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Study for Frequency Response of SAW Devices with SiO_xN_y Film Using $LiTaO_3$ Substrate

$LiTaO_3$基板を用いたSAWデバイス周波数応答に対するSiO_xN_y膜依存性

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1. Introduction

Recently, the need for SAW (Surface Acoustic Wave) devices in multi-band system has increased as capacity and speed in mobile phone communication systems increase. Agaist this background, studies to improve frequency response and TCF (Temperature Coefficient of Frequency) of SAW devices have been actively conducted. For example, one method being explored is to deposit SiO_2 film, which has frequency temperature coefficients whereby positive and negative are different from those of the substrate material, on the IDT electrode formed on the $LiTaO_3$ or $LiNbO_3$ substrate [1, 2, 3, 4, 5].

On the other hand, the effect of SiO_xN_y, which is widely used in electrical devices, on the frequency responses of SAW devices and TCF has not been fully investigated. In recent years, there was an interesting observation that showed the change in the refractive index of SiO_xN_y film causes the change in acoustic velocity of SiO_xN_y bulk film[6].

Here, we have conducted a study to evaluate the effect of refractive index on SAW device frequency characteristics by depositing SiO_xN_y film with different refractive indexes on the IDT electrode.

2. Experimental Procedures

One-port resonators were fabricated on Al IDT electrode/42°Y-X $LiTaO_3$ substrate structure. Then dielectric films (SiO_xN_y, SiO_2 and Si_3N_4) having different refractive indexes shown in Table 1 were deposited on IDT electrode. The IDT pitch was set at λ=1.8, 2.0, 2.2(μm) and the Al layer for IDT electrode was deposited at thicknesses of $h_{IDT}/\lambda=0.094$, 0.085 and 0.077 each in this experiment. RF sputtering was performed to deposit the dielectric film on the one-port electrode at thicknesses of $h_{dielectric}/\lambda=0.11$, 0.10 and 0.09 each.

These dielectric films were deposited by sputtering while oxygen and nitrogen were added using Si target. The refractive index of SiO_xN_y films was varied by changing the additive amount of O_2 gas and N_2 gas.

Table 1. Split table for 1-port resonator evaluation.

Split	Dielectric	Refractive Index @633[nm]	y/(x+y) [%] (Caluclated from RI)
(A)	SiO_2	1.478	0
(B)	SiOxNy	1.558	14.8
(C)	SiOxNy	1.610	24.4
(D)	SiOxNy	1.712	43.3
(E)	Si_3N_4	2.019	100
(F)	N/A	N/A	N/A

The refractive indexes of SiO_2 or Si_3N_4 film that were measured by spectroscopic ellipsometry shown on Table 1 have similar values to reference [7, 8]. The content ratio of nitrogen y/(x+y) in SiO_xN_y films was calculated by putting the obtained data of refractive indexes of SiO_xN_y films in a proportional equation that was given by the assumption that the content ratio of N in the SiO_2 film is 0 (%) and the content ratio of N in the Si_3N_4 film is 100 (%). Here we measured the frequency response of one-port resonators fabricated in this experiment.

3. Result and Discussion

Figure 1 shows the Y(1,1) admittance characteristics of the one-port resonators with λ=2.0(μm). The same as the reference [2, 3], the frequency of sample (A) for which SiO_2 film was deposited on IDT electrode was lowered compared to that of sample (F) with no dielectric film on IDT electrode. On the other hand, the frequency of sample (E) with Si_3N_4 film deposited on IDT electrode rose compared to that of sample (F). This phenomenon is considered to reflect the effect of the velocity of each SiO_2 film and Si_3N_4 film deposited on IDT electrode.

Also, Figure 1 shows that the resonator frequency of sample of SiO_xN_y films deposited on IDT electrode (B, C, D) takes a value in the middle between sample (A) with SiO_2 film deposition and sample (E) with Si_3N_4 film deposition. It was also confirmed that the frequency of resonators with SiO_xN_y films rises as refractive index of SiO_xN_y film increases. This shows that the velocity of SiO_xN_y films increases as refractive index of SiO_xN_y film increases [6].

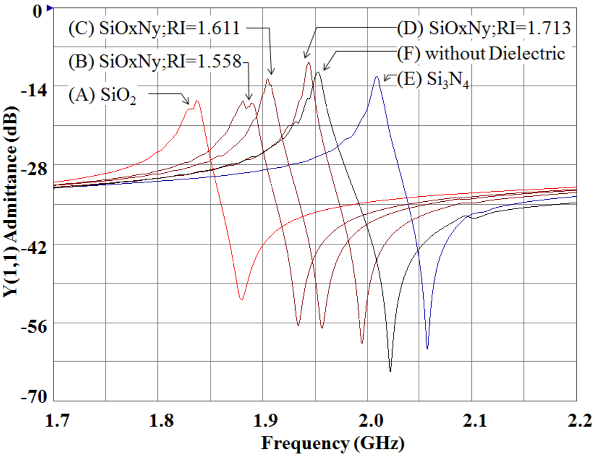

Figure 1. Frequency characteristics of one-port resonators with λ=2.0µm.

Figure 2 shows the change rate of frequency between resonators with no dielectric film on IDT electrode and resonators with dielectric film on IDT electrode against the refractive indexes of each dielectric film. Compared to the frequency of resonators with no dielectric film, the frequency of resonators with SiO_2 film (refractive index 1.478) lowers and the frequency of resonators with Si_3N_4 film (refractive index 2.019) rises with any of the resonators at λ=1.8-2.2. The frequency of resonators with SiO_xN_y film changes as refractive index of SiO_xN_y film changes. Meanwhile, Figure 2 shows that the change rate of frequency increases as the wavelength (λ) of resonators decreases. This behavior may include effect that the dielectric film thickness $h_{dielectric}/\lambda$ increases as the wavelength (λ) of resonators decreases.

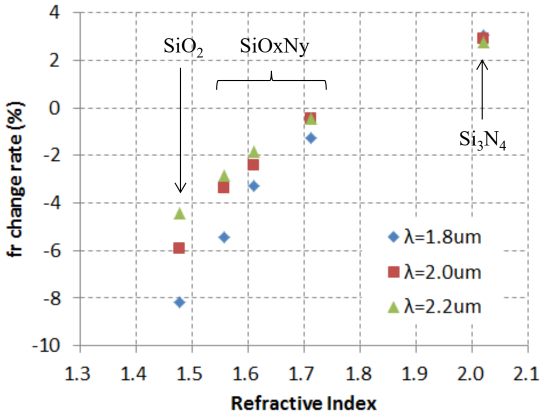

Figure 2. Frequency of resonance (fr) change rate caused by dielectric deposition as a function of refractive index.

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As Figure 2 shows, the amount of change in frequency by SiO_xN_y film deposition becomes larger as the refractive index gets smaller (film has less nitrogen) and it becomes smaller as the refractive index gets larger (film has more nitrogen). This data tells that the frequency of resonators with SiO_xN_y film deposition is the same as that of resonators with no SiO_xN_y film in refractive index from 1.7 to 1.8. This means as a result of depositing SiO_xN_y film, there is certain refractive index in which zero drift of frequency occurs.

4. Conclusion

In this study, we investigated the effect of refractive index with SiO_xN_y film deposited on the IDT electrode on the frequency characteristics of the SAW device and observed the following findings.

- The frequency of one port resonator with SiO_xN_y film takes the middle value of the frequency between the frequencies with SiO_2 film and Si_3N_4 film. The frequency of a resonator rises as refractive index of SiO_xN_y film increases.
- Frequency change rate by SiO_xN_y film deposition increases in the range of refractive index has low value (film has less oxygen). On the other hand, frequency change rate by SiO_xN_y film deposition become smaller in the range of refractive index has high value (film has less oxygen). The frequency of resonators with SiO_xN_y film deposited in refractive index from 1.7 to 1.8 is same of the frequency of resonators with no SiO_xN_y film.

This study showed that controlling refractive index of SiO_xN_y film enables adjustment of frequency of SAW devices. In addition, controlling refractive index of SiO_xN_y film allows suppression of frequency drift of SAW devices. This indicates controlling refractive index of SiO_xN_y film is useful to control the property of SAW devices.

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