Real Time Etch-depth Measurement Using Surface Acoustic Wave Sensor

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Abstract: Measuring the depth of etching layers is one of the major difficulties in fabrication process, considering the improvements made in electronically devices manufacturing, which commonly takes place after etching stage. In this paper, it has been tried to do the measurement of etching layer depth simultaneously and parallel with the etching stage, using Surface Acoustic Wave (SAW) sensors which have the ability to measure all kinds of physical parameters. The way of this sensor performance and its design, based on different available parameters and the study of this design accuracy, are the main purposes of this paper.

Key words: piezoelectric, interdigital transducers, SAW sensor, etching

INTRODUCTION

For making integrated circuits with minimum features size, we’ll need exact control of different manufacturing parameters. There are various methods for controlling and measuring this parameters but most of them don’t take place simultaneously. This means that after etching stage, depth of etched area is measured through particular devices or systems. So, we can’t have exact control over this stage. The methods which can show the depth of etching area together with improvement of the stage and so we can have exact and more efficient control over this stage, are of importance. We can use different sensors for implementation of these methods. One of these sensors is SAW. These sensors active through surface acoustic waves and can measure the variations by varying amplitude or waves phases (Draft.B, 2001; Morgan David P, 1998; Yudistira et al., 2009; heribsek et al., 2010).

How we can use these waves and design a sensor to be used for controlling and displaying the depth of etching area, is studied in this paper and a sensor is designed for this purpose.

2 Sensor Performance:

SAW sensor used in the design is an oscillator delay line stabilized (Crrab et al, 1973) which has covered diffusion path with thin layer of material which is due to be etched. During the etching by taking this material, the mass covered delay line decreases and causes the increase of oscillator frequency (Lee et al., 2004). So by having an oscillator with reference frequency and comparing it with the above mentioned oscillator frequency, we can compute reduced mass. This means that the sensor is composed of two SAW oscillator devices. In this paper, we have used photoresist for covering sensor that the thickness of this layer is ultimately measured while etching.

3 Sensor Design:

For designing SAW sensor, we should consider its two main parts: 1) piezoelectric substrate; 2) interdigital transducers (IDT) (Wang et al, 2006), that choosing materials used for both parts and designing IDT is studied in this part (Slobodink et al., 1976; Ballantine et al., 1997).

3.1 Choosing Piezoelectric Substrate:

The most suitable piezoelectric materials which are used in SAW sensor are: Y-Z LiNbO₃, 128°Y-X, LiNbO₃, ST-Quartz, Y-Z LiTa₂O₆, among which Quartz and Lithium Niobate are of most use in making SAW devices as there are rather thorough information about their features. For designing the expected SAW sensor, piezoelectric substrate Lithium Niobate has particular significance despite its high importance because of high coupling coefficient, as it has less signal distortion and losses and the accuracy of designed sensor rises regarding SAW device application as a sensor.

3.2 Choosing suitable material for IDT deposit:

For IDT deposit in SAW devices, Aluminum and gold are often used. We choose Aluminum as it sticks the surface of substrate well, has fair price, is deposited easily, has good condition, and has less density.
3.3 Design Computations:

Considering available lithographic facilities, and as 25μm line width can be made well, we have the following for the expected devices:

\[ W_f = \frac{\lambda}{4} = 25\mu m \Rightarrow \lambda = d = 4 \times 25\mu m = 100\mu m \]

So, the width of each finger for producing expected central frequency \( W_f = 25\mu m \) and center space to digital coupled finger center from two IDT electrode is \( \frac{\lambda}{2} = 50\mu m \). Central frequency in substrate can be computed as:

\[ f_0 = \frac{v}{\lambda} \]

where \( v = 3488 \text{ m/sec} \) is Wave velocity in substrate and \( \lambda \) is the wavelength.

So, we have:

\[ f_0 = \frac{3488}{100\mu m} = 34.88 \text{MHz} \]

Number of fingers per electrode and bandwidth of SAW sensor can be computed as:

\[ N_p^2 = \frac{\pi}{2k^2} = \frac{\pi}{2 \times 0.048} = 32.725 \Rightarrow N_p = 5.72 \Rightarrow N_p \approx 6 \]

\[ BW = \frac{f_0}{N_p} \frac{34.88\text{MHz}}{6} = 5.81\text{MHz} \]

where \( k^2 = 4.8\% \) and is electromechanical coupling coefficient.

For getting the best reply from the expected device, interdigital transducer impedance should match with measurement systems impedance. After designing if input and output impedance of the device don’t match with the systems connected to it, we should use external matching circuits for collating together. If we choose IDT impedance for matching with measuring devices and transferring utmost power in 50 Ω central impedance:

\[ W = \frac{1}{2Z_0\phi_s} \frac{4k^2N_p}{\pi^2 + \left(4k^2N_p\right)^2} \]

\[ W = 0.01058 \times 10.6\text{mm} \Rightarrow W = 11\text{mm} \]

where \( C_s = 4.6438 \times 10^{-10} \text{F/m} \).

as \( W_{ch} \) doesn’t have any effects on the design, we suppose it six fold each finger width:

\[ W_{ch} = 6 \times 25\mu m = 150\mu m \]

\[ h = W + W_{ch} = 11.15\text{mm} \]

The other parameter is center-to-center space of two transducers in SAW sensor. It is chosen in away that scattering losses and direct electromagnetic coupling between two IDTs become the least. For having less scattering losses and also less embedded losses, two IDTs should be close to each other. But this causes the rise of probable direct electromagnetic coupling between two transducers. The amount mentioned for this parameter is usually one hundred fold to three-hundred fold of wave length. We consider one hundred fold of wave length in this part.

In the table 1, the parameters related to the design have come altogether. According to these parameters, the susceptance, inductance and impedance of SAW sensor on Y-Z LiNbO3 Substrate are shown in figure 1.

<table>
<thead>
<tr>
<th>Table 1: parameters used to IDT on Y-Z LiNbO3 Substrate.</th>
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<tbody>
<tr>
<td>IDT Parameters</td>
</tr>
<tr>
<td>Number of fingers per electrode (N_p)</td>
</tr>
<tr>
<td>Fingers width (W_f)</td>
</tr>
<tr>
<td>Spacing width (W_s)</td>
</tr>
<tr>
<td>Fingers period length (d)</td>
</tr>
<tr>
<td>Distance between IDT centers(l)</td>
</tr>
<tr>
<td>Acoustic aperture(W)</td>
</tr>
<tr>
<td>IDT total length(h)</td>
</tr>
<tr>
<td>IDT channel width (W_ch)</td>
</tr>
</tbody>
</table>
Fig. 1: The susceptance, inductance and impedance of SAW sensor on Y-Z LiNbO3 Substrate.

Also, we can do the design for Lithium Niobate, i.e., \( LiNbO_3 \). Design values are in the table 2. According to these values, we can obtain the results which shown in Figure 2.

4 Experiments:
Because of mass loading, the frequency of covered oscillator are less than the frequency of reference oscillator \[9\]. By using approximate equation, we can tell:

\[
(f_1 - f_2) = \Delta f = (k_1 + k_2)h
\]

that \( k_1 \) and \( k_2 \) are material constant, \( h \) is density, \( h \) is photoresist layer. In this experiment, \( h=1.1 \times 10^{-6} \text{m} \) and \( h=10^3 \text{kg/m}^3 \). Also we know that for Lithium Niobate \((k_1+k_2)=1.21 \times 10^{-7} \text{m}^2 \text{sec/kg}\).

For Y-Z \( LiNbO_3 \):
\[
f_1 = 34.88MHz \\
\Delta f_0 = 161.931KHz \Rightarrow f_2 = 34.718MHz
\]

A shift of electrical phase is added to the ring oscillator which is covered with photoresist so that it decreases \( f_2 \), as much as 150 KHz.

The purpose of exerting this phase shift is certainty of the fact that even after photoresist etching, \( \Delta f \) doesn’t become zero:
\[
f_2 = 34.718MHz - 150KHz = 34.568MHz
\]

So \( \Delta f = 312KHz \) at the beginning of etching stage and measuring sensor.

In the same way for \( 128^\circ Y-X \) \( LiNbO_3 \):
\[
f_2 = 39.92MHz \\
\Delta f_0 = 212.109KHz \Rightarrow f_2 = 39.708MHz \\
f_2 = 39.708MHz - 150KHz = 39.558MHz
\]
Table 2: parameters used to IDT on 128°Y-X LiNbO3 Substrate

<table>
<thead>
<tr>
<th>IDT Parameters</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of fingers per electrod (Np)</td>
<td>5</td>
</tr>
<tr>
<td>Fingers width (Wf)</td>
<td>25μm</td>
</tr>
<tr>
<td>Spacing width (Ws)</td>
<td>25μm</td>
</tr>
<tr>
<td>Fingers period length (d)</td>
<td>100μm</td>
</tr>
<tr>
<td>Distance between IDT centers(l)</td>
<td>10mm</td>
</tr>
<tr>
<td>Acoustic aperture(W)</td>
<td>10mm</td>
</tr>
<tr>
<td>IDT total length(h)</td>
<td>10.15mm</td>
</tr>
<tr>
<td>IDT channel width (Wch)</td>
<td>150μm</td>
</tr>
</tbody>
</table>

Fig. 2: The susceptance, inductance and impedance of SAW sensor on 128°Y-X LiNbO3 Substrate.

Therefore, \( \Delta f = 362\text{KHz} \) at the beginning of etching stage and measuring sensor. Frequencies of reference oscillator and oscillator covered with photoresist, follow each other by temperature, so \( \Delta f \) is almost independent of temperature and varies only with photoresist layer thickness. Frequency of reference oscillator gives us temperature rate of substrate. \( \Delta f \) has been drawn in terms of photoresist layer thickness in figure 3 during etching process. As we see in figure 3, after complete etching and photoresist removal, \( \Delta f \) remains constant over 150KHz. \( \Delta f \) versus etching time, has been shown in figure 4. We notice that \( \Delta f \) variations in \( \tau_1 < t < \tau_2 \), that \( \tau_1 = 15\text{min}, \tau_2 = 40\text{min} \), is linear.

Fig. 3: deference of frequency versus the Thickness of photoresist film during etching process

For \( 0 < t < \tau_2 \), the speed of variations is much smaller than \( \tau_1 < t < \tau_2 \).this can be explained by figure 5 that shows the typical variations of SAW sensor speed as a function of \( h/\lambda \) for average layers consisting of a slow layer (photoresist) over a fast layer (LiNbO3).
Here, $h$ is photoresist layer thickness, and $\lambda$ is SAW wave length. We see that for small amount $h/\lambda$ speed variations are linear. By $h/\lambda$ increase, graph slope decreases. In our etching experiment, $h/\lambda$ in $t=0$ has the most amount and decreases by time increase. So, at the beginning a certain variations in film thickness will make a small variation in SAW speed. Considering $\Delta f/\Delta t = \Delta v/v$, variation in speed makes some variation in oscillator frequency. Although etching rate can be steady, $\Delta f$ chart of time will have smaller slope for smaller amount of time. At the end of 40min, almost the whole photoresist layer has been removed. The survey of device in 45 min shows pieces of resistant that are some parts of diffusion site. For $t > 52$ min, photoresist layer has been completely removed, as a result $\Delta f$ almost remains constant (Williams et al., 1997).

**Conclusion:**

The smallest variation that can take place in photoresist thickness has been limited by short time stability of SAW oscillator. Short time stabilities better than $1 \times 10^9$ can be achieved by SAW delay lines oscillator and is also possible by SAW oscillator instead of delay line. For having a glimpse, we must to study short-term stability of $1 \times 10^7$. This means that $\Delta f/\Delta t$ variations can be $1 \times 10^7$. In the present device, $1\mu m$ decreases in film thickness, creates a frequency shift of 693KHz. This is in accordance with $9.25 \times 10^{-3}$ variation in $\Delta f/\Delta t$ for $1\mu m$ variation in thickness. A short time stable oscillator can yield 0.01nm accuracy.

**REFERENCES**


