APPLICATION OF LINE-FOCUS-BEAM ACOUSTIC MICROSCOPE TO INHOMOGENEITY DETECTION ON SAW DEVICE MATERIALS

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ABSTRACT

The line-focus-beam acoustic microscope is applied to nondestructive evaluation of SAW device materials. For this study, a new system is developed which has an excellent performance to inspect elastic inhomogeneity with measurement accuracy better than ±0.01% in velocity at a point. As a whole system error, it is estimated lower than ±0.03% over a scanning area of 55mm X 55mm. The performance of this system for material evaluation is demonstrated for PZT ceramics, $LiNbO_3$, $LiTaO_3$, and ZnO on glass using an acoustic line-focus-beam sapphire lens at 225 MHz. It is shown that this system is very useful to solve some serious problems in production line of materials as well as devices.

1. Introduction

Various types of SAW devices have been produced in practical use with various materials such as α-quartz, $LiNbO_3$, $LiTaO_3$, PZT ceramics, and ZnO thin films on nonpiezoelectric substrates. To design the devices, selection of device materials should be properly made to obtain the desired device characteristics, taking into account the following parameters: electromechanical coupling factor, SAW velocity, propagation loss, and temperature coefficient, including operating frequency and cost. The devices utilize directly the phenomenon of SAW propagation on a surface, so that their characteristics depend on acoustic properties of materials. The SAW velocity is one of the most important material parameters to evaluate materials. From a point of view of mass production of the devices, it should be greatly required for the material to have less variation of velocity not only on a wafer but also among wafers. Generally, the variation should be within ±0.1% for filters and within ±0.04% for resonators [1].

So far, it is the only way that we measure the characteristics of SAW devices with practical or testing interdigital electrode patterns fabricated on wafers in order to estimate the velocity variation. Recently, the material characterization method by means of the line-focus-beam (LFB) acoustic microscope was established [2]. The method has the most valuable feature as follows: The measurement can be done in the desired wave propagation direction. The accuracy is very high enough to detect small change of elastic properties. The measurement is nondestructive and noncontacting. With the method, we can quantitatively determine the velocity and attenuation of leaky surface acoustic waves (LSAWs) excited on the boundary between a specimen and a reference liquid of water by the LFB acoustic lens and transducer device through the V(z) curve analysis. This method, therefore, is most useful to make such inspection of elastic inhomogeneity on wafers.

In this paper, the material characterization method is applied to inspect velocity variations on SAW device wafers. Experiments are made for PZT ceramics, $LiTaO_3$, $LiNbO_3$, and ZnO on glass substrates, which are commercially obtained.

2. System and Accuracy

Fig. 1 shows a block diagram of the newly constructed system which is applied to the present research purpose. The system comprises an LFB acoustic probe, a pulse mode measurement system of transmitting and receiving electrical signals, a mechanical system of alignment and movement to record V(z) curves with a scanning area of 55mm X 55mm, and a computer for controlling the whole system and for processing recorded curves. V(z)

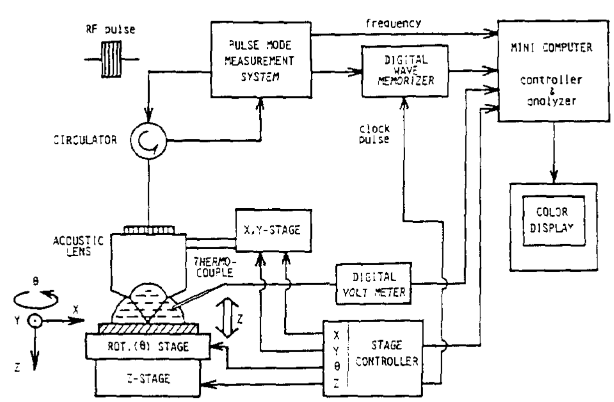

Fig.1. Block diagram of the LFB acoustic microscope system.

curves are the ultrasonic transducer outputs recorded synchronously with clock pulses of stepping motor which translates the acoustic lens along Z axis to determine the distance z between the acoustic lens and specimen surface. The temperature of water and acoustic frequency are also measured. A set of data, namely, V(z) curve, temperature, and frequency, is used to determine the velocity and attenuation precisely at a point according to the processing procedure developed previously [2]. For the two dimensional mapping of elastic properties, the acoustic probe is scanned along x and y directions. In this study, the velocity measurement is made to evaluate two-dimensional elastic inhomogeneity of materials using an acoustic LFB sapphire lens of 1.0 mm in radius at a frequency of 225 MHz.

The measurement reliability of this mapping system was checked to investigate inhomogeneity of materials. A (111) GGG is taken as a specimen, which is a typical single crystal without defects. It was confirmed that the system has the relative velocity resolution better than ±0.01% at one point and the overall system error lower than ±0.03% over a whole scanning area.

3. Experiments

A. PZT Ceramics

Velocity Variation

Experiments were made for a number of PZT ceramic wafers of two-inch diameter with a grain size of 1-2 μm practically in manufacturing SAW TV-IF filters.

A typical V(z) curve was measured as shown in Fig. 2. By analyzing this curve, the LSAW velocity was determined to be 2419.9 m/s. First, we tried to examine the velocity variation and poling effect among wafers. Six wafers were pulled out from one lot of wafers. The poling operation was made for half of them. The LSAW velocities for all the six wafers were measured at the center of each wafer. The results are given in Table 1. The values in the table are average for nineteen results measured by rotating the samples every ten degree with respect to the LFB probe. The average velocities are around 2290 m/s for the samples before poling and around 2420 m/s for the samples after poling. The velocity increase by poling is observed to be about 130 m/s. It can be seen from these experiments that the velocity variation among wafers before poling is very small, while the variation after poling becomes relatively larger.

The velocity distribution on a wafer was measured. To estimate the two-dimensional property, an area on a wafer is segmented into pieces of 5mm X 5mm, and the velocity is measured at the center of every segment. The distribution is shown in Fig. 3, where five graded scales are selected corresponding to every velocity change of 0.2%. The two-dimensional average value is 2435.6 m/s. The remarkable inhomogeneity showing a maximum difference of 0.7% in velocity is observed here.

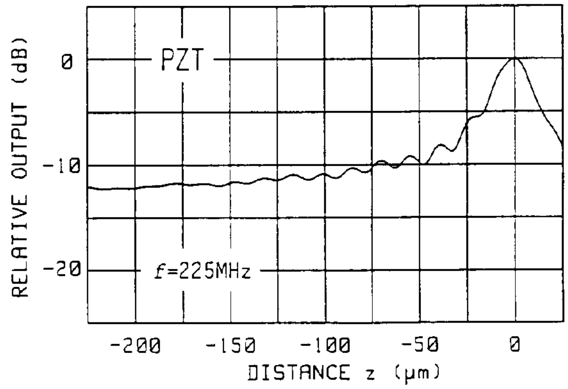

Fig.2. Typical V(z) curve measured for PZT ceramic wafer at 225 MHz.

Table 1. Velocity variation among PZT ceramic wafers and poling effect.

After Poling		Before Poling	
Sample No.	Average Velocity(m/s)	Sample No.	Average Velocity(m/s)
A-1	2414.3	A-4	2288.6
A-2	2396.2	A-5	2287.1
A-3	2419.9	A-6	2288.2

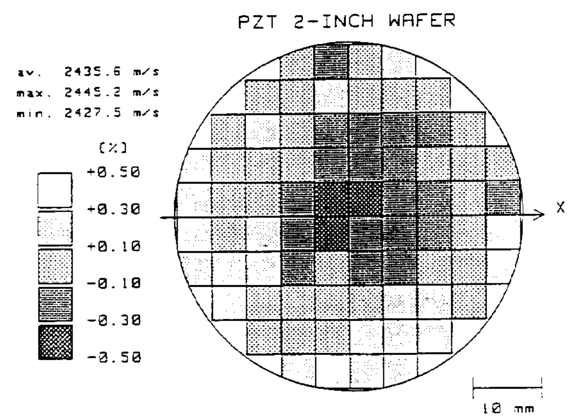

Fig.3. Distribution of LSAW velocity on PZT ceramic wafer.

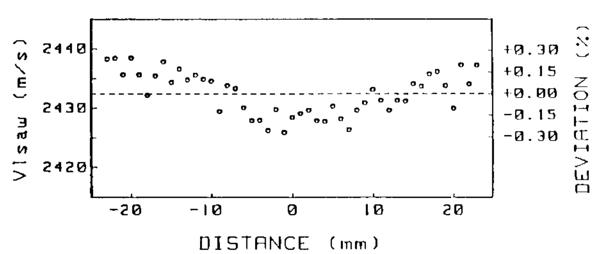

Fig.4. Velocity variation of PZT ceramic wafer along X-scanning shown in Fig.3.

Fig. 4 shows the velocity variation along the X-scanning depicted in Fig. 3. The velocities vary strongly depending on the position. The velocities near the center region are slower than those for the outer region on the wafer. This is a common tendency observed for all PZT ceramic wafers employed in the experiments.

Comparison with SAW Filter Characteristics

Velocity variations on wafers evaluated by this system are compared with frequency characteristics of SAW filters. We fabricated forty pairs of normal interdigital transducers (IDTs) on a wafer with the parameters shown Table 2. The dimensions of each device are 3.72mm X 9.90mm. Frequency responses of all devices are measured. A typical frequency response is shown in Fig. 5. The center frequency of devices depends clearly on the location of devices as shown in Fig. 6. The average center frequency is 36.264 MHz with a maximum difference of 0.5%. The distribution of the center frequency can be converted to that of the SAW velocity using the relation that $v_{saw}=f_0 \cdot \lambda$, where v_{saw} is the SAW velocity, f_0 is the center frequency, and λ is the wavelength (now 66.74μm from the dimensions of IDT). For example, the average center frequency of 36.264 MHz corresponds to the velocity of 2420.3 m/s.

Table 2. Parameters of normal IDTs of SAW filters.

Electrode Width (um)	Gap Width (um)	Number of Electrode Pairs	Aperture Width (mm)	Propagation Distance (mm)
16.68	16.69	8.5	1.42	3.09

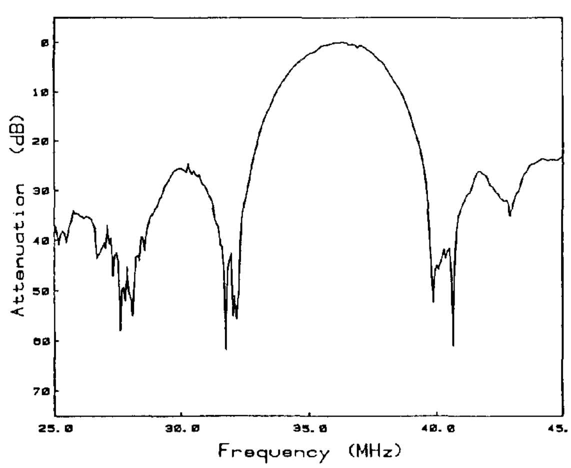

Fig.5. Typical frequency response of SAW filter.

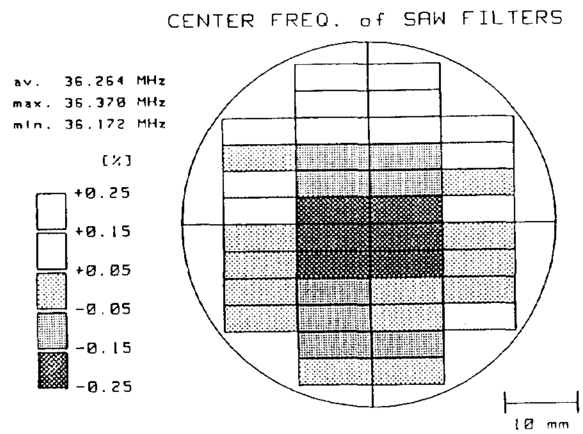

Fig.6. Distribution of center frequency of SAW filters on PZT ceramic wafer.

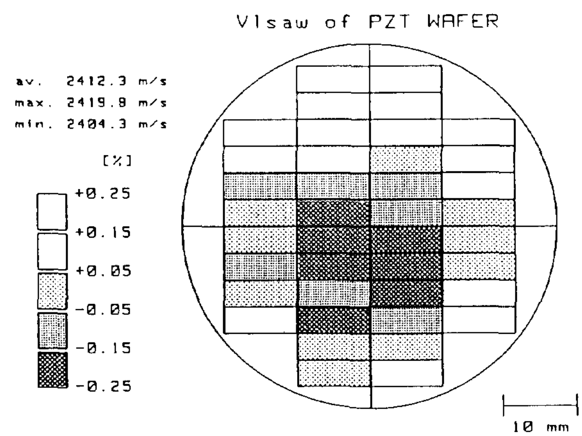

Fig.7. Distribution of LSAW velocity on the same wafer used in Fig.6.

After removing aluminum electrodes by etching , we applied the system to measure the distribution of LSAW velocity at the corresponding location of the devices measured above. Velocity measurements were made at three positions in each device, that is, at the centers of transmitting and receiving transducers and the middle point between the two transducers. The average of velocities measured at the three points is calculated. Fig. 7 shows the experimental results. The average velocity is 2412.3 m/s with a maximum difference of 0.6%. Comparing Figs. 6 and 7, the distribution of the average velocity measured in this way corresponds closely to that of the device center frequency, although there is still a little difference between them. The difference is maybe due to the different experimental conditions that characteristics of SAW devices respond to a whole device area on which SAWs propagate, and, on the other hand, measured average LSAW velocities respond to only three positions on the location of devices.

B. Single Crystals

The system is applied to investigate inhomogeneity on $LiTaO_3$ and $LiNbO_3$ wafers which are most widely used for SAW device substrates. The as-grown crystals are processed into SAW device wafers through a variety of fabrication process such as annealing, poling, grinding, slicing, and polishing. Some problems on the crystal growth process and the wafer fabrication process might give rise to serious elastic inhomogeneity on wafers.

Recently, there occurred a serious problem in industrial production line of X-cut $LiTaO_3$ wafers. The X-ray methods such as diffractometer and topographic techniques are available to analyze imperfection or defects in crystals. The optical method using photoelasticity is also useful to evaluate the residual stress distribution in crystals. However, these methods could not resolve this problem at all. The LFB system was applied to examine many wafers selected from different lots.

Fig. 8 shows a typical velocity distribution of X-cut $LiTaO_3$ wafer on which LSAWs propagate along the rotated 112° Y direction. Fig. 9 shows a velocity variation measured along the diameter direction over a distance of 55mm from the left end, parallel to the orientation flat. A great velocity change was observed especially around the center. The average velocity is 3288.2 m/s and the maximum difference is 0.42%. It is, therefore, revealed that the problem was due to the great velocity variation which might correspond to the inhomogeneity introduced by some undesirable problems such as nonuniform distribution of electric fields in the poling operation.

System is also applied to the commercially available wafers of X-cut $LiTaO_3$ as well as 128° rotated Y-cut $LiNbO_3$ to inspect the elastic inhomogeneity. Figs. 10 and 11 show typical experimental results on the two materials. The results for the $LiTaO_3$ wafer satisfy the specification for SAW devices. On the other hand, the velocity variation for the $LiNbO_3$ wafer is around ±0.05%, relatively larger than that for the $LiTaO_3$ wafer.

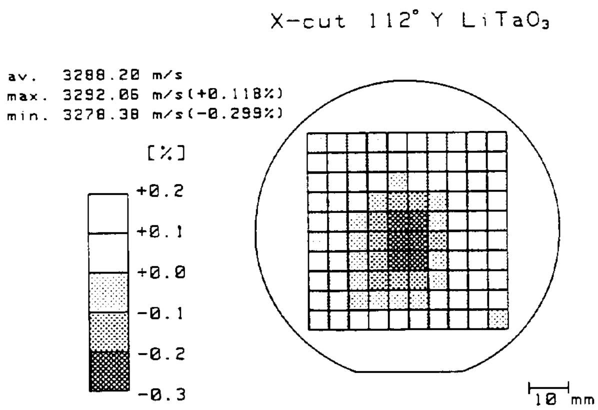

Fig.8. Distribution of LSAW velocity for X-cut 112° Y $LiTaO_3$.

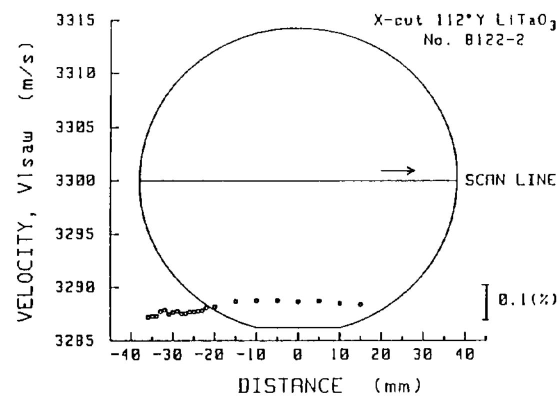

Fig.10. Typical velocity variation for commercial X-cut 112° Y $LiTaO_3$.

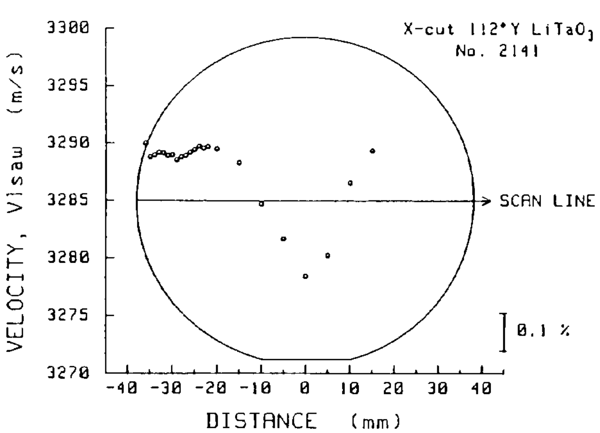

Fig.9. Velocity variation along diameter direction in Fig.8 for X-cut 112° Y $LiTaO_3$.

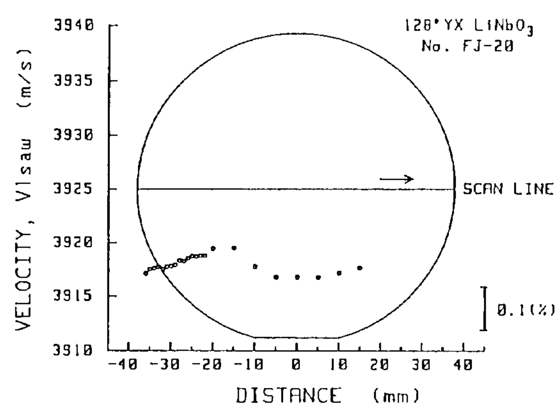

Fig.11. Typical velocity variation for commercial 128° YX $LiNbO_3$.

C. ZnO on Glass

The structure of a SAW filter made of ZnO film on a glass substrate is also in practical use. There happened sometimes the serious problem as to production rate of the device. The rate of inferior devices was about 20%. They considered the following possible causes: 1) velocity variation on a glass substrate and among substrates, 2) variation of elastic properties and thickness of ZnO films made by sputtering, and 3) thickness variation of aluminum electrodes.
With the LFB acoustic microscope, it was found that the problem was due to the first cause. The dimensions of a glass substrate for the devices were 50mm X 50mm. In the mapping examination of inhomogeneity on a substrate, we could not measure any significant velocity variation on the substrate, because the maximum difference was within ±0.03%. So, velocity measurement were performed at the center for 50 substrates selected from many different lots. Fig. 12 shows the experimental results of velocity distribution among substrates. These are two groups. One is around the velocity of 3230 m/s, and the other is around the velocity of 3207 m/s. The difference is around 0.7%. The substrate group with the lower velocities is proper for the fabrication of ZnO film SAW devices. After this investigation, the number of the rate of inferior devices reduced to several percent.

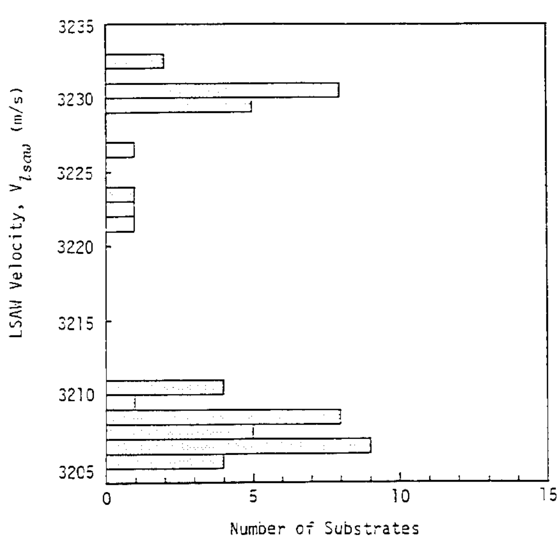

Fig.12. Velocity distribution among glass substrates for ZnO film SAW devices.

4. Conclusion

The LFB acoustic microscope system has been developed which can be applied to evaluate elastic inhomogeneity of materials over an area of 55mm X 55mm with high measurement accuracy. Application of the system has been successfully demonstrated for the inspection of velocity variation on commercial SAW device materials such as PZT ceramics, $LiTaO_3$, $LiNbO_3$, and ZnO on glass. This is one of the most promising applications because the evaluation is directly made without fabrication of interdigital electrodes on wafers. It is demonstrated as examples that the problems actually encountered in the production line have been effectively and successfully resolved with the use of LFB acoustic microscope.

It can be expected, in the near future, that this system will be one of the important instruments in the nondestructive testing of new semiconductor and optoelectronic materials such as GaAs and InP.

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