Abstract: - The actuator consisting of rectangular silicon membrane with the planar meander-line winding on the surface and the electromagnetic transducer was analysed. The silicon device was placed in the static magnetic field. The finite element method FEM was used to the analysis of generated strains and displacements.

Key-Words: - silicon actuator, microelectromechanical system (MEMS), electromagnetic transducer, FEM

1 Introduction

In microsensors and other devices the silicon structures are often used. The vibrations are generated by means of electromagnetic transducers [1,2]. In the structure used in work the planar transducer winding was supplied with the alternating current of particular frequency. The membrane was placed in a static magnetic field. The system with such waves can be applied in actuators in which membrane vibrations force the liquid flow (micro pumps). The vibrating particles go around the axis, which is parallel to the membrane surface and the wave front as well.

2 The microactuator construction and principle of operation

The model of the membrane actuator with the plate wave generated in the electromagnetic transducer EMT is presented in Fig.1 [2].

The conductive metal patterns were deposited on the membrane surface in the way, which is shown in the figure. A membrane with the meander-line conductive patterns was placed in the static magnetic field with the magnetic flux density $B$. Where the pattern is supplied with the alternating current $I$ of the particular frequency it is under the influence of Lorentz forces [3,4]. In the performed sensor model analysis the following assumptions were made: the thickness of the homogenous, isotropic membrane is smaller or comparable with the wavelength, the other membrane sizes, i.e. its length and width are significantly higher than the wavelength. The wave velocity can be calculated from the differential movement equation [1]:

$$DV^2
\nabla^2 w - T \nabla^2 w + Z_0 \frac{\partial w}{\partial t} + m \frac{\partial^2 w}{\partial t^2} = -F$$

(1)

Where: $D = \frac{Ed}{12(1-\nu^2)}$ - the effective bending stiffness of the plate, $T$ – the component of tension in the x-direction, $m$ – the mass per unit area, $E$- Young’s modulus, $Z_0$ – mechanical impedance from fluid loading, $\nu$- Poisson’s ratio, $d$- membrane thickness, $F$- the normal to the membrane surface force, $w$- the surface normal displacement.

Fig.2. The equivalent parallel circuit model for the membrane sensor with the single mode wave generated $n.l$ ($n=P/\lambda_m$) [3]
\[ L_1 = \frac{1}{D k_n^4}, \quad L_2 = \frac{1}{T k_n}, \quad C = m, \quad R = \frac{\omega}{D k_n^4 \delta} \quad (2) \]

Where: \( \delta \) - the loss resulting with the internal membrane dispersing, \( k_n = n \pi / a \), \( a \) and \( b \) - the length and the width of the membrane respectively, \( \omega = 2 \pi f \), \( f_{n,1} \) is the wave frequency for the \( n,1 \) mode [5].

An equivalents series or parallel circuit model can characterize the mechanical membrane impedance \( Z \), whereas an ideal transform can describe the electro mechanic-coupling factor \( K \). The equivalent parallel circuit model of the membrane actuator operated in vacuum (\( Z_0 = 0 \)) with the single mode wave generated \( n,1 \) (where \( n = P / \lambda_n \), \( P \) - the generating transducer period in the frequency range close to \( f_{n,1} \) ) is shown in Fig.2 [3].

For the membrane model presented in Fig.2 the amplitude and phase characteristics as well as the resonant frequency for the wave mode, \( n = 24 \), were determined using Matlab program.

![Fig.3. The amplitude characteristic for the silicon membrane model for the wave mode 24,1](image)

The results for the model with clamped at all edges supported membrane are presented in Fig.3. The other factors used in calculations were following: \( a = 2.5 \) mm, \( b = 2 \) mm, \( d = 0.01 \) mm, \( \nu = 0.0625 \), \( E = 1.69 \times 10^{11} \) N/m², \( P = 0.2 \) mm, \( D = 14.1 \times 10^{-6} \) Nm, \( T_0 = 122 \) N/m, \( \rho = 2.42 \times 10^3 \) kg/m³, \( m = 24.2 \times 10^{-3} \) kg/m² (silicon)[3,5]. The modelling was carried out for the silicon membrane with aluminium conductive patterns. The resonant frequency was equal to \( f_{n,1} = 2695 \) kHz (for the phase shift equal to zero) and \( f_{n,2} = 2700 \) kHz (for \( K_{max} \) amplitude characteristic).

The finite element method (FEM), allows to simulate a variety of mechanical structures including silicon devices in a form or one or two sides - supported beams and hybrid structures as well. It is possible to analyse the anisotropic materials such as monocrystalline silicon, too.

3 The analysis of the silicon membrane vibrations by means of ANSYS programme

It is possible to analyse the anisotropic materials such as monocrystalline silicon, too. From the crystallographic point of view silicon was treated as an orthotropic material with the orientation <100>. The appropriate choice of the boundary conditions is also very important [12]. In the investigated, generation - type system the dynamic Lorentz forces were induced as a result of interaction of alternative current and the static magnetic field (fig. 5,6). The silicon membrane <100> with the thickness, width and length equal to 10\( \mu \)m, 2000\( \mu \)m and 2500\( \mu \)m respectively was examined. Twelve electromagnetic transducer electrodes were placed on the membrane and the transducer itself took up a half of the membrane surface. The pattern width and the interval size were equal to 50\( \mu \)m; the pattern length and thickness were equal to 2mm and 1\( \mu \)m respectively. The first and the last electrodes were placed at the distance of 25\( \mu \)m from the membrane edge.

![Fig.4 The dynamic mesh for three-dimensional model](image)

The FEM model consisted of ca 125,000 regular cuboids parts with the sizes of 10\( \mu \)m*10\( \mu \)m*5\( \mu \)m. A such large number of the cuboids elements resulted from
significantly small membrane thickness in respect to its length and width. An electrodynamics force was induced by the \( I = 100 \text{mA} \) current which supplied the conductive patterns placed at the magnetic field with the magnetic flux density \( B = 1 \text{T} \) (Fig. 2). The results of the membrane displacements simulation under the influence of the force are presented in Fig.5.

<table>
<thead>
<tr>
<th>The number of current periods</th>
<th>The first path (nm)</th>
<th>The second path (nm)</th>
<th>The third path (nm)</th>
<th>The fourth path (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.572</td>
<td>-0.536</td>
<td>0.522</td>
<td>-0.521</td>
</tr>
<tr>
<td>2</td>
<td>0.512</td>
<td>-0.930</td>
<td>0.156</td>
<td>-0.177</td>
</tr>
<tr>
<td>3</td>
<td>0.161</td>
<td>-0.205</td>
<td>0.266</td>
<td>-0.305</td>
</tr>
<tr>
<td>4</td>
<td>0.331</td>
<td>-0.377</td>
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<td>-0.515</td>
</tr>
<tr>
<td>5</td>
<td>0.595</td>
<td>-0.586</td>
<td>0.567</td>
<td>-0.614</td>
</tr>
<tr>
<td>6</td>
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<tr>
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<td>0.724</td>
<td>-0.692</td>
</tr>
<tr>
<td>8</td>
<td>0.605</td>
<td>-0.566</td>
<td>0.717</td>
<td>-0.616</td>
</tr>
</tbody>
</table>

The displacements in the transducer area are observed. The wave from the transducer area shifts to the rest of the membrane surface. The standing wave nodes are formed in the \( Y \) axis direction. The frequency of the supplying current was selected in the way that allowed to generate a standing wave, \((n,1)\) for \( n=24 \) with the nodes at membrane edges and with arrows at pattern placements. The simulation results for the X-axis direction of wave propagation at following periods of time are presented in Figs.5 and 6. Fig.6 shows the strains for time equal to 12 supplying wave periods.

4 Conclusion

The results of the strain and displacement analysis for the thin silicon membranes leads to the conclusion that the finite element method FEM not only allows to perform the static analysis but also can be applied to the stimulation of dynamic states. The boundary conditions as well as the element sizes need to be carefully chosen.

The simulation was carried out by means of ANSYS programme with the Shell sub-programme for the thin membrane operating in dynamic conditions. The membranes with clamped and rotational support edge were investigated. The orthotropic silicon model with \(<100>\) orientation was chosen. In order to verify FEM simulation the analytical membrane model with the generated plate wave of \( n,1 \) mode was used. The calculations were performed by means of Matlab programme. The resonant frequencies for \((24,1)\) mode and FEM method with the clamped edge support calculations \( f=2.62 \text{MHz} \) are in fairly good agreement with the calculations for analytical model \( f_{n,1}=2.7 \text{MHz} \). The discrepancies observed are mainly due to simplifying assumptions for analytical model and material data as well. The calculations allowed to determine the maximum and minimum strains and displacements resulting from the membrane vibrations. The results of the work are going to be used in further investigations on the analysis of fluid movement close to the membrane surface.

References: