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Evaluation of Bonded Substrate for SAW Device Using LFB Acoustic Microscopy

直線集束ビーム超音波顕微鏡を用いた SAW デバイス用接合基板の評価

Osamu Kawachi [1†], Rei Oikawa[1], Yoshiaki Takaoka [1] and Jun-ichi Kushibiki[2]
([1]TAIYO YUDEN Mobile Technology Co., Ltd. ; [2]Grad. School Eng., Tohoku Univ.)
川内　治 [1†]，及川　怜 [1]，高岡　良知 [1] 櫛引　淳一 [2]
([1] 太陽誘電モバイルテクノロジー株式会社, [2] 東北大学　大学院　工)

1. Introduction

Along with the recent development of mobile communication, the improvement of the characteristics of Surface Acoustic Wave (SAW) device used for an RF circuit is progressing rapidly. In the past few years, characteristics improvement using bonded wafer technology has been actively carried out[1][2]. In a bonded structure it is important to accurately evaluate acoustic properties of the bonded substrate as well as those of the constituent substrate materials.

A line-focus-beam (LFB) Acoustic Microscope is useful for characterizing the elastic properties of a piezoelectric substrate and a non-piezoelectric supporting substrate with high accuracy in a non-destructive, non-contact method [3]. The LFB system enables measuring the phase velocity and propagation attenuation of leaky surface acoustic waves (Leaky SAW: LSAW) wherein water is added to the surface of a specimen, the waves are transmitted from an LFB ultrasonic lens through the water couplant, and propagated on the specimen surface.

In this report, we applied LFB Acoustic Microscopy to evaluate a bonded structure of $LiTaO_3$ (LT) piezoelectric substrates bonded with sapphire substrates using surface-activated room-temperature bonding method [4].

2. Specimens and measurements

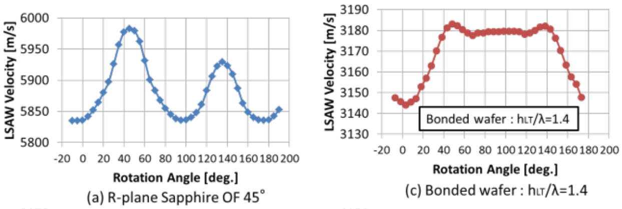
A SAW device structure is $LiTaO_3$/Sapphire bonded wafer by a direct bonding technique using 42°-rotated Y-cut X-axis propagating (42°YX)-LT as the piezoelectric substrate and R plane of sapphire for the supporting substrate. We prepared evaluation specimens using surface-activated room-temperature bonding. The bonding condition was with Argon irradiation current through the piezoelectric substrate/supporting substrate being 50 mA/50 mA, respectively. Four specimens were prepared with LT thicknesses of 3 μm, 5 μm, 10 μm, and 20 μm. The wafer size was 4-inch diameter, and the sapphire thickness was 500 μm. $LiTaO_3$ was adjusted to the desired thickness by grinding and polishing after bonding.

We used a measurement system of LFB ultrasonic material characterization (LFB-UMC) installed at μSIC of Tohoku University. The system operates with an LFB device with a cylindrical lens of 1-mm in radius. The system has a capability of measuring LSAW velocities with high accuracy of 0.002% for 2σ (σ: standard deviation) in frequencies of 100-275 MHz.

3. Results and discussions

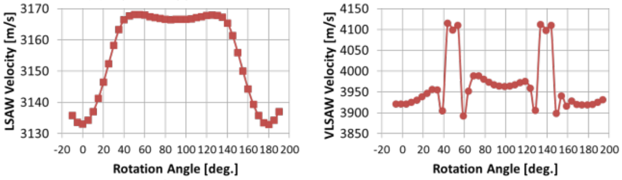
3.1 Anisotropy

Fig. 1(a) and 1(b) present the measured results of the LFB-LSAW velocity anisotropy for the sapphire R plane orientation flat (OF) 45° and 42°YX-LT at 225MHz. In these figures, the rotation angle of 0° corresponds to the direction perpendicular to the OFs of both substrates. They exhibit clear anisotropic propagation characteristics reflecting each crystal symmetry.



(a) R-plane Sapphire OF 45°

(c) Bonded wafer : h_{LT}/λ=1.4



(b) 42° Y-X $LiTaO_3$

(d) Bonded wafer : h_{LT}/λ=0.3

Fig. 1 LFB-LSAW Anisotropy measured at 225MHz

Fig. 1(c) and 1(d) present the LFB-LSAW velocity anisotropy when $LiTaO_3$ thickness is varied: h_{LT} 20.07μm in Fig. 1(c) and 5.093μm in Fig. 1(d). The thickness of $LiTaO_3$ was normalized by the wavelength determined from the measurement frequency and the measured velocity. When h_{LT}/λ is greater than unity, the anisotropy characteristics mainly reflects $LiTaO_3$ properties. When it is less than unity, it exhibits a little bit complicated anisotropy characteristics, significantly reflecting the LSAW propagation characteristics of R-plane sapphire substrate, which is due to the SAW energy distributed in the sapphire substrate.

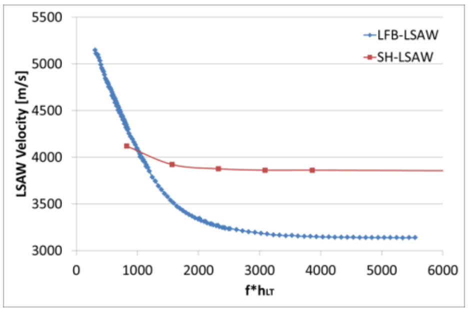


Fig. 2 $f*h_{LT}$ dependences of measured LFB-LSAW velocities and calculated SH-LSAW velocities by FEM/SDA.

3.2 fh_{LT} dependence

Then we measured the frequency dependences of the LFB-LSAW velocities at central position for four bonded substrate specimens in a frequency range from 100 to 275 MHz by 5-MHz steps in the propagation direction of 0°. Fig. 2 shows the measured fh_{LT} dependences of LFB-LSAW velocities, together with the calculated results of SH-LSAW velocities used for actual SAW devices obtained by FEM/SDA. In this bonded structure, LFB-LSAWs exist in the velocity range from 5835 m/s at $h_{LT}=0$ to 3133 m/s at $h_{LT}=\infty$. When the LT thickness increases, fh_{LT} greater than 3000 Hzm, the LFB-LSAW velocity does not change so much. In a range of below 2000 Hzm, the velocity shifts to the high speed side influenced by the sapphire substrate. At 1000 Hzm or less, it is faster than the SH-LSAW velocity.

3.3 Estimated LT thickness

We tried to estimate the LT thickness distributions by the LFB-LSAW velocity measurements, using the fh_{LT} characteristics in Fig. 2. We conducted velocity measurements on the surface of the four bonded substrates: X-/Y-(90X-)line scanned in the X-axis propagation. Fig. 3 shows the distributions of LFB-LSAW velocities and estimated LT thicknesses, together with the measured LT thicknesses at 10-mm steps by an optical method. When the LT thickness is 3 μm, the LFB-LSAW results correspond well to the optical results. However, when the LT thickness is 20 μm, we could observe some significant differences between them, especially along the Y-line scan. It might suggest that it is affected by somewhat changes at the interface by the bonding other than LT thickness.

4. Concluding remarks

In this study, we demonstrated that LFB acoustic microscopy is very useful and productive for resolving the technical problems concerning the bonded substrates which will be employed for future SAW devices.

We will continue to make further experiments to find a better way in the application as a function of measurement frequency and LT thickness, and also other bonding combination with different crystal substrates and different crystal planes and wave propagation directions.

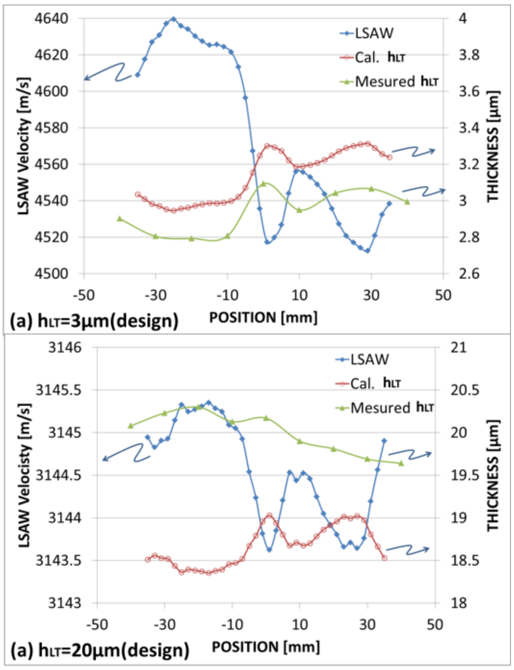


Fig. 3 Measured LFB-LSAW velocity distributions at 225MHz for X-axis propagation and estimated LT-thickness distributions using the results of Fig.2. Thickness data of triangle at each 10-mm position were measured by the optical method.

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e-mail : osamu.kawachi@jmty.yuden.co.jp