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GaAs Lamb Wave Micro Sensor

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Abstract: Acoustic Lamb Wave microsensors are suitable for label free sensing in liquid. The device relies on the interaction between acoustic waves propagating within a thin membrane and the liquid. Lamb wave sensors have been previously studied using AlN/Si structure to detect multi-parameters of a liquid, such as its temperature, density, sound velocity and viscosity using various modes as A0 and S0. These devices already showed good ability to perform measurements on fluids (gas or liquid). In this case, wet chemical etching of silicon was used to obtain thin membranes and an AlN piezoelectric layer was deposited to generate and detect the acoustic wave. This paper reports the use of Gallium Arsenide as piezoelectric material to generate and propagate Lamb waves. GaAs material presents intrinsically interesting piezoelectric properties and is compatible with wet chemical etching process. The fabrication process allows producing a thin membrane but is also adapted for microfluidic microchannels. So, the same substrate can be used for the resonant structure and its excitation. The design of the resonant structure has been optimized using simulations to adapt the design of interdigital electrodes to the GaAs substrate taking into account the shear piezoelectric coefficient and its orientation. An experimental setup has been realized and measurements of the interaction with fluids are presented.

Keywords: Lamb Wave; sensors; GaAs

Introduction

Acoustic Lamb Wave microsensors are suitable for label free sensing in liquid. The device relies on the interaction between acoustic waves propagating within a thin membrane and the liquid.

Lamb waves have several advantages over bulk waves in the case of designing a sensor in a liquid medium. First, although the plate wave sensors are more complex to produce than other types of sensors, they have better sensitivity due to confinement of the acoustic energy on a thin material. Moreover, they operate at relatively low frequency. Lamb wave sensors have been previously studied using AlN/Si structures to detect multi-parameters of a liquid, such as its density, sound velocity and viscosity [1]. These devices already showed good ability to perform measurements on fluids (gas or liquid) but in this case, wet chemical etching of silicon was used to realize thin membranes combined with an AlN piezoelectric layer.

The great advantage of GaAs is that just as if it can be machined by wet etching hence the possibility to machine a large number of devices simultaneously at a low cost with a reproducible process. In addition, while the silicon is not piezoelectric and so would require the deposition of a piezoelectric layer (AlN, ZnO), GaAs is piezoelectric material with good mechanical properties. Finally, a surface of GaAs can be directly bio-functionalized and proteins can be grafted on it which is a great advantage for the realization of the biosensor. Previous work reported fabrication of thin membranes using GaAs [4] and its use as biosensor using Lateral Field Excitation of a bulk acoustic wave. This paper reports the use of Gallium arsenide as piezo material to generate and propagate Lamb waves. The fabrication process allows producing a thin membrane but is also adapted for microfluidic microchannels. Electrodes have been optimized to excite the Lamb wave in GaAs using simulation results. An experimental setup has been realized and measurements of the interaction with fluids are presented.

1. Design of the Sensor

The design of the structure has been optimized using simulations to adapt the design of interdigital electrodes to the GaAs substrate taking into account the shear piezoelectric coefficient and its orientation.

The challenge is to find the optimum orientation of the IDTs to generate Lamb waves on a (100) GaAs wafer. COMSOL Multiphysics® software is used to simulate, in a first step, a thin membrane clamped at its ends, on which there are two inter digital transducers one to ground and the other to a potential of 10V. The properties of GaAs, defined in COMSOL Multiphysics® (coupling matrix, matrix of elasticity, relative permittivity) are those corresponding to a (100) wafer with reference crystallographic axes. By varying the angle ψ (Figure 1), we can observe the displacement along the z axis for different orientations of the membrane on a wafer (100). This study allows us to determine the optimal orientation of the IDTs with the primary flat of the wafer (100) (angle $\psi = 45$ °).

The geometry of the electrodes has an effect on the generation of Lamb waves in the GaAs membrane. Various geometries are modeled which orientation corresponds to the alignment of the electrodes with the flat of (100) wafer. A simplified model of the resonant device is used, a 3x4mm^2 membrane, 150 microns thick surrounded by a clamped membrane. Figure 2 shows some results of the Static deformation of the GaAs membrane. It shows the importance of the geometry of the IDTs and their positioning with respect to the vibrating membrane.

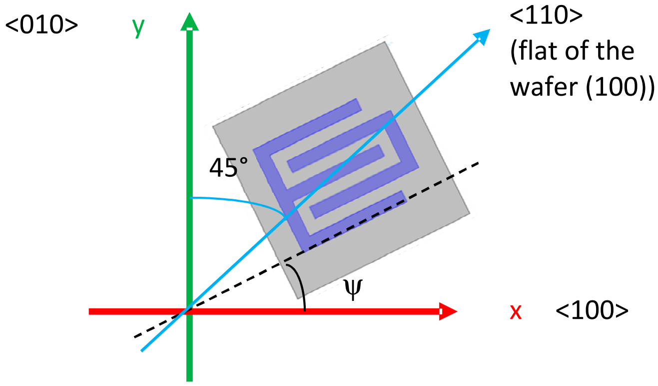

Figure 1. Orientation of membrane and IDTs.

There is an asymmetry phenomenon in the result of the configuration A. Geometry corresponding to the configuration A seems to be adapted for generating Lamb waves as symmetric displacements are observed. A modification of the arrangement of IDTs (figure 2B) shows that this is due to the influence of potential distribution at the head of the electrodes.

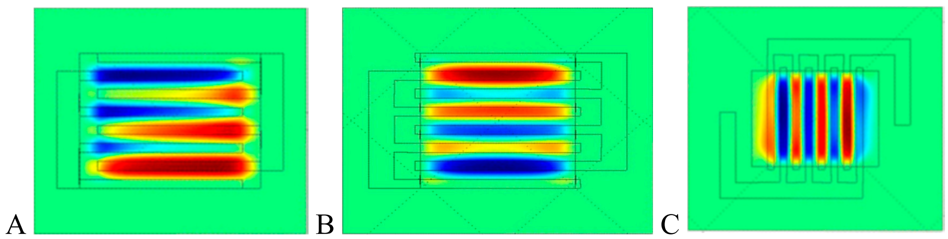

Figure 2. Examples of Simulation of electrodes configuration for Lamb wave excitation.

A theoretical calculation allows to determine approximately the frequency of the plate modes as a function of the thickness of the membrane and its constituent material. In the case of the geometry (figure 3), the displacement observed along z direction corresponds to 1-10 mode.

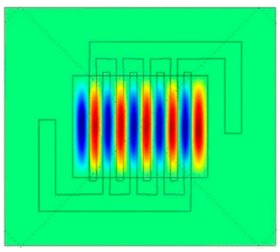

Figure 3. Simulation of the Vibrating Mode 1-10.

2. Experimental Setup

The first step of our process of fabrication was to perform electrodes and electric connections on front face. To do that, we used a classical lift-off technique to pattern the gold-chromium layer. The second step consisted in thinning the GaAs wafer with the chemical solution 7 H_3PO_4 : 5 H_2O_2 : 8 H_2O. During the last step, we fabricated the membrane. It was carried out using two successive wet etching with the chemical solution 1 H_3PO_4 : 9 H_2O_2 : 1 H_2O. The first one forms thickness controls and the second one etches the membrane. The details of this process are reported in the paper [4] and the choice of wet etching baths and the etching conditions are detailed in [5].

An experimental set up has been realized which integrates the electrical connection and microfluidic ports (Figure 4). The microfluidic chamber is made in silicon using also wet chemical etching. Real-time analysis of sensor response was recorded.

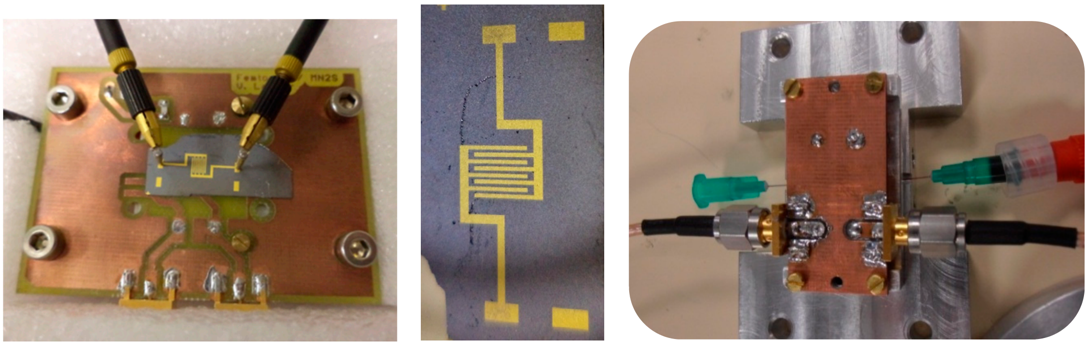

Figure 4. Example of device and experimental setup with electrical and fluidic connections.

3. Results and Discussion

Generating the A_0 Mode (flexural plate waves) is verified using a heterodyne interferometric probe to measure frequency response of the displacement at the surface of the membrane. An XY stage is used to scan the surface to obtain the amplitude and the phase of the vibrating mode. Several modes are mixed together and are not clearly identified. Table 1 shows the frequencies of the modes 1-x (x antinodes along longest size of the membrane). The experiments are made for a device 3mm x 3950mm membrane and a thickness of 180µm.

Table 1. Frequencies in kHz of first 1-x modes.

Modes	1-2	1-3	1-4	1-5	1-6	1-7	1-8	1-9
Calculation	191	320	495	716	981	1291	1646	2044
Simulation		332	512	730	982	1262	1712	1894
Experiment	199	366	581	842	1130	1415	1790	2175

Some measurements using an impedance analyzer at higher frequency (21030 kHz) corresponding to BAW modes have been done and a Q factor of about 1300 and sensibility to the temperature has been measured (-65ppm). This will be used to distinguish influence of temperature on the other modes. Finally, the process of fabrication produced some variations on the thickness of the membrane. This will be solved using specific stop etch markers to control more precisely the chemical etch process.

4. Conclusions

A GaAs microsensor based on Acoustic Lamb wave interaction with liquid has been simulated and tested. In future work, multiparameters analysis as temperature and fluid properties using various modes as A0 and S0 and BAW modes need to be performed. Various experiments showing the variation of the frequency due to fluid circulation in the cavity will also be done. Some device with thin membrane below 20 µm and higher modes will be tested. GaAs surface can also be functionalized to enhance interaction with proteins. This type of sensor opens up a lab on chip integrating microchannels and sensing in the same substrate.

Acknowledgments

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Conflicts of Interest

The authors declare no conflict of interest.

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