Using COMSOL Multiphysics for Modeling Processes in Microbolometer

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Abstract – **Thanks to modern simulation tools, a designer can study the properties of MEMS devices before they are actually fabricated. In this paper, we perform a study of dynamic thermal phenomena occurring in Ti-based microbolometer using Finite Element Method (FEM) simulation in COMSOL Multiphysics environment.**

Keywords – **MEMS, microbolometer, finite element method, thermal simulation, heat flux**

I. Introduction

In the past decade of rapid development of microelectromechanical devices (MEMS). Given the high competition in this industry, most MEMS optimization parameters is a key challenge for quality and successful commercial products. MEMS production is high-tech and high-tech, so technologists and engineers have to solve challenges at all stages of the process. Great help in solving these problems render modern computer programs and complex computer modeling of various physical processes with the ability to optimize the parameters of the model

II. Problems of modeling of physical processes

At present, the simulation of physical processes in most cases based on the use of numerical modeling techniques. In solving problems of numerical modeling requires appropriate software that is capable of sufficient accuracy and efficiency to provide a range of opportunities for the most rapid and high-quality construction of physical models.

There is a large group of electromechanical devices in which electromagnetic processes impossible to investigate because of their small size or complexity. These and many other phenomena can be observed and explore using 2D and 3D-modeling of electromagnetic processes with special programs. Some of these programs use a long and focused on appropriate hardware, such as a program ANSYS[1] known for about 20 years. Others have appeared recently, such as the software package Comsol Multiphysics [2], designed by Swedish company Comsol, global developer of software for modeling various physical processes.

III. Use of COMSOL Multiphysics

COMSOL Multiphysics package can simulate almost all the physical processes that are described by differential equations partial differential (PDE). In COMSOL Multiphysics enough to set the required equation, with no need to change the code. The program contains a variety upshot, with which you can make the numerical simulation of complex physical systems that interact with each other. Interaction with the program may in a graphical user interface (GUI), or by using scripting programming language COMSOL Script or MATLAB. COMSOL Script, which is integrated with COMSOL Multiphysics can operate as a standalone package. This language interpreter includes more than 600 commands for numerical calculations and visualization using the command line, and allows you to create scripts (procedures, written in text format)[3].

The functionality of COMSOL Multiphysics:

• installation dimension models (1D, 2D, 3D);

• Choice of one or more application templates (application mode);

• geometric constructions or import from external CAD systems;

• physics models, boundary conditions and subdomain setup;

• Generation of the grid (in free mode or interactive input parameter grid);

• problem solving (stationary, transient, parametric, in search of eigenvalues);

• postprocessing (ordering, circuits, animation, etc.).

COMSOL Multiphysics integrates with a variety of CAD applications and allows you to import files into DXF and IGES, provides efficient data exchange with well-known products of geometric modeling (Autodesk, Inventor, SolidWork, CATIA, Pro / E, NX, SolidEdge, etc.). COMSOL Multiphysics implemented for OS Windows, Mac, Linux, UNIX.

The program is based on a system of differential equations in partial derivatives. There are three mathematical way of assignment of such systems:

• coefficient form designed for linear and near-linear models

• general form for nonlinear models

• weak form, for models with PDE at the borders, edges or models used with mixed conditions and the time derivative.

To solve the PDE, COMSOL Multiphysics uses the finite element method (FEM). The software runs with finite element analysis together with the mesh allows for a geometric configuration of bodies and control errors using various numerical solver. Since many physical laws are expressed in the form of PDE, it is possible to model a wide range of scientific and engineering phenomena in many areas of physics such as acoustics, chemical reactions, diffusion, electromagnetism, hydrodynamics, filtration, optics, quantum mechanics, semiconductor devices many others.

In addition to the above, the program allows using variable connection (coupling variables) to connect the model in different geometries and link the models of different dimensions.

IV. Research of physical processes of Microbolometer in COMSOL

Microbolometer sensitive to the entire spectrum of radiation. Therefore, studies of the physical processes that take place in it is necessary to consider a large number of parameters. Among them are:

- the active thermistor resistance at rated temperature;
- operating voltage;
- sensitivity at a certain frequency modulation of light flux;
- threshold of sensitivity;
- time constant;
- noise level.

Our simulated microbolometer structure is similar to the one presented in [4]. It is described in detail in our precious paper. In short, the pixel size is 50x50 μm^2. The structure hangs 10 μm above the substrate. The absorbing material is made from titanium and is 0.05 μm thick. The titanium layer is "sandwiched" between two membranes made of silicon nitride, 0.5 μm[5].

Simulations were performed using FEM simulator Comsol Multiphysics which is quite easy to take into account all the necessary parameters for the study mikrobolometra. All necessary material parameters were defined and included in the simulator. They are listed in Table I. The resistivity of titanium is normally one order of magnitude lower. However, in our work we consider a thin film of titanium, which has different properties than bulk Ti[6].

TABLE I

MATERIAL DATA

	Resistivity [Ωm]	Thermal conductivity [$Wm^{-1}C^{-1}$]	Specific heat [$Jkg^{-1}C^{-1}$]
Titanium (thin film)	1.6e-6	22	540
Silicon nitride	1.0e14	30	700
Silicon	1.0e-3	124	702
Chromium	1.3e-7	93.9	460

V. Simulation Results

Figures 3 and 4 shows the results obtained. It is seen that the electric potential supplied to one of the rods termistror leads to an increase in temperature. Of course, the larger the voltage and the higher temperature is reached. For example, as shown in FIG. 4, at a voltage of 0.2 V, we get an increase in temperature to 308.21 K, ie above 13 degrees relative to the ambient temperature, which is quite significant. Moreover, the calculation of the present on the computer (Intel (R) Core (TM) 2 CPU 6600@2.4 GHz, RAM 4 GB) taken in the vicinity of 53 to 60 seconds. A similar experiment was conducted with the heat flux (heat flux), which was send to an element bolometer (Fig.). Time of settlement lasted an average of 12 seconds. Our model can serve as a useful tool for the designer to find a compromise between these constraints. Through our research, the designer can roughly estimate the best value of the heat flow and voltage based on an acceptable temperature rise.

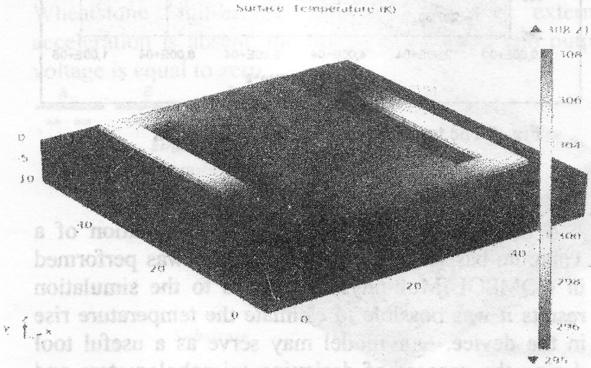

Fig.1 Thermal distribution in microbolometer

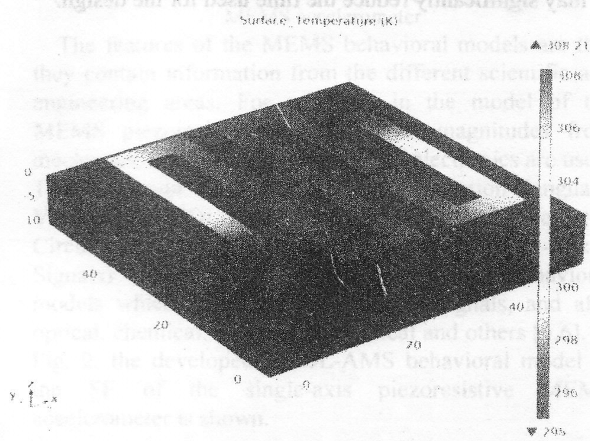

Fig. 2 Thermal distribution in microbolometer (hidden insulators)

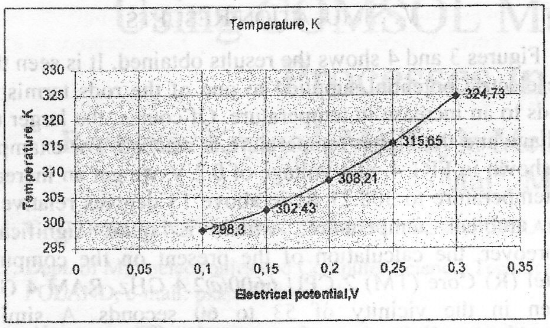

Fig. 3 The temperature increase with increasing voltage

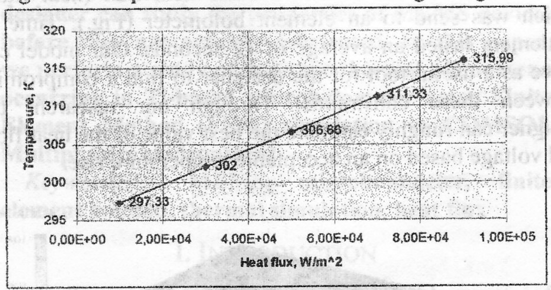

Fig. 4 The temperature increase in heat flux

VI. Conclusions

A transient thermal and heat flux simulation of a Titanium-based microbolometer model was performed in COMSOL Multiphysics. Thanks to the simulation results it was possible to estimate the temperature rise in the device. Our model may serve as a useful tool during the process of designing microbolometers and may significantly reduce the time used for the design.

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VHDL-AMS Model of Single-Axis Piezoresistive MEMS Accelerometer for Behavioral Design Level

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Abstract - **In the paper, VHDL-AMS model of the single-axis piezoresistive MEMS accelerometer has been developed. The proposed model allows to simulate the behavior of the sensitive element, changes of the resistances of the measuring piezoresistors and output voltage of the Wheatstone full-bridge circuitry depending on the applied acceleration for the defined construction parameters of the microsensor, and also to conduct the analysis of the integrated device at the behavioral design level.**

Keywords - **Micro-Electro-Mechanical Systems (MEMS), sensitive element (SE), single-axis piezoresistive MEMS accelerometer, piezoresistor, acceleration, VHDL-AMS, hAMSter, computer-aided design.**

I. Introduction

MEMS technologies made possible to produce devices in which miniature mechanical structures are integrated along with microelectronic components [1]. Among MEMS devices, a special group of inertial sensors for measuring acceleration can be distinguished - MEMS accelerometers. Nowadys, MEMS accelerometers are widely used in the different engineering areas, such as: automobile industry, consumer electronics, military applications and many others.

In MEMS accelerometers, one of the following measuring methods can be used: piezoresistive, capacitive and piezoelectric. Among them, piezoresistive method has some advantages: simple sensing electronic circuitry, high sensitivity and reliability, cheap bulk production. Therefore, for research a construction of a single-axis piezoresistive MEMS accelerometer has been chosen.

Modern design of MEMS with required engineering-operation characteristics, their reliability improvement provides development of behavioral models in the hardware description languages such as VHDL-AMS and Verilog-AMS using the special software Virtuoso Platform (Cadence Design Systems), hAMSter, SMASH (Dolphin Integration) and others [2].

II. Development of VHDL-AMS Model of the Single-Axis Piezoresistive MEMS Accelerometer

In Fig. 1 the schematic view of the construction of the SE of the single-axis piezoresistive MEMS accelerometer is shown. Silicon structure consists of the working mass, spring elements (cantilever beams) which connect the working mass with the substrate of the integrated device. In order to achieve a maximum sensitivity, in the places with a maximal stress due to external acceleration, along each cantilever beam the strain gauges (piezoresistors) are deposited [3,4]. The piezoresistors are connected in a Wheatstone full-bridge circuitry. If the external acceleration is absent, the bridge is balanced and output voltage is equal to zero.

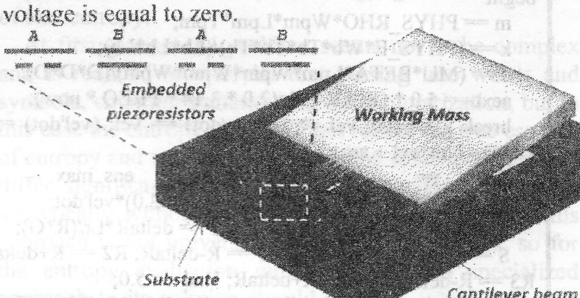

Fig. 1 Schematic view of the SE of the single-axis piezoresistive MEMS accelerometer

The features of the MEMS behavioral models are that they contain information from the different scientific and engineering areas. For example, in the model of the MEMS piezoresistive accelerometer, magnitudes from mechanics, electrical engineering and electronics are used. The extension of the hardware description language VHDL to VHDL-AMS (Very High Speed Integrated Circuits Hardware Description Language Analog-Mixed Signals) allows to develop mixed-signal behavioral models which use not only electrical signals, and also optical, chemical, thermal, mechanical and others [5,6]. In Fig. 2, the developed VHDL-AMS behavioral model of the SE of the single-axis piezoresistive MEMS accelerometer is shown.

III. Results of Computer Simulation

Using hAMster VHDL-AMS simulation software [2] the results were obtained at the sinusoidal change of acceleration with the amplitude of 5g which are graphically illustrated in Fig. 3, 4. From the obtained results the output voltage of the Wheatstone full-bridge circuitry changes from -67 μV to 67 μV. Therefore, for such construction parameters of the SE of the single-axis piezoresistive MEMS accelerometer the highly accurate amplifiers and high-sensitive electronic circuits for processing of such small changes of the signals are required.

```
library ieee, disciplines;
use disciplines.kinematic_system.all;
use disciplines.electromagnetic_system.all;
use ieee.math_real.all; entity mems_piezoresistive_accel is
end entity mems_piezoresistive_accel;
architecture top_level of mems_piezoresistive_accel is
constant Lpm: real := 3500.0e-6; constant Wpm: real := 3500.0e-6; constant Tpm: real := 300.0e-6; constant Lb: real := 1200.0e-6; constant Wb: real := 250.0e-6; constant Tb: real := 35.0e-6; constant Lr: real := 100.0e-6; constant Wr: real := 20.0e-6; constant Tr: real := 2.0e-6; constant D: real := 20.0e-6; constant RHO : real := 640.0; constant PHYS_RHO: real := 2330.0; constant PHYS_E: real := 160.0e9; constant PHYS_EPS0: real := 8.85e-12; constant MU: real := 18.75e-6; constant BETA: real := 0.42; constant G: real := 120.6; constant GRAV: real := 9.81; constant FREQ: real := 100.0;
quantity m, k, c, aext: real; quantity z: displacement; quantity vel: velocity; quantity eps_max, S: real; quantity R, deltaR, deltaLr, R1, R2, R3, R4: real; quantity I, I1, I2: current;
quantity Vad, Vac, Vcd, Vab, Vbd, Vcb, Vout: emf;
begin
  m == PHYS_RHO*Wpm*Lpm*Tpm;
  k == (PHYS_E*Wb*Tb*Tb*Tb)/(Lb*Lb*Lb);
  c == (MU*BETA*Lpm*Wpm*Wpm*Wpm)/(D*D*D);
  aext == 5.0 * GRAV * sin(2.0 * 3.14 * FREQ * now);
  break z => 0.0, vel => 0.0; (z'dot) == vel; (vel'dot) == -k/m*z - c/m*vel + aext;
  R == RHO*Lr/(Wr*Tr); eps_max == 1.5*m/(PHYS_E*Wb*Tb*Tb)*(Lb+Lpm/2.0)*vel'dot;
  deltaR == R*G*eps_max; deltaLr == deltaR*Lr/(R*G);
  S == deltaR/(R*vel'dot); R1 == R-deltaR; R2 == R+deltaR; R3 == R-deltaR; R4 == R+deltaR; Vad == 5.0;
  I == Vad*(R1+R2)*(R3+R4)/(R1+R2+R3+R4); I1 == Vad/(R1+R2); I2 == Vad/(R3+R4);
  Vac == I1*R1; Vab == I2*R4; Vcd == I1*R2; Vbd == I2*R3; Vcb == Vcd - Vbd; Vout == Vcb;
end architecture top_level;
```

Fig. 2 VHDL-AMS model of single-axis piezoresistive MEMS accelerometer

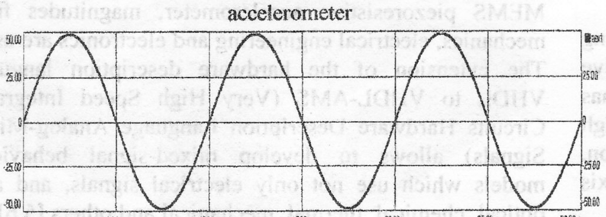

Fig. 3 Change of the external acceleration a_{ext}

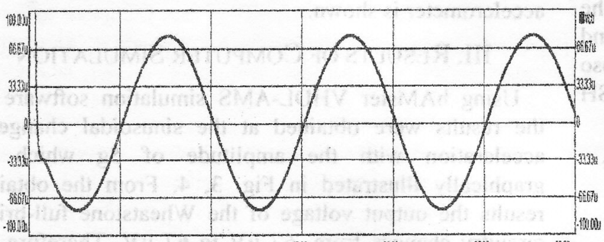

Fig. 4 Change of the output voltage V_{out}

IV. Conclusion

VHDL-AMS model of the SE of the single-axis piezoresistive MEMS accelerometer has been developed which allows to simulate the behavior of the SE, resistance changes of the measuring piezoresistors and output voltage of the Wheatstone full-bridge circuitry depending on the applied acceleration for the defined construction parameters of the microsensor. The developed model also allows to conduct the analysis of the integrated device at the behavioral design level.

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