Comparative Analysis of Simulation Results and Experimental Data of Deflection of Silicon Membrane of MEMS Pressure Sensor

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Abstract – **The article presented research results of stressed and strained state of sensitive element of MEMS sensor depending on the pressure applied. A code for the ANSYS system was developed allowing to automate the process of constructing a solid model of pressure sensor and stressed and deformed state, taking into account technological features of their production. As a result of the program processing one gets graphical dependencies in the plate of the sensor and it's maximum displacement depending on the pressure applied. Experimental study of sensitive element of pressure sensor was conducted, which enable to compare simulation results with experimentally obtained.**

Keywords – **pressure sensor, manufacturing technology, computer-aided design, MEMS, finite element method, multi-physics analysis.**

I. Introduction

Since the discovery of piezoresistivity in silicon in the mid 1950s, silicon-based pressure sensors have been widely fabricated [1]. Increasing demands for new technical systems induce the use of modern element base that allows to decrease their mass and dimensions and broad functional parameters. Most modern parts of complex technical devices use principles, which accumulate technological and physical processes from various fields of science and technology. One of these areas is microelectromechanical systems (MEMS) [2], which allows producing devices with smaller size and weight, much cheaper and more reliable then macro devices [3, 4]. These miniaturized electromechanical devices are built on silicon substrates using well-established chip process technologies [5].

Large market segment of MEMS devices has been taken by pressure sensors [6]. Most MEMS pressure sensors are based on the change in capacitance of the built-in electric capacitor and electric resistance built into the design of the sensor piezoresistance [7]. These sensors have micron sizes and are made mostly of silicon, polysilicon and other semiconductor materials [8]. In most cases these technological parameters define the output parameters of the device. From this point of view comes vitality of the conducted research. Therefore, the design and research of stress-strain state of sensitive element of pressure sensor including technological features are the urgent tasks. This task lies, firstly, in the study of stress-strain state of sensitive element of the most common design of capacitive pressure sensor, secondly, to automate the process of research and, thirdly, to compare the results of calculations with experimental data.

MEMS pressure sensors as high-tech devices are used in various fields of science and technology, such as military equipment, space and automotive industries, mobile technology, household devices, etc [5, 6].

II. Principles of Operation and Construction

Pressure sensors of capacitive type, which is manufactured using MEMS technologies, are made of sensitive element in the form of a thin plate and capacitor that includes two covers. The first cover is placed on a thin plate and has the ability to perform the move under applied pressure. the second cover is tightly connected with the casing and can not perform movements. The frame with real size in microns is shown in fig.1.

The principle of the pressure sensor is based on the impact of measured pressure on the sensitice element in the form of a thin plate. Due to the fact that it has the ability to perform the movement depending on the applied pressure, these movements can take different values. However, it must be noted that generated movement causes tensions, which have exceeded the critical value of specific material. If tension is equal or exceeded this value the destruction of the sensor takes place. In engineering so called safety factor is used that determines how close we can go to the critical value, in this case, to the tension. Offset of plate leads to reduction in the distance between the plates of electric capacitor, which leads to change of output parameters of electrical circuit comprising a given capacitor. Capacity of electric capacitor depends on the design of the sensitive element, which in turn depends on process parameters.

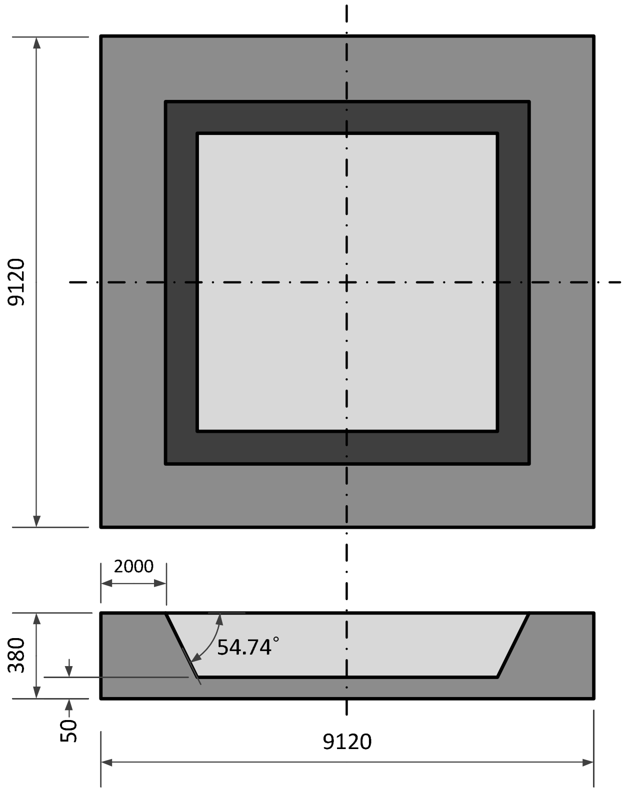

Fig.1. The design of MEMS capacitive pressure sensor

III. AUTOMATION FOR GRAPHICAL DEPENDENCIES

To get the results of calculations necessary to build graphical dependencies one needs to change the applied pressure or other simulation parameters each time. So it was proposed to develop a software code that would help to make all necessary calculations and build graphical dependence automatically [9]. Once geometry has been built, material properties have set, the partitioning to get the finite element mesh has conducted and boundary conditions have been provided, the program for ANSYS system is used to automate the storage of the results (fig. 2).

Parts of results of the software code processing are presented in fig. 3 and fig. 4. In particular strain (fig.3) and stress (fig.4) distribution in the sensitive element of MEMS pressure sensor depending on the pressure applied are presented. In addition, the program on the base of previously recorded data automatically builds other graphical dependencies.

```
/units, uMKS
*AFUN, DEG
x=2560
x1=1712
z=50
z1=380
s=TAN(180-90-54.74)*(z1-z)
L=4560
kk=(x-s)/x
kk1=1/kk
/PREP7
BLC5, , ,x*2,x*2
VEXT,1, , ,0,0,z1-z,kk,kk,,
BLC5, , ,L*2,L*2,z1
VSBV,      2,      1
ET,1,SOLID187
EX,1, 2e5                     ! Modulus
PRXY,1, 0.33                  ! Poisson's ratio
mp, DENS,1, 2330e-18          ! Density kg/m3        kg/μm3
ESIZE,150,0,
VMESH, All
/GO
!TUNIF,22,          ! Initial temperature
DA,13,ALL,0
!SFA,8,1,PRES,70000e-6  ! MPa
FINISH
PPres=0.0                   ! Starting pressure
KPres=70000e-6          !   End pressure
SPres=10000e-6          !   Step
*SET,NN,((KPres-PPres)/SPres+1)
!___________________________________________
*DIM,Pressure,ARRAY,NN
NPP=1   !
/SOL
*DO,PRESS,PPres,KPres,SPres
/GO
SFA,8,1,PRES,PRESS  ! MPa
*SET, Pressure(NPP),PRESS
NPP=NPP+1
SOLVE
*ENDDO
FINISH
! Revelation arrays
*DIM,MSEQV,ARRAY,NN
*DIM,MUSUM,ARRAY,NN
!*DIM,MTEMP,ARRAY,NN
/POST1
SET,FIRST
!*
/EFACET,1
/SHOW,JPEG,,0
PLNSOL, S,EQV, tvg,1.0
*GET,MSEQV(1),PLNSOL,0,max
PLNSOL, U,SUM, tvg,1.0
*GET,MUSUM(1),PLNSOL,0,max
!
*DO,NT,2,NN,1
SET,NEXT
PLNSOL, S,EQV, tvg,1.0
*GET,MSEQV(NT),PLNSOL,0,max
PLNSOL, U,SUM, tvg,1.0
*GET,MUSUM(NT),PLNSOL,0,max
*ENDDO
/SHOW,CLOSE
FINISH
```

Fig. 2. Code for the ANSYS system

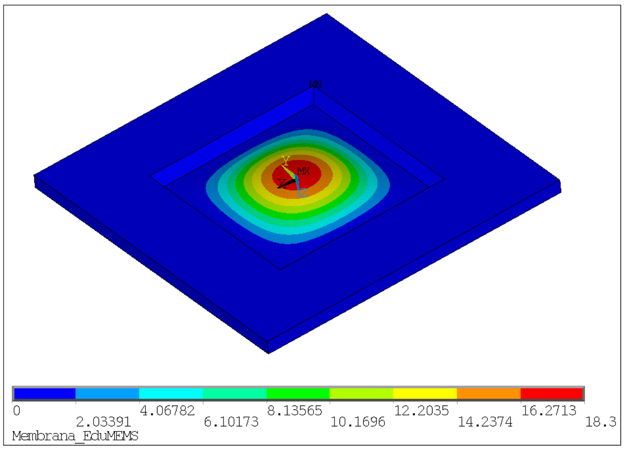

Fig.3. Example of distribution of deformations in the elastic element of pressure sensor 70 [kPa]

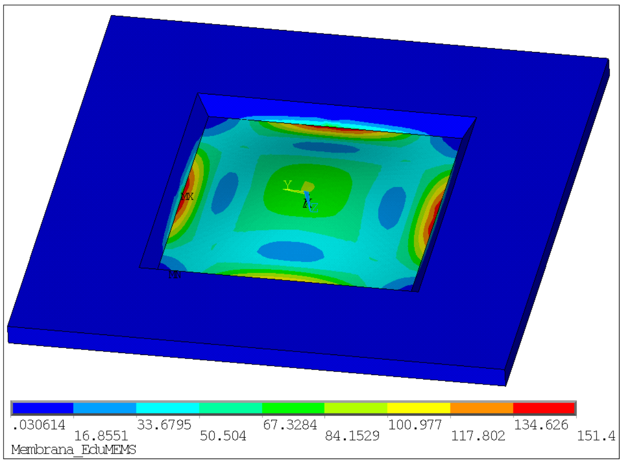

Fig.4. Example of stress distribution in an elastic element of pressure sensor 70 [kPa]

IV. FEATURES OF EXPERIMENT

The experiment took place using a measuring stand in Division of Microengineering and Photovoltaics of Politechnika Wrocławska, an example of which is shown in fig.5 [10], and the example of sensor (designed and manufactured in the same division) in fig.6. The methodology of the experiment is described in the [11].

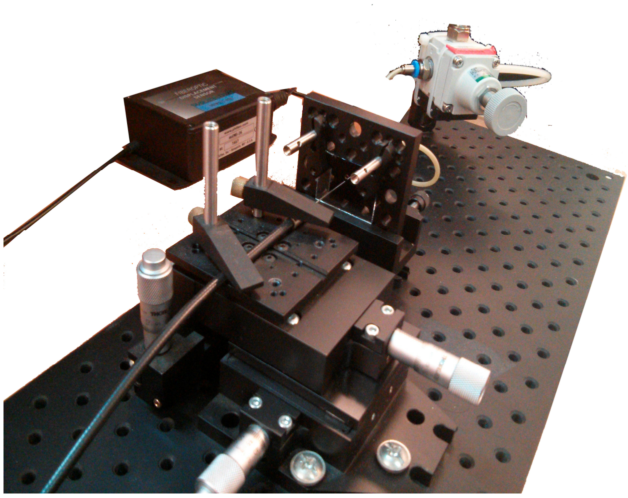

Fig. 5. Stand for the experiment

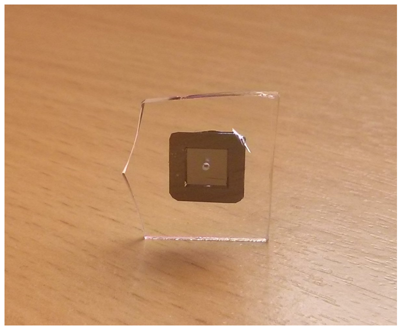

Fig. 6. Sample of sensitive element of pressure sensor

V. RESULTS AND ANALYSIS

Usage of the developed software code has enabled to build automatically the dependency of maximum displacement from the pressure applied, which changed from 0 to 70 kPa. From the received data one can see that this dependency is linear. The similar dependency is observed for generated tensions in the sensitive element. The results of changes are shown in Fig.7.

The experiments made it possible to receive the dependence of the displacement shift under the pressure applied (range 0 to 70 kPa) using the abovementioned stand. Worked out experimental results are shown in fig.7.

Analysis of studies (fig.7) allows to assert that the results of calculations of displacement of sensitive element of capacitive pressure sensor is bigger in the given range to of pressure changes (0 to 70 kPa). However, the error value in the pressure range of 25 to 70 kPa does not exceed 5 -10%, and for a range of 10 - 25 kPa the relative error is more than 10%. Moreover, with approaching from 25 kPa to 0kPa the relative error increases and reaches a value of 70 - 75% but later it's value is close to zero. Such a large error in the range from 0 to 25 kPa is caused by characteristic of optic sensor called Fiberoptic sensor Model D6, which has a low sensitivity in minor deviations of membrane. [2, 3]. These results make it possible to assert that the model of membrane of pressure sensor may be used for research and design of pressure sensors in the pressure range of 25 to 70 kPa.

The program for the ANSYS system enables to quickly change the range of pressures and design parameters, making it a versatile tool in the study of membrane type.

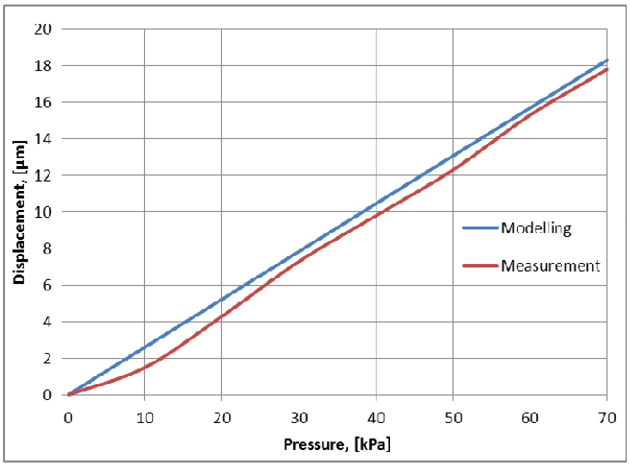

Fig.7. Chart of dependency of maximum values of displacement with applied pressure (results of simulation and experiment)

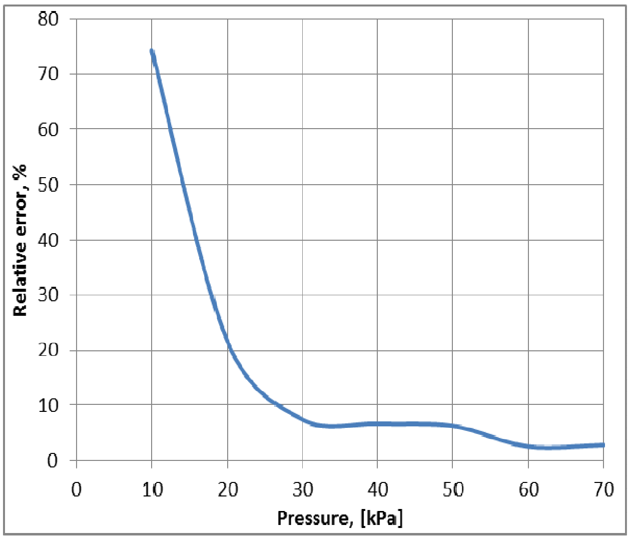

Fig.8. Chart of dependency of the relative error for different values of the applied pressure

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VI. Conclusion

Graphic dependence of shift and dependence of relative error between theoretical and experimental data in the range from 0 to 70 kPa was built in the result of the simulations of elastic element of pressure sensor using ANSYS system and conducted experimental studies. It was established that in the zone of low pressure the value of calculation errors greatly increases. Accordingly, a pressure sensor should be used in the range of 25 to 70 kPa. Upper value of the measured pressure is limited to the critical value of stress generated in the thin plate.

To automate the research process a code for the ANSYS system is developed, which allows to automate the process of research, and automatically construct graphic dependences.

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