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"Trends of $LiTaO_3$ and $LiNbO_3$ single crystals for electronic device applications"

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1. Introduction

Since 1965, when $LiTaO_3$ and $LiNbO_3$ single crystals were first grown by the Czochralski method, numerous developments on their applications to electonic devices. Among them, these crystals have been gaining the most warranted position in the surface acoustic wave (SAW) device application field and the pyroelectric detector application field. On the other hand, these crystals have been under development as opto-electronic devices. For applications to these electronic devices, many intensive efforts have been made to establish massproduction conditions of high quality crystals and their scaling up conditions in a diameter, and lower their mass-production cost.

In this review, trends of $LiTaO_3$ and $LiNbO_3$ single crystal growths, wafer fabrications and the crystal qualities will be demonstrated. Moreover, application to various electronic devices will be reviewed.

2. Crystal technology

The crystal growth process for $LiTaO_3$ and $LiNbO_3$ single crystals have been carried out by the well-known czochralski method. The yields of these crystal pulling process are dependent on the quality of the raw materials and the conditions of crystal growth. Table 1 indicates typical pulling conditions for the 3-inch $LiTaO_3$ and

Table 1 : Typical growth conditions for 3-inch crystals

	$LiTaO_3$	$LiNbO_3$
Pulling axis	X-axis	128°Y-axis
Crystal diameter/ crucible diameter	0.60-0.70	0.60-0.70
Linear growth velocity(mm/h)	5-7	5-7
Weight growth velocity(g/h)	180-260	110-160
Crystal rotation (rpm)	8-10	6-10
Temp. gradient (℃/cm)*	15-30	30-80
Initial melt weight (kg)	6.5-7.5	4.5-6.0
Grown crystal weight (kg)	3.5-5.0	2.5-3.5
Grown crystal length (mm)	80-120	80-120
Cooling velocity (℃/h)	50-100	50-100

LiNbO3 crystal. At the Toshiba factory, 3-inch and 4-inch LiTaO3 and LiNbO3 crystals are mainly massproduced. But, 5-inch crystals are engineering level not massproduction level.

The wafer fabrication process for SAW wafers and pyroelectric wafers is shown in figure 1. As shown in fig. 1, the SAW wafer fabrication process has two particular processes of poling and roughening of rear surface, compared to the normal semiconductor silicon wafer process. The orientation flat cutting, slicing, beveling and polishing of the front surface have been established by modifying the silicon wafer fabrication process. For the roughening process, three methods have been adopted; figure 2-(a) shows the result of a normal lapping process using coarse abrasive of GC #180, and (b) is given by a hole pattern honing method. Figure 2-(c) illustrates the groove pattern made by a dicing machine. These hole or groove pattern wafers can be effectively used in SAW devices with a severe frequency specification in the outer path band region.

3. Wafer quality for SAW devices

Quality factors of SAW wafers which influence the SAW device performance and the device production yield are as follow:

(1)compositional variation
(2)surface quality (flatness, rear roughness, polishing defects, etc.)
(3)impurity concentration
(4)resistance to cracking
(5)cut orientation accuracy
(6)perfectness of poling

Of these factors, compositional variation is the most important quality factor, and this will be discussed in detail. Center frequency or resonance frequency of SAW devices is dependent on the SAW velocity of the SAW wafers, and also on the crystal composition. SAW velocities of LiTaO3 and LiNbO3 crystals are around 4,000m/s. Deviation from the center frequency of the SAW device is required to be within ±0.025% for reason of device specification and device production yields. So, this requirement of SAW devices is that SAW velocity variation of SAW wafers is within ±1 m/s. However, the SAW velocity of wafers cannot easily be measured. At the stage of research and development, the relationship between SAW velocity and Curie temperature of LiTaO3 and LiNbO3 crystals was established, based on the fact that the Curie temperature changes linearly with crystal composition. From experimental results, it could be concluded that SAW velocity changes linearly with the Curie temperature; as shown in figure 3 for LiNbO3 crystals, for a example. From these result, it has been estimated that the Curie temperature of the crystals have to be controlled to within ±2.5℃ for LiTaO3 and ±1.2℃ for LiNbO3 in order to satisfy the SAW device requirements. The Curie temperatures of SAW wafers could be measured by using methods - dielectric measurement during heating of the crystals, differential thermal analysis (DTA) or differential scanning calorimeter (DSC), for examples. These measurements of the Curie temperature of the SAW wafers constitute the most important quality control process. Figure 4 shows a typical Curie temperature distribution for LiTaO3 SAW wafers in the Toshiba factory. As shown in figure 4, the Curie temperatures fall within a range of 606±3 ℃, and this deviation value corresponds nearly to ±1.2 m/s of SAW velocity.

The surface quality such as surface flatness required for the SAW wafers depends on the purpose for which it is to be used. The SAW frequency for mobile communication equipment such as a hand-held telephone, cellular phone or pager, is higher than that for TVs and VCRs, so the flatness of the SAW wafers is more important and total thickness variation (TTV) should be less than 5 μm for the former, whereas less than 12 μm will suffice for the TVs and VCRs. On the other hand, the rear surface roughness (Ra) of the wafers for mobile communication equipment is not so important. Ra of those wafers can be less than 1.0 μm, whereas 1.0 to 3.5 μm is required for TVs and VCRs.

4. Applications and future trends

LiTaO3 and LiNbO3 single crystals have found applications as SAW devices and infrared detectors, based on their excellent piezoelectric and pyroelectric properties. Figure 5 illustrates fields of application for SAW devices using LiTaO3 and LiNbO3 crystals. Formerly, the main applications were TV-IF filters and VCR-RF modulators, but in more recent years various SAW devices for mobile communication equipment have been developed and manufactured.

LiTaO3 single crystals are also used for pyroelectric detectors. The main application of LiTaO3 detectors are in light switches and human detector. Non-contact thermometer and pyro-visions are relative minor application for LiTaO3 infrared detectors.

The trend of the total quantity of SAW devices in the world is shown in figure 6. As shown in the figure, increased growth rates are due to the spread of VCRs around 1984 and the expansion in mobile communication systems from 1992. At the beginning of the 21'st century, the market size will be 1.4 times the size of today's market.

Future trends in the size and quality of SAW wafers can also be forecast. For wafer diameter, in 1996 40% of total production is 4-inch diameter, and 60% 3-inch diameter. In 2000, we believe this will be 70% of 4-inch diameter and 30% of 3-inch. The total production in the world can be estimated 650kp per year for LiTaO3 wafers, 800kp per year for LiNbO3, in terms of 3-inch wafer pieces. These values will become to 750kp and 900kp per year at 2000.

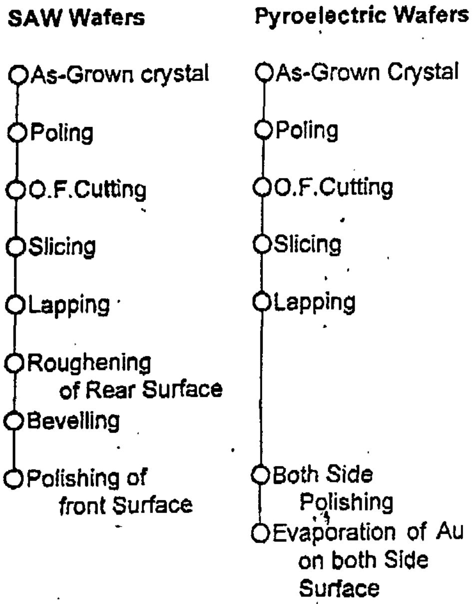

Fig.1 Wafer fabrication process

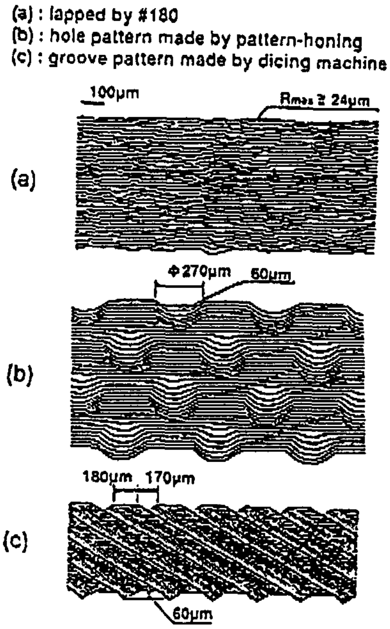

Fig.2 Figures of rear surface roughness

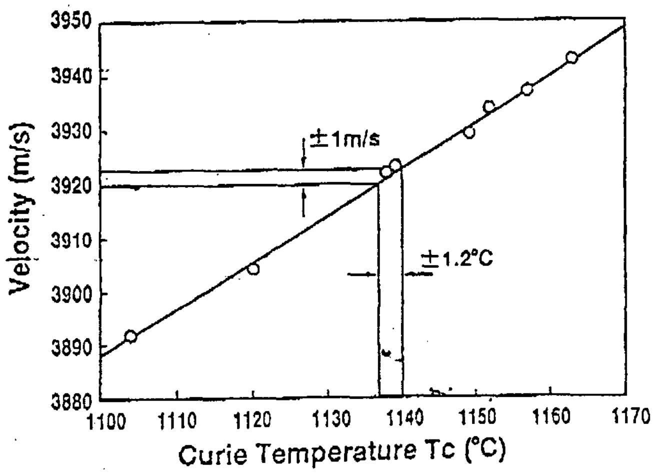

Fig.3 Relation of SAW velocity to Curie temperature for LiNbO3 crystals

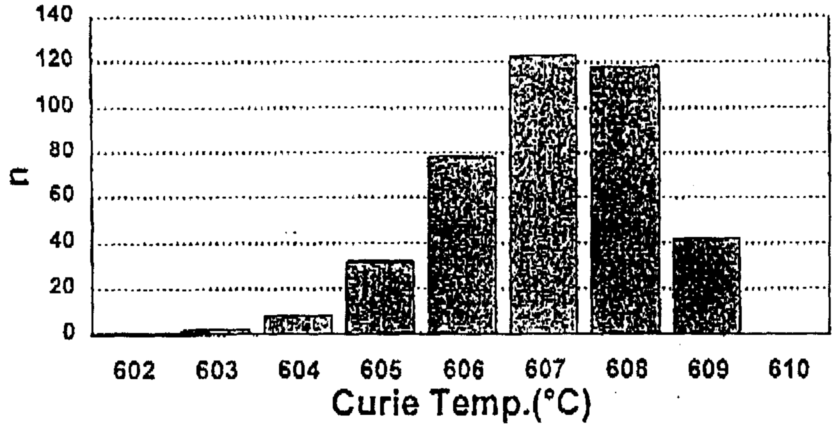

Fig.4 Tc distribution of LiTaO3 SAW wafers

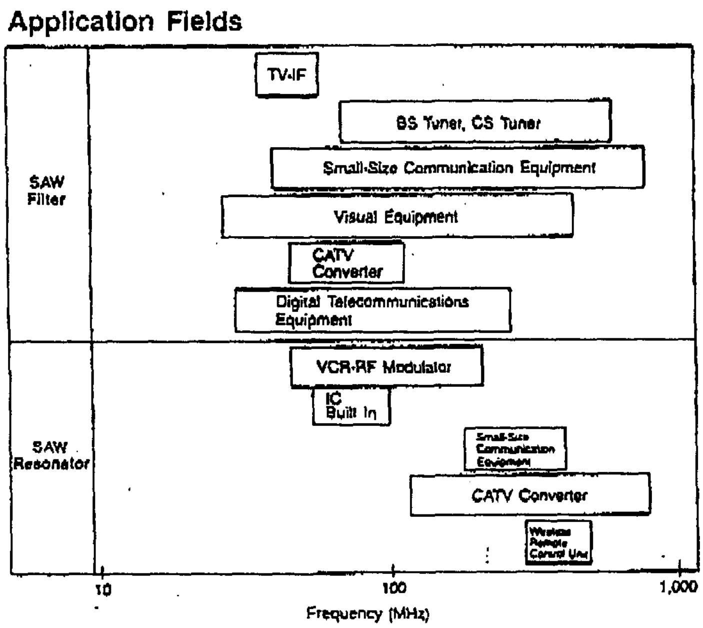

Fig.5 Applications for SAW devices

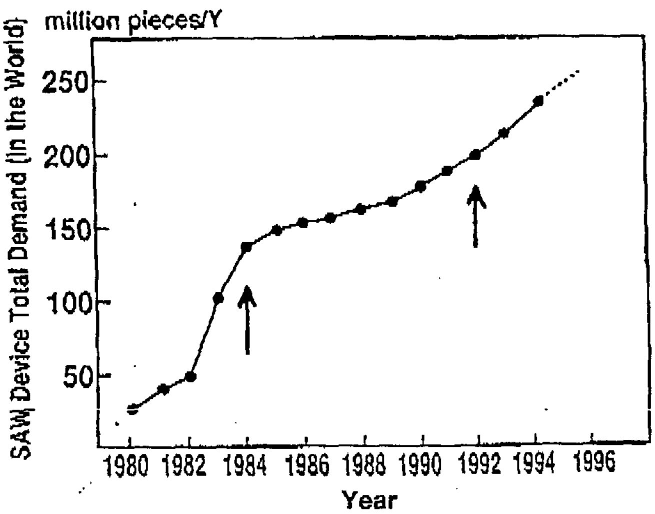

Fig.6 Trend in quantities of SAW devices in the world