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Design and analysis of saw gas sensor

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ABSTRACT

In this paper, we have designed SAW gas sensor by using COMSOL Multiphysics software version 4.2 (a). In this model, we investigated the resonance frequencies of a SAW gas sensor. This causes a shift in resonance to a slightly lower frequency.

Key words: MEMS, COMSOL Multiphysics, sensors, actuators, SAW, IDT.

INTRODUCTION

MEMS is a process technology used to create tiny integrated devices or systems that combine mechanical and electrical components. They are fabricated using integrated circuit (IC) batch processing techniques and can range in size from a few micrometers to millimetres. These devices (or systems) have the ability to sense, control and actuate on the micro scale, and generate effects on the macro scale [**1, 2, 3**].

The interdisciplinary nature of MEMS utilizes design, engineering and manufacturing expertise from a wide and diverse range of technical areas including integrated circuit fabrication technology, mechanical engineering, materials science, electrical engineering, chemistry and chemical engineering, as well as fluid engineering, optics, instrumentation and packaging. The complexity of MEMS is also shown in the extensive range of markets and applications that incorporate MEMS devices. MEMS can be found in systems ranging across automotive, medical, electronic, communication and defense applications. Current MEMS devices include accelerometers for airbag sensors, inkjet printer heads, computer disk drive read/write heads, projection display chips, blood pressure sensors, optical switches, microvalves, biosensors and many other products that are all manufactured and shipped in high commercial volumes.

MEMS have been identified as one of the most promising technologies for the 21st Century and have the potential to revolutionize both industrial and consumer products by combining silicon based microelectronics with micromachining technology. Its techniques and micro system based devices have the potential to dramatically affect

of all of our lives and the way we live. If semiconductor micro fabrication was seen to be the first micro manufacturing revolution, MEMS is the second revolution [4, 5, 6].
In this paper, we have reported the design and analysis of SAW gas sensor by COMSOL Multiphysics version 4.2a.

2. Modeling of SAW gas sensor by COMSOL Multiphysics
Figure 1 shows a conceptual view of the gas sensor in this model.

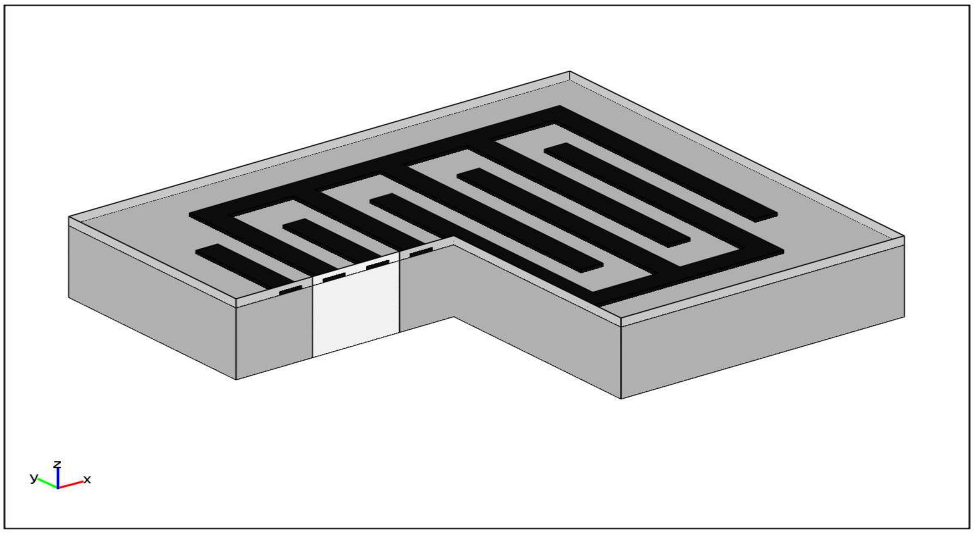

Figure 1: SAW gas sensor, showing the IDT electrodes (in black), the thin PIB film (light gray), and the LiNbO3 substrate (dark gray). For the sake of clarity, the dimensions are not to scale and the IDT has fewer electrodes than in common devices. A slice of the geometry is removed to reveal the modeled unit cell (in white).

IDTs used in SAW devices may have hundreds of identical electrodes, and each electrode can be about 100 times longer than it is wide. One can therefore neglect the edge effects and reduce the model geometry to the periodic unit cell shown in Figure 2. The height of this cell does not have to extend all the way to the bottom of the substrate but only a few wavelengths down, so that the SAW has almost died out at the lower boundary. In the model, this boundary is fixed to a zero displacement.

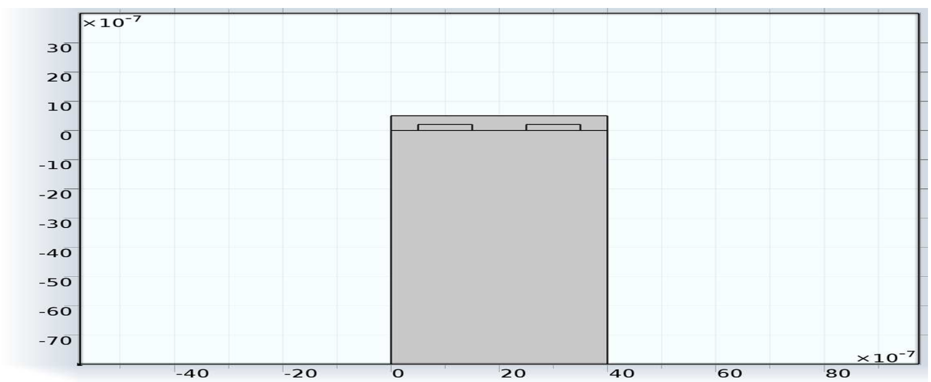

Figure 2: The modeled geometry of the model. A 500 nm PIB film covers two 1 µm-wide electrodes on top of the LiNbO3 substrate. The substrate subdomain has a total height of 22 µm.

Set up the model using the predefined physics interface Piezoelectric Devices. Use the Plane Strain approximation so that the out-of-plane strain component is zero. This should be a valid assumption, considering that the SAW is generated in the model plane, and that the sensor is thick in the out-of-plane direction.

We have used periodic boundary conditions to dictate that the electric potential and displacements be the same along both vertical boundaries of the geometry. This implies that the wavelength will be an integer fraction of the width of the geometry. The lowest SAW eigenmode has its wavelength equal to the width of the geometry, 4 μm. The eigenfrequency of this mode multiplied by 4 μm hence gives the velocity of the wave.

The Poisson's ratio is taken to be 0.48, which corresponds to a rather rubbery material. The Young's modulus is set to 10 GPa [**7**]. Even at the comparatively high frequencies considered in this model, this is likely an overestimation. However, a much lower value would result in a multitude of eigenmodes located inside the film. While those may be important to consider in designing a SAW sensor, the focus in this model is on the SAW modes.

The adsorption of DCM gas is represented as a slight increase of the density of the PIB film. In the third and final version of the model, the sensor is exposed to 100 ppm of DCM in air at atmospheric pressure and room temperature. The "partial density" of DCM in the PIB film is then calculated as

$$\rho_{DCM,PIB} = KMc \quad \text{---------(1)}$$

Where $K = 10^{l.4821}$ [**7, 8**] is the air/PIB partition coefficient for DCM, M is its molar mass, and

$$C = 100.\ 10^{-6}.\ p/\ RT \quad \text{----------(2)}$$

is its concentration in air. Any effects of the DCM adsorption on the material properties other than the density are neglected.

RESULTS AND DISCUSSION

The presence of the aluminum IDT electrodes and the PIB film cause the lowest SAW mode to split up in two eigensolutions, the lowest one representing a series resonance, where propagating waves interfere constructively and the other one a parallel ("anti-") resonance, where they interfere destructively. These two frequencies constitute the edges of the stopband, within which no waves can propagate through the IDT.

The resonance and anti-resonance frequencies evaluate to approximately 841 MHz and 850 MHz, respectively. Figure 3 and Figure 4 show the corresponding SAW modes.

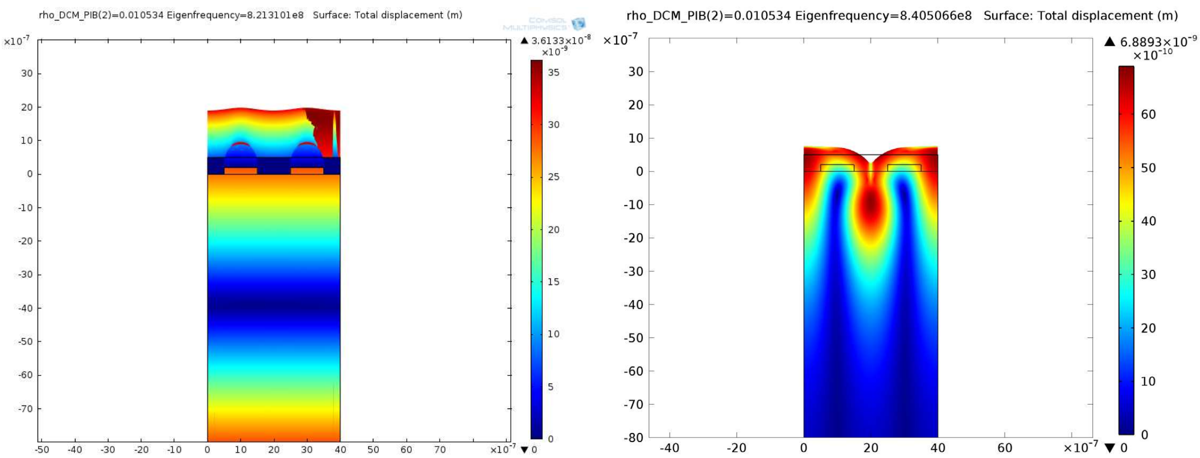

Figure 3: Deformed shape plot of the resonance SAW mode.

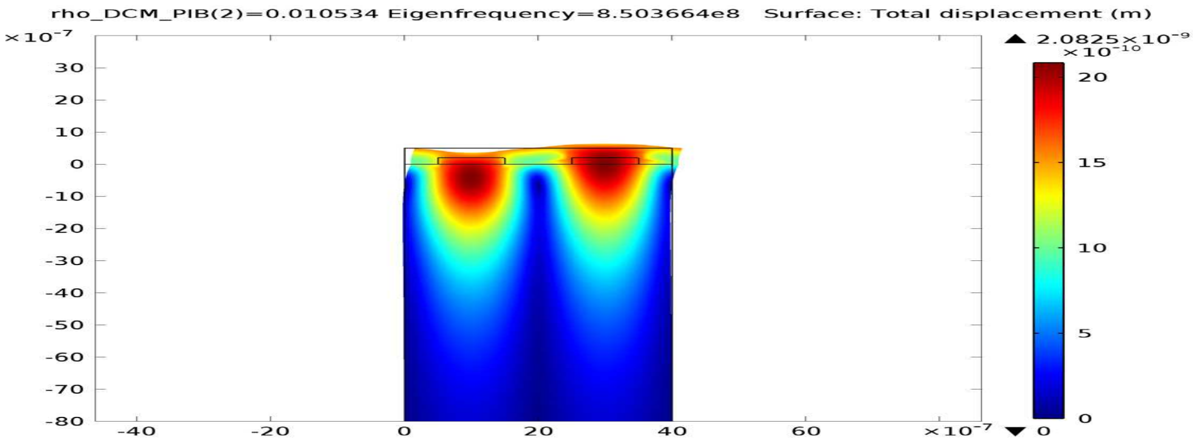

Figure 4: Deformed shape plot of the anti-resonance SAW mode.

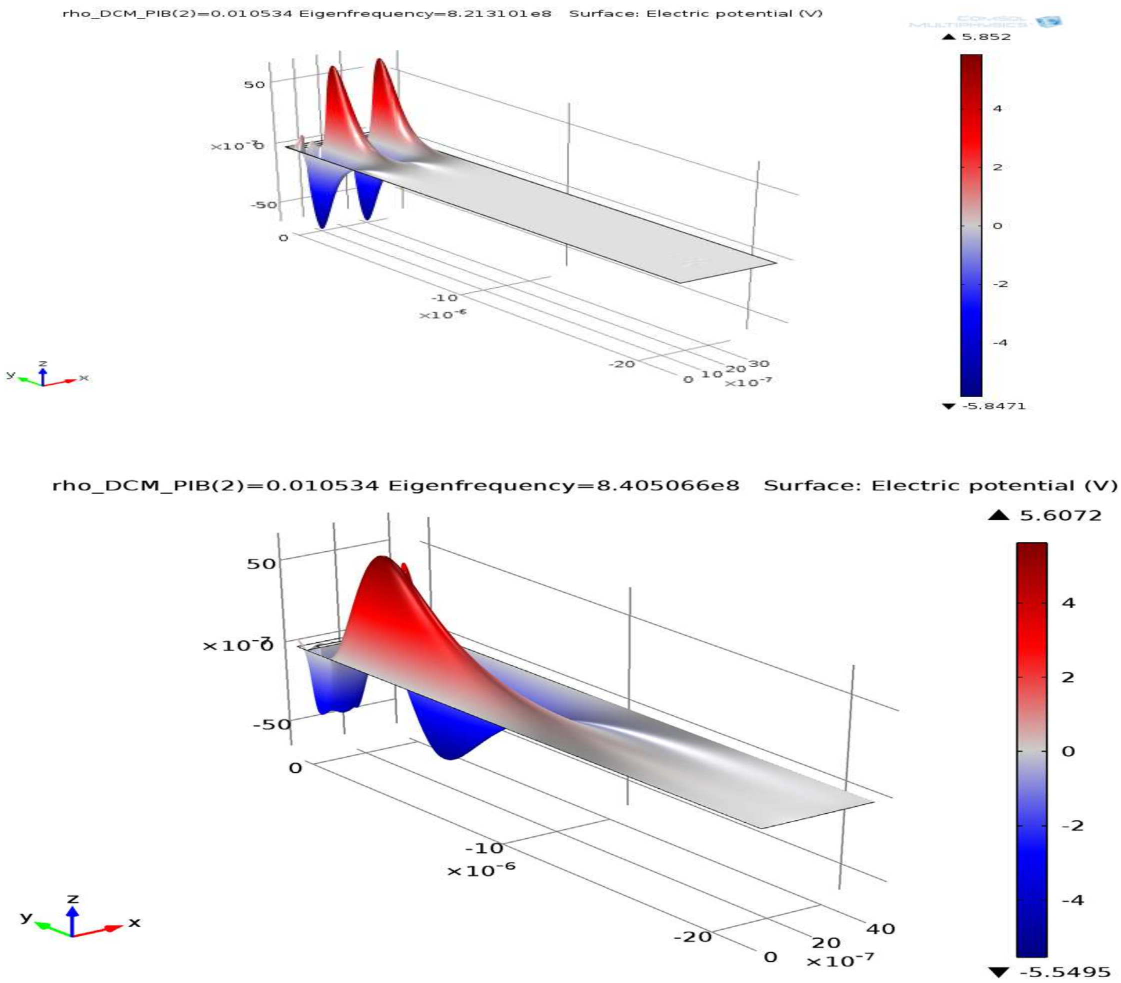

Figure 5: Electric potential distribution and deformations at resonance, symmetric with respect to the center of each electrode.

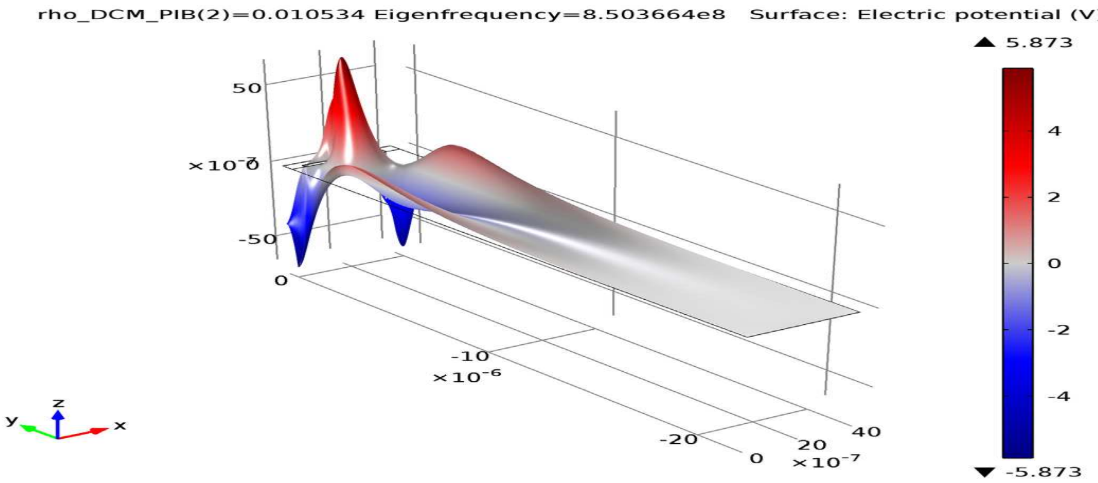

Figure 6: Electric potential distribution at anti-resonance, anti-symmetric with respect to the center of each electrode.

Exposing the sensor to a 100 ppm concentration of DCM in air leads to a resonance frequency shift of approximately 227 Hz downwards. This is computed by evaluating the resonance frequency before and after increasing the density of adsorbed DCM to that of the PIB domain.

Note that the computational mesh is identical in both these solutions. This implies that the relative error of the frequency shift is similar to that of the resonance frequency itself. Thus the shift is accurately evaluated despite being a few magnitudes smaller than the absolute error of the resonance frequency. In a real setup, the drift is often measured by mixing the signal from a sensor exposed to a gas with a reference signal from one protected from the gas. The beat frequency then gives the shift. Figure 5 and Figure 6 show the electric potential distribution characteristics for these solutions.

CONCLUSION

In this paper, we have designed SAW gas sensor by using COMSOL multyphysics software version 4.2a. A surface acoustic wave (SAW) is an acoustic wave propagating along the surface of a solid material. Its amplitude decays rapidly, often exponentially, with the depth of the material. SAWs are featured in many kinds of electronic components, including filters, oscillators, and sensors. SAW devices typically use electrodes on a piezoelectric material to convert an electric signal to a SAW, and back again. Here, we have investigated the resonance frequencies of a SAW gas sensor. The sensor consists of an interdigitated transducer (IDT) etched onto a piezoelectric $LiNbO3$ (lithium niobate) substrate and covered with a thin polyisobutylene (PIB) film. The mass of the PIB film increases as PIB selectively adsorbs $CH2Cl2$ (dichloromethane, DCM) in air. This causes a shift in resonance to a slightly lower frequency.

The area of MEMS is an emerging research field and industry orientation from the past few years and continued to find major new applications in future. Large portion of MEMS applications involves sensors and actuation,

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