IMPROVEMENT IN TEMPERATURE CHARACTERISTICS OF PLATE WAVE RESONATOR USING ROTATED Y-CUT $LITAO_3$ / SIN STRUCTURE

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ABSTRACT

Realization of a high frequency resonator for 3.6 GHz-band filter in the International Mobile Telecommunication Advanced (IMT-Advanced) system is desired. It is difficult to accomplish such a high frequency resonator using conventional surface acoustic wave (SAW) technology, because the strip width of the inter-digital transducers (IDT) becomes too narrow. Although anti-symmetry 1st (A1) mode Lamb type plate wave is known to have a high propagation velocity, however it has a problem such as large temperature coefficient of frequency (TCF). This paper reports an improved technique for TCF in A1 mode Lamb type plate wave resonator with air-gap type membrane by using rotated Y-cut single crystal $LiTaO_3$ thin plate. The fabricated plate wave resonator has excellent characteristics such as a zero TCF, a large electromechanical coupling coefficient (k^2) of 7 % and a high acoustic wave velocity of 12,142 m/s.

INTRODUCTION

3.6 GHz-band filters are required in the International Mobile Telecommunication Advanced (IMT-Advanced) systems. Conventional filters used in the 2 GHz-band Wideband Code Division Multiple Access (W-CDMA) mobile phone systems are employing a surface acoustic wave (SAW) technology with acoustic wave velocity of about 4000 m/s [1][2]. Since a strip width of an inter-digital transducer (IDT) used in SAW devices is a quarter wavelength of the SAW, its dimension becomes too narrow in the range of 0.2 - 0.3 μm, when 3.6 GHz-band filters are designed. In addition, the narrower the strip width is, the higher the electrode resistance is, which causes insertion loss degradation of the filter. On the other hand, film bulk acoustic resonator (FBAR) devices are suitable for high frequency such as 3 to 4 GHz, but its electromechanical coupling factor (k^2) is small (about 6 % [3]-[5]), which makes the wide bandwidth for the filter unachievable.

An A1 mode Lamb type plate wave resonator is very attractive because its acoustic wave velocity is very high. Toda et al. fabricated a plate wave device using a Z-cut X-propagation $LiTaO_3$ crystal substrate with thickness of 100 μm and showed the A1 mode of the Lamb type plate wave had a higher velocity [6]. Kadota et al. reported a Lamb wave resonator using A1 mode of the Lamb wave on a Z-cut X-propagation twin epitaxial $LiNbO_3$ 0.48 μm thin film, deposited by a chemical vapor deposition (CVD) method [7]. They demonstrated that the resonator had a very high Lamb wave velocity of 14,000 m/s and a resonant frequency of 4.5 GHz.

However, these devices have some limitation due to the small k^2 and the extremely large temperature coefficient of frequency (TCF).

In addition, the conventional thin plate fabrication has some drawbacks. In the case of the CVD deposition method, only Z-cut $LiNbO_3$ film (same as a c-axis oriented film) is able to be grown, whereas the deposition of rotated Y-cut single crystal $LiTaO_3$ thin film is very difficult. Moreover, although alternative technique to obtain single crystal $LiNbO_3$ thin film by polishing a substrate of 50 to 100 μm thickness has been reported [8], the polishing method with high thickness uniformity is not easy because this technique is strongly influenced by the original thickness distribution of the unpolished wafer. A propagation velocity of A1 mode Lamb type plate wave has a strong dependency on the plate thickness. Therefore, in the mass production process of A1 mode of the Lamb type plate wave device, the uniformity of the plate thickness is extremely important.

The authors proposed a novel technique for improving k^2 and TCF of the plate wave resonator by using rotated Y-cut single crystal $LiTaO_3$ membrane [9]. In this work, the resonator had a large k^2 of 8 % and a improved TCF of -38 ppm/^{o}C which were almost the same as SAW devices, but larger than that of AlN-FBAR devices with a TCF of -25 ppm /^{o}C. The plate wave resonator was formed by application of the Smart-cut ® process, which is based on high-dose hydrogen implantation and wafer bonding. It is a thin film layer transfer technique, invented by Bruel in 1995 [10], and recently used for manufacturing of silicon on insulator (SOI) wafers. We had firstly demonstrated that such a technique could be applied to fabricate the membrane structure of a single crystal $LiTaO_3$ thin film for the plate wave device.

This paper presents a further TCF improvement technique of the plate wave resonator and a fabrication process which is able to realize a highly accurate thickness of the single crystal $LiTaO_3$ membrane.

STRUCTURE AND FABRICATION PROCESS

Figure 1 shows a structure for TCF improvement of plate wave resonator. The TCF improvement is attempted by a temperature compensation film with a small thermal expansion coefficient on the $LiTaO_3$ thin plate. In this work, for the temperature compensation film, SiN with high elasticity and SiO_2 with positive temperature coefficient of elastic stiffness are experimented. The conventional SAW devices have a temperature compensation film covered over IDT, which has difficulty to form the flat film due to steps of IDT fingers. But, in the case of plate wave device, the

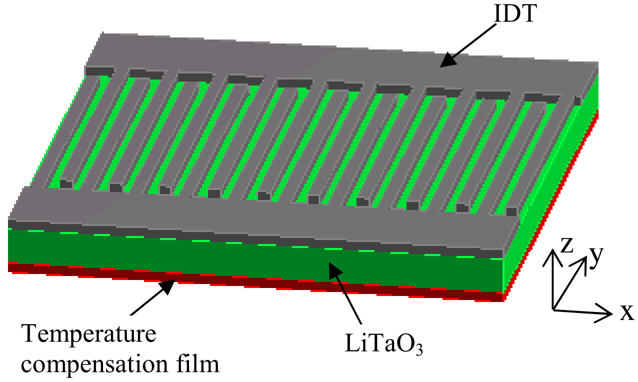

Figure 1: Structure for TCF improvement of plate wave resonator.

formation of the film on the even back side of $LiTaO_3$ plate is possible, so it is easily to form the film.

Figure 2 shows a process flow for the formation of the plate wave resonator using rotated Y-cut $LiTaO_3$ membrane and temperature compensation film by applying the ion implantation technology. The detailed steps are as follows:

(a) Preparation of a 121 ° Y-cut $LiTaO_3$ wafer and a support wafer. This cut angle is equal to the Euler angle of (180 °, 149 °, 180 °).

(b) H+ ions implantation into $LiTaO_3$ wafer with 100 keV and formation of a release layer at the distance of 0.7 µm from the surface of the $LiTaO_3$ wafer. The H^+ ions implantation dose is 8 x 10^{16} / cm^2.

(c) Deposition of a temperature compensation film (SiN or SiO_2) by using RF magnetron sputtering.

(d) Formation of a sacrificial layer and a support layer on the surface of ion implanted $LiTaO_3$ wafer by using photolithography and etching techniques. The material of the sacrificial layer is Cu with the thickness of 2 µm, which is formed by e-beam evaporation. The material for the support layer is SiO_2 with the thickness of 5 µm, formed by sputter-deposition.

(e) Bonding of the $LiTaO_3$ wafer and the support wafer.

(f) Heating to 500 °C and splitting into two parts: the $LiTaO_3$ thin film remaining bonded to the support wafer (the multilayer wafer) and the rest of the $LiTaO_3$ wafer on the release layer.

(g) Removal of 0.1 µm thickness surface layer of the $LiTaO_3$ thin plate on the multilayer wafer by polishing.

(h) Fabrication of IDT electrodes along the x-axis of the $LiTaO_3$ plate by using photolithography and formation of through-holes on the $LiTaO_3$ thin plate by etching.

(i) Removal of the sacrificial layer from the through-holes by etching and completing of a membrane structure for the $LiTaO_3$ thin plate.

In the process used in the present study, the $LiTaO_3$ plate thickness for the membrane is determined by the ion implantation energy. Since this process is not influenced by the starting $LiTaO_3$ wafer thickness, it has an advantage over the CMP process. In addition, in Figure 2 (f), the $LiTaO_3$ thin wafer can be recycled after polishing its surface, so the described production method uses materials effectively and has a low environmental impact. In this study, the support wafer is used a $LiTaO_3$ wafer which has same cut angle to the piezoelectric film. An alumina wafer and a glass wafer which are cheaper in the mass-production, can also be applied to a support wafer. A $LiNbO_3$ is also applicable, since its thermal expansion coefficient is very close to $LiTaO_3$.

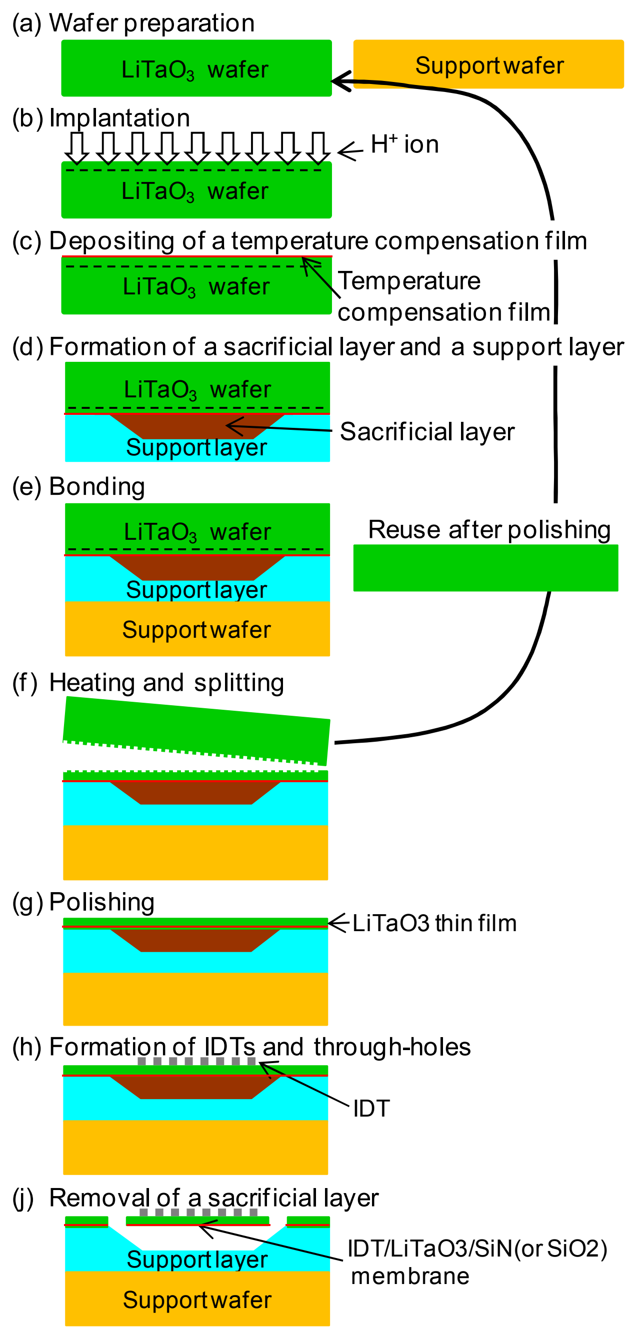

Figure 2: Process flow to form the single crystal thin film of $LiTaO_3$.

Figure 3 shows the thickness distribution of the rotated Y-cut $LiTaO_3$ thin plate on the 100 mm diameter wafer, which is measured at the step (f) in figure 2. The measured thickness values are found to be very small deviation in the range of 1.112 to 1.118 µm (+/- 0.27 %).

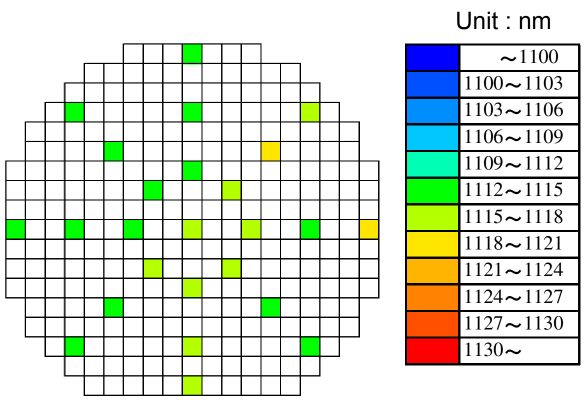

Figure 3: Thickness distribution of the $LiTaO_3$ thin film.

ELECTRICAL CHARACTRISTICS

Figure 4 shows a photograph of the fabricated sample of A1 mode Lamb type plate wave air-gap type membrane resonator using a 121 ° Y-cut single crystal $LiTaO_3$ thin plate and a SiN temperature compensation film. Here, the IDT pitch is 3.5 µm and the $LiTaO_3$ thickness is 0.63 µm (corresponding to 0.18 wavelengths) and the temperature compensation film made of either SiN or SiO_2 has thickness of 0.175 µm.

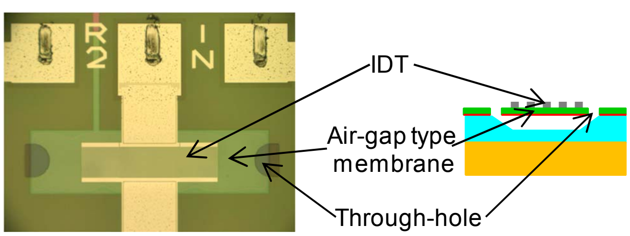

Figure 4: Photograph of the plate wave resonator.

Figure 5 and Figure 6 show impedance characteristics of the $LiTaO_3$ plate wave resonator. The fabricated plate wave resonator has an impedance ratio Za / Zr of 62.5 dB, a resonant frequency of 3.469 GHz and a frequency difference (Fa - Fr) / Fr of 3.2 %, where, the Zr is resonance impedance, the Za is an anti-resonance impedance, the Fr is a resonant frequency and the Fa is an anti-resonant frequency. The k^2 value calculated with the frequency difference is about 7 % and the acoustic velocity estimated with the Fr is achieved to be 12,142 m/s. The spurious response of the other modes is found to be very small compared with the main-A1 mode response.

Figure 7 shows the $LiTaO_3$ thickness dependency of the TCF. Each TCF value is determined by the measured Fr at 25 °C, 45 °C and 65 °C. It is shown that the SiN film indicates more effective improvement than SiO2 film. We presume that this effect is coursed by the high elasticity of SiN. In this study, the temperature compensation film is formed on the $LiTaO_3$ back surface. This film can be also formed over the IDT or both side of IDT / $LiTaO_3$ to improve TCF.

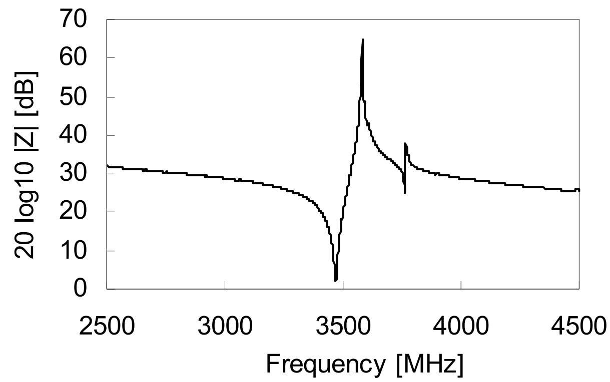

Figure 5: Impedance characteristic near the resonant frequency of the $LiTaO_3$ plate wave.

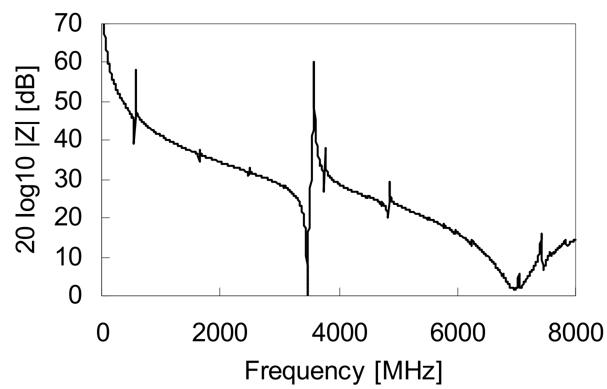

Figure 6: Impedance characteristic of the wide frequency range.

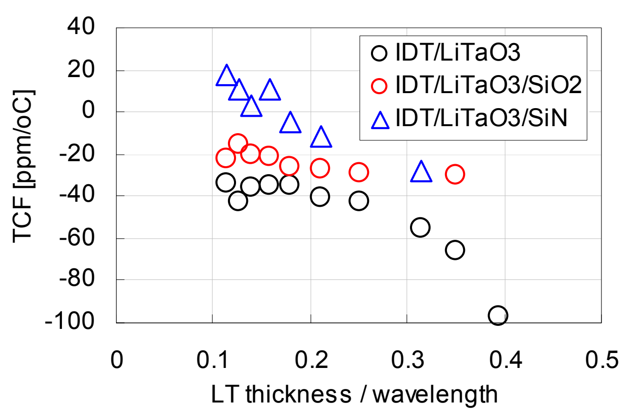

Figure 7: Measured TCF of the plate wave resonator..

CONCLUSIONS

An improved technique for TCF in A1 mode Lamb type plate wave resonator with air-gap type membrane by using rotated Y-cut single crystal $LiTaO_3$ thin film is proposed. The fabricated plate wave resonator has a excellent TCF of almost zero, a large k^2 of 7 % and a high acoustic velocity of 12,142 m/s.

The TCF of A1 mode Lamb type plate wave air-gap type resonator was improved by using the temperature compensation film. Compared with the conventional AlN-FBAR, the fabricated plate wave resonator has better characteristics, such as TCF of about 0 ppm / ^oC and a large k^2 of 7 %. Furthermore, the plate wave resonator has a higher acoustic wave velocity of 12142 m / s than the conventional SAW resonator. By using this technology, we believe that a 3.6 GHz-band filter can be fabricated easily.

Additionally, this fabrication process which is able to realize highly accurate thickness of the single crystal $LiTaO_3$ membrane is widely utilizable for MEMS devices and it is believed to contribute to higher frequency MEMS, and to improvement of sensitivity and performance in some other MEMS devices.

ACKNOWLEDGEMENT

The authors would like to thank Messrs. Toshimaro Yoneda, Masahiro Hiramoto, Takashi Fujii, Makoto Kumatoriya and Yuji Kimura for useful discussion and help in this study. Thanks also member of business development department II for prototyping the resonator.

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