COMSOL Multi-Physics Applied to MEMS Simulation and Design

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AIN based LAMB WAVE pressure sensor
AIN based LAMB WAVE pressure sensor

The simulation is to investigate the nature characteristics of a novel ruggedized high temperature pressure sensor operating in lateral field exited (LFE) Lamb wave mode, which can be operated in harsh environment such as oil & gas exploration, automobile and aeronautic applications.

The comb-like structure electrodes on top of aluminum nitride (AlN) were used to generate the wave. A Membrane was fabricated on SOI wafer with 10 µm, 30 µm and 50 µm thick silicon device layer.

The phase velocity dispersive curve of the Lamb wave under different Si thickness (Bulk, 10 µm, 30 µm and 50 µm) are simulated. Compared with the phase velocity dispersion curves of Lamb wave in pure AlN/Al plate that has been reported before, higher order Lamb wave mode are observed with a non-dispersive behavior over a wide range (from 10 to 50 µm Si thickness) comparable to S₀ mode for thin plates.
Simulation approach

Physics employed: Piezoelectric Devices (pzd)

**Condition setting:**

<table>
<thead>
<tr>
<th>Piezoelectric material model 1</th>
<th>AIN</th>
<th>Periodic Condition 1</th>
<th>Line 3,4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Free 1</td>
<td>default</td>
<td>Zero charge 1</td>
<td>default</td>
</tr>
<tr>
<td>Initial values 1</td>
<td>default</td>
<td>Electrical material model 1</td>
<td>Al, Si, SiO₂</td>
</tr>
<tr>
<td>Ground 1</td>
<td>Line 1</td>
<td>Global Definitions: Parameters</td>
<td>Lambda: 20 μm</td>
</tr>
<tr>
<td>Electric potential 1</td>
<td>Line 2, ( V_0 = 1 ) V</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Linear Elastic Material Model 1</td>
<td>Al, Si, SiO₂</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Mesh setting:**

- Sequence type: Physics-controlled mesh
- Element size: Normal

**Study 1:**

- Step: Frequency Domain
- Frequency: 200 MHz-1000 MHz

Simulation: different thickness of AIN to lambda ratio (0.05-0.4) vs phase velocity have been investigated on different structures with underneath Si layer of thickness 10 μm, 30 μm, 50 μm, bulk Si and pure AIN.
Si thickness of 10 µm:

Simulation results

442.12 MHz
S₀ wave

502.98 MHz
Lamb wave
Simulation results

Si thickness of 30 µm:

247.80 MHz
$S_0$ wave

503.15 MHz
Lamb wave
Simulation results

Si thickness of 50 µm:

246.41 MHz
S₀ wave / SAW

511.078 MHz
Lamb wave
The phase velocity dispersive curve of the Lamb wave under different Si thickness (Bulk, 10 µm, 30 µm and 50 µm) are simulated. Compared with the phase velocity dispersion curves of Lamb wave in pure AlN/Al plate, higher order Lamb wave shows a non-dispersive behavior over a wide range.
Stress investigation of metal thin film microbolometer
Stress investigation of metal thin film microbolometer

Metal (Pt, Au, Ag, Ni, …) and dielectric (SiO2, SiN, Al2O3, …) thin films are used extensively in microelectromechanical system (MEMS) devices as structural layer. **Stress control** of these films is of particular importance to guarantee integrity and reliability of the MEMS devices. Stress-free of film stacks is required to achieve **membrane flatness**, which is very critical in some MEMS devices, especially microbolometer to ensure optimum light exposure and absorption.

Stress is developed throughout the film deposition process due to **lattice mismatch and thermal expansion coefficient** difference between deposited film and material underneath. The film stress can be minimized by tuning the process parameters but it is a very time consuming and challenging task.

Simulations are thus employed to **design** the membrane structure that able to accommodate certain amount of film stress and still retain the membrane flatness. **Stress-controlled trenches** are added surrounding the free-standing membrane to improve the membrane flatness.
Simulation approach

Physics employed: Solid Mechanic (solid)

Materials
Anchor cross-sectional (A-A’):

\[ \begin{align*}
100\text{nm Pt} \\
100\text{nm } \text{Al}_2\text{O}_3 \\
\text{Stress-controlled trenches}
\end{align*} \]

Conditions Setting

<table>
<thead>
<tr>
<th>Domain</th>
<th>Linear Elastic Material</th>
<th>Initial Stress and Strain (Al2O3)</th>
<th>Initial Stress and Strain (Pt)</th>
<th>( S_0 ) (N/m(^2))</th>
<th>( \varepsilon_0 ) (1) = Default</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domain</td>
<td>Initial Values</td>
<td>Default</td>
<td></td>
<td>( \begin{pmatrix} 10^{-6} &amp; 10^{-6} &amp; 0 \ 10^{-6} &amp; 10^{-6} &amp; 0 \ 0 &amp; 0 &amp; 0 \end{pmatrix} )</td>
<td></td>
</tr>
<tr>
<td>Boundary</td>
<td>Free</td>
<td>Default</td>
<td></td>
<td>All domain</td>
<td>All except “Fixed Constraint”</td>
</tr>
<tr>
<td>Boundary</td>
<td>Fixed Constraint</td>
<td></td>
<td></td>
<td>End of the two anchors</td>
<td></td>
</tr>
</tbody>
</table>
By adding the stress-controlled trench at the periphery of the membrane, deflection reduced from 0.065µm to 0.0218µm.
Thermal behavior of acoustic wave microbolometer
Figure-of-merit (FOM) of a bolometer is determined by the device sensitivity and speed. Time dependent study of heat transfer physics in the simulation can be employed to obtain the thermal time constant (speed) and amount of temperature rise (sensitivity) of the bolometer.

The important parameters to describe a bolometer thermal behavior are heat capacity and thermal conductance. Since the dimension of all the materials used in the bolometer govern these two important parameters, device structure design is very critical.

Depending on each particular application, bolometer can be designed with high speed or high resolution by optimizing the device structure design. However, trade-off is always needed between speed and resolution. Thus, the time dependent heat transfer is very useful to estimate the bolometer over performance.
Simulation approach

Physics employed: Heat Transfer (ht)

Materials
Anchor cross-sectional (A-A’):
- 10nm TiN
- 300nm AlN
- 200nm SiO₂

Conditions Setting

<table>
<thead>
<tr>
<th>Domain</th>
<th>Heat Transfer in Solids</th>
<th>Initial Values</th>
<th>Boundary Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Domain</td>
<td>Default</td>
<td>Default</td>
<td>All domain</td>
</tr>
<tr>
<td>Domain</td>
<td>Initial Values</td>
<td>Default</td>
<td>All domain</td>
</tr>
<tr>
<td>Boundary</td>
<td>Thermal Insulation</td>
<td>Default</td>
<td>All except “Temperature” and “Boundary Heat Source”</td>
</tr>
<tr>
<td>Boundary</td>
<td>Temperature</td>
<td>T = room temperature</td>
<td>End of the two anchors</td>
</tr>
<tr>
<td>Boundary</td>
<td>Boundary Heat Source</td>
<td>General source</td>
<td>Top surface of TiN on top of AlN</td>
</tr>
<tr>
<td></td>
<td>Qₜ = 20<em>0.5</em>(sign(t)-sign(t-0.1)) W/m²</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Temperature profile and the change of temperature with time.

The maximum temperature rise within the free-standing membrane was obtained directly from the simulation.

Thermal time constant can be extracted by fitting the curve below with exponential function.
Fluid-structure interaction (FSI) model for piezoelectric based energy harvest
Plenty of energy can be taken from surrounding fluid sources. A classical flow pattern is the von Kármán vortex street that can form as fluid flows past an object. These vortices may induce vibrations in the object. This vortex shedding phenomenon is implemented by IME in the development of a MEMS micro-belt (AIN) based energy harvester.

Thus, have a good understanding on the fluid-structure interaction behavior is critical to guide the MEMS device design. In this simulation, we look into the fluid velocity, beam stress, force versus time and beam tip displacement in x and y directions.
Simulation approach

Physics employed: Fluid Flow > Fluid-Structure Interaction (fsi)

A parabolic velocity profile is prescribed at the left channel inflow

\[ v_f^0(0, y) = 1.5U \frac{y(H - y)}{(H / 2)^2} \]

**Definitions**

| Function (step 1) | Location: 0.5  
|                  | Smoothing: size of transition zone (1) |
| Function (Gaussian Pulse 1) | Location: 1.5 (s)  
|                  | Standard deviation: 5e-2 (s) |
| Integration | Line1(blue)  
|              | All Boundary |
| Global Variable Probe | Lift:  
|                  | -intop1(fsi.T_stressx) |
|                  | Drag:  
|                  | -intop1(fsi.T_stressy) |

**Condition setting**

Reference Point for Moment Computation > Discretization > Discretization of fluids choose **P2+P1**

**P2:** 2\textsuperscript{nd}-order Lagrange elements model the velocity components

**P1:** linear elements model the pressure

**Fixed Constraint 1**

Block \textbf{a} fixed

**Force:** \textbf{point 1}

<table>
<thead>
<tr>
<th>0</th>
<th>x</th>
</tr>
</thead>
<tbody>
<tr>
<td>gp1(t)</td>
<td>y</td>
</tr>
</tbody>
</table>

**Inlet 1**

Laminar Flow > Inlet select **Boundary1**

\[ U_0: 1.5^2 [m/s] y^2(0.41[m] - y)/(0.41[m]/2)^2 \text{step1}(t) \]

**Outlet 1**

Laminar Flow > Inlet select **Boundary2**

**P:** 0

**Mesh:** Element size (Fine)

**Studies:** Time Dependent; Type 0 range (5, 5e-3, 6)
Channel length $L$: 2.5 m, Channel height $H$: 0.41 m

The bluff body square is positioned at $C=(0.2, 0.2)$ and the side length is 0.1 m. The elastic structure beam has length $l=0.35$ m and height $h=0.02$ m, the right bottom corner is positioned at $(0.6, 0.19)$, and the left end is fully attached to the fixed square.
Simulation Results

Displacement of point 1

Lift and drag force of point 1

Lift force

Drag force
Thank you for your attention!

Questions?