Temperature Compensation with SiO$_2$ Thin Films on LiNbO$_3$ Substrates for Surface Acoustic Wave

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Abstract

The temperature compensation with SiO$_2$ thin films on z-cut LiNbO$_3$ substrates for surface acoustic wave (SAW) were investigated by rf magnetron sputtering. The results showed that the temperature coefficient of frequency (TCF) of SAW decreased with the increase of $h/\lambda$, where $h$ was the thickness of SiO$_2$ films and $\lambda$ was the wavelength. The TCF of SAW on SiO$_2$/LiNbO$_3$ device was measured to be about -51 ppm/°C at $h/\lambda=0.12$. It indicated that the SiO$_2$ thin films deposited on LiNbO$_3$ substrates could improve the temperature stability, as compared with the TCF of SAW on bare LiNbO$_3$. Furthermore, the phase velocity ($V_p$) of SAW on SiO$_2$/LiNbO$_3$ device was not altered by the increase of SiO$_2$ thickness (h/\lambda).

Keywords: LiNbO$_3$, Surface Acoustic Wave, RF Magnetron Sputtering, Temperature Coefficient of Frequency

使用二氧化硅薄膜作為鈣酸鋰
表面聲波溫度之補償
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摘 要

本研究係將二氧化硅(SiO$_2$)薄膜，沉積在鈣酸鋰(LiNbO$_3$)基板上，以作為鈣酸鋰表面聲波(Surface Acoustic Wave, SAW)元件溫度補償之用，沉積的方式是利用射頻鈍鍍法。實驗的結果顯示，SAW元件的頻率溫度係數(Temperature Coefficient of Frequency, TCF) 有隨$h/\lambda$之增加而呈現遞減的趨勢，其中$h$為SiO$_2$薄膜的厚度，$\lambda$為波長。這意味著元件的溫度反應有變好的現象。當$h/\lambda=0.12$時，元件的TCF值約為-51 ppm/°C，此值與在鈣酸鋰基板上所量測的值相比，可見鈣酸鋰薄膜確實可用來補償鈣酸鋰SAW之負溫度反應。再者SAW元件的波速($V_p$)經量測發現並未隨$h/\lambda$之增加而有明顯的改變。

關鍵字：鈣酸鋰，表面聲波，射頻鈍鍍法，頻率溫度係數

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I. Introduction

In selecting a suitable substrate for surface acoustic wave (SAW) devices, the temperature coefficient of frequency (TCF) is one of the important factors to be considered. Lithium niobate (LiNbO$_3$) has been widely adopted for application as SAW devices for its large electromechanical coupling coefficient ($K^2$) and moderate surface acoustic wave velocity, but its temperature coefficient of frequency (TCF) is as large as –70.2 ppm/°C [1,2]. On the other hand, silicon dioxide (SiO$_2$) thin film was attractive in optical and acoustic applications because of its low refractive index, high transparency and positive TCF [3-6]. Deposition of SiO$_2$ thin film on LiNbO$_3$ substrate should make an improvement of temperature characteristics of SAW devices.

SiO$_2$ thin films depending on its applications have been deposited by thermal oxidation [7], plasma enhanced chemical vapor deposition (PECVD) [8], atmospheric pressure chemical vapor deposition (APCVD) [9], liquid phase deposition (LPD) [10] and reactive rf sputtering [11]. The reactive rf sputtering method is widely adopted because of its low-temperature operation, smooth surface morphology and ease of fabrication. In this study, we investigate the temperature characteristics of SAW devices on SiO$_2$/z-cut LiNbO$_3$ substrates.

II. Experiment

The rf magnetron sputtering system employed a simple chamber and a 99.995 % pure SiO$_2$ target with copper backside disk of 2 inches diameter. The 4-inches-diameter z-cut LiNbO$_3$ cut into 2-centimeter square were used as the substrates. Table I showed the deposition parameters to grow the amorphous SiO$_2$ thin films on substrates.

<table>
<thead>
<tr>
<th>Substrate</th>
<th>Z-cut LiNbO$_3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Substrate to target distance</td>
<td>5.0 cm</td>
</tr>
<tr>
<td>Target</td>
<td>SiO$_2$ (2 inch diam.)</td>
</tr>
<tr>
<td>Residual pressure</td>
<td>6×10$^{-6}$ Torr</td>
</tr>
<tr>
<td>rf power</td>
<td>80W</td>
</tr>
<tr>
<td>Sputtering pressure</td>
<td>3 mTorr</td>
</tr>
<tr>
<td>Ar flow rate</td>
<td>3 sccm</td>
</tr>
</tbody>
</table>

The single electrode interdigital transducers (IDTs) were employed to excite and receive the SAW signal. The fabrication of SAW devices using photolithography and lift-off technique was compatible with integrated circuit technology. The wavelength ($\lambda$) of SAW at center frequency is 32 µm. The aluminum (Al) electrode with thickness of about 1500Å was deposited by thermal evaporation on the top surface of SiO$_2$ films. The ratios of SiO$_2$ film thickness to wavelength (h/$\lambda$)
were controlled by the sputtering time. The properties of SAW devices were measured by the Hewlett-Packard (HP) 8720ET network analyzer.

III. Results and Discussion

The SOPRA spectroscopic ellipsometer was used to evaluate the refractive index and thickness of SiO$_2$ thin film. The measurements were carried out in the wavelength range of 270 to 870 nm with 5nm step and angle of incidence. Analysis and calculation of indices used advanced material mixing laws (Bruggeman, Alloy) based on numerous physical models. The refractive index of tested thin film was accorded with the N&K database of standard SiO$_2$, as shown in Fig. 1. The result was also similar to that obtained by R. P. Howson et al [12].

![Figure 1. Reflective index of tested thin film with variable wavelength](image)

The thickness of SiO$_2$ thin film was measured by scanning electron microscopy (SEM) carried out on the Hitachi S-4200 microscopy. By controlling of deposition time, different thickness of SiO$_2$ thin film could be obtained. Figure 2 showed the relationship between deposition time and film thickness. The growth rate of about 0.49 µm/h was obtained.
Figure 2. The relationship between deposition time and film thickness

The frequency responses of the fabricated SAW devices were measured using the HP 8720ET network analyzer. Figure 3 showed the frequency response of the SiO₂/LiNbO₃ SAW device with \( h/\lambda = 0.12 \). The center frequency of the transducers \( (f_c) \) and insertion loss \( (IL) \) of SAW were measured to be about 121.7 MHz and –20.0 dB, respectively. The \( V_p \) of SAW was therefore calculated to be about 3894 m/sec from the relationship of \( V_p = f_c \times \lambda \). Figure 4 showed the variation of \( V_p \) of the SiO₂/LiNbO₃ based SAW devices as a function of \( h/\lambda \). By comparing with the z-cut LiNbO₃ single crystal, the \( V_p \) of SAW was not altered obviously. This phenomenon may be due that the acoustic wave velocity of SiO₂ is similar with that of LiNbO₃ substrates [3, 4].
Figure 3. The frequency response of the SiO$_2$/LiNbO$_3$ SAW device with $h/\lambda = 0.12$.

Figure 4. The variation of $V_p$ of the SiO$_2$/LiNbO$_3$ SAW devices as a function of $h/\lambda$. 
The TCF was determined by the following relationship:

\[ TCF = \frac{1}{f_0} \times \frac{df}{dT}, \]

where \( f_0 \) was the center frequency of SAW at 20 °C. Measurements of the temperature dependence of surface acoustic wave velocity were carried out for propagation on LiNbO₃ with and without SiO₂ films over the temperature range from 0 °C to 80 °C. Figure 5 showed the temperature dependence of the fractional change of oscillation frequency, \((f-f_0)/f_0\), where \( f_0 \) is the center frequency of SAW for SiO₂/LiNbO₃ based devices at T=20 °C. The slope of the temperature dependence of SAW on SiO₂/LiNbO₃ devices was obviously negative.

![Figure 5. The temperature dependence of the fractional change of oscillation frequency.](image)

The TCF of SAW on SiO₂/LiNbO₃ based structures with various \( h/\lambda \) was shown in Fig. 6. Since the TCF of SiO₂ is positive, the absolute value of TCF will be decreased as \( h/\lambda \) increased. The TCF values of SAW devices on SiO₂/LiNbO₃ substrates were obviously less than that on the pure z-cut LiNbO₃ single crystal of our experimental value of -73 ppm/°C. It revealed that SiO₂ layer indeed improved the poor temperature stability of LiNbO₃ due to the inherent TCF of SiO₂ material. The least value of TCF was measured to be -51 ppm/°C at \( h/\lambda = 0.12 \) in this study.
IV. Conclusion

In conclusion, we had successfully investigated the temperature effect of the SAW properties on SiO$_2$ thin films deposited on z-cut LiNbO$_3$ substrates by rf magnetron sputtering. The TCF of SAW was significantly decreased as the SiO$_2$ thin film was deposited on z-cut LiNbO$_3$ substrate. The least value of TCF was measured to be about -51 ppm/°C at $h/\lambda=0.12$. It revealed that the SiO$_2$ thin film deposited on z-cut LiNbO$_3$ substrate could improve the temperature stability of the SAW device. Moreover, the experimental results showed that the $V_p$ of SAW was not altered as the SiO$_2$ thickness ($h/\lambda$) was increased. Comparing with the SAW on the pure z-cut LiNbO$_3$ single crystal, it is obvious that the z-cut LiNbO$_3$ substrate with deposited SiO$_2$ thin film will be a promising choice for SAW device applications.

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References


