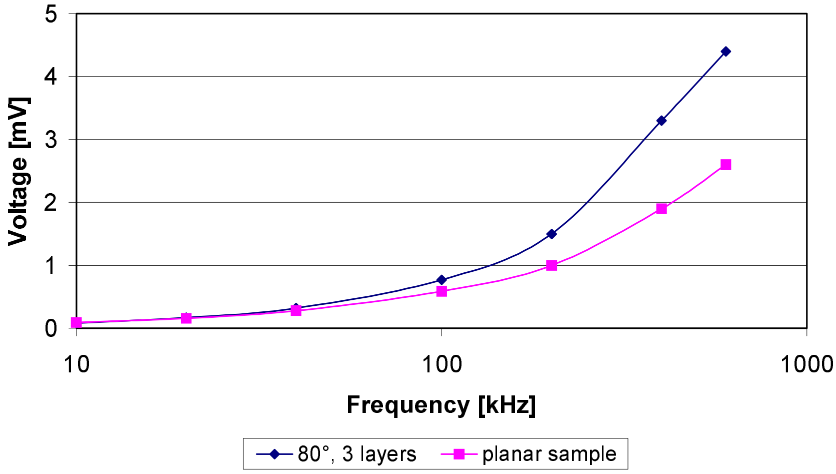
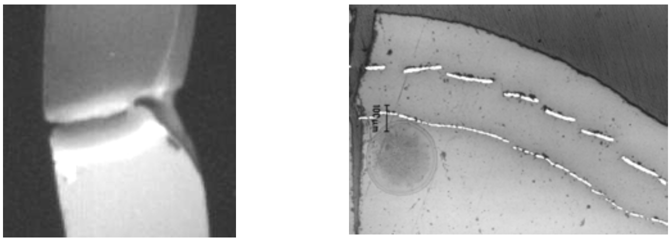


Fig. 7. Dependence of voltage cross talk signalvs frequency in the plane and in the bending structure



a *b*

Fig. 8: a – Failure of bending structure; b – Failure of conductor signal in bending multilayer structure

Investigation shown that bending under angle 80° is possible. Further bending up to angle 80° is critical and as is shown in the Fig. 8. there can be broken either thick film conductor line or whole bending LTCC multilayer (2-8 layers structure).

6. CONCLUSION

LTCC has a unique capability for integrating interconnection circuitry, hermetic packaging, and many passive components into a single monolithic structure. The benefits are reduced size, improved reliability, improved performance and lower cost. Results of investigation of unconventional using LTCC have shown that LTCC is reliable and advantageous material that can be produced in a many types of thick film sensors. An analysis of the expected results have shown that bending technology predicts and demonstrates stabile bending multiplayer signal up to angles 80^0. The approach to this analysis brings interesting results and experience that could be used in the further research work. New materials and processes under development will improve the range and performance of thick film sensors. LTCC brings new quality in the investigation of the thick film sensors.

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ВПЛИВ АТОМІВ ВОДНЮ НА СИСТЕМУ Ni-Ge

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Досліджується процес гетеродифузії в германії під впливом атомарного водню на основі модельної системи Ni-Ge. Розглянуто вплив процесу дефектоутворення на протікання дифузії атомів нікелю в приповерхніх прошарках германію. Розраховано розподіл концентрації нікелю в германії. Запропоновано фізичну модель процесу стимулювання гетеродифузії атомарним воднем з урахуванням впливу дефектів.

Based upon a model system Ni-Ge, research of diffusion stimulated by hydrogen atoms is held. It is shown that defect creation processes caused by hydrogen-atom-recombination have a great effect on nickel diffusion in germanium subsurface layers. The nickel-in-germanium concentration distribution is calculated. The physical model of chemistimulated diffusion is suggested.

Вступ

Однією з найважливіших задач електронної технології є зниження температури процесу дифузійного легування. Проведено дослідження із стимулювання дифузії атомів домішки в напівпровідниках за допомогою енергії жмуту високоенергетичних часток [1-3] (радіаційно стимульована дифузія – РСД) або електромагнітного випромінювання [4-8] (фотостимульована дифузія – ФСД).

Метод РСД дозволяє знизити температуру дифузії до 573 – 773 К [2-3], проте через необхідність відпалу радіаційних дефектів при 1173 К він не має перспективи як самостійний метод легування, але може бути використаний для розгонки домішки після її загонки методом термічної дифузії або іонної імплантації. Серед методів ФСД великі перспективи має лазерне твердофазне легування, що призводить до зниження температури дифузії до 673 – 773 К і дозволяє створювати напівпровідникові структури за дуже малий час (1 с).

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