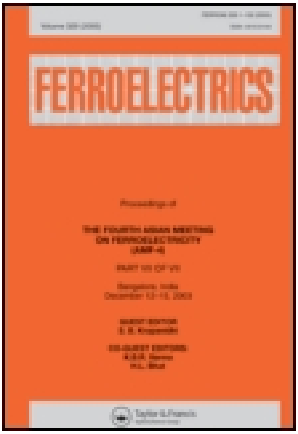

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Acoustic superlattice with linear taper of period and applications

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Acoustic Superlattice with Linear Taper of Period and Applications

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In this report, Y-doped acoustic superlattice (ASL) lithium niobate (LN) crystal with linear taper of period was grown by the Czochralski method. The ferroelectric domain structure was revealed by optical photomicrograph. When an alternating electric field of frequency ranging from 680 MHz to 1100 MHz was applied, a ultrasonic wave with the same frequency was excited implying that a high-frequency bulk wave device with broad bandwidth could be fabricated.

Keywords: lithium niobate; acoustic superlattice

INTRODUCTION

Acoustic superlattice (ASL) lithium niobate (LN) with periodic laminar ferroelectric domain structures is an artificial crystal of high response frequency and very low insertion loss.[1, 2, 3] It has been applied in acoustic devices with some advantages. For example, the transducer made of ASL combines a piezoelectric transducer with a transmission

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medium in a single crystal.[4, 5] In an ASL LN, however, the more the periods are, the narrower the bandwidth is. In this paper, the relationship between periods of the ferroelectric domains and acoustic bandwidth of ASL LN is discussed.

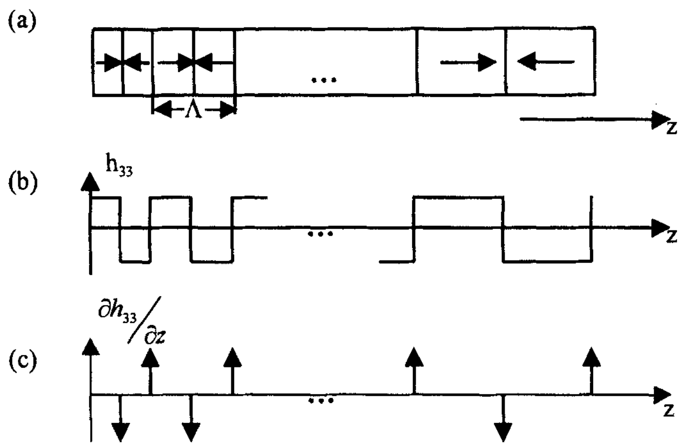

FIGURE 1 ASL LN for excitation of one longitudinal wave. (a) Schematic diagram of ASL; (b) Corresponding piezoelectric coefficient as a function of z; and (c) Corresponding sound δ-sources

In the ASL, domains are arranged in one dimension along z-axis (FIGURE 1a). Our previous study has already proved that in this material, all the odd-rank tensors will change signs from one domain to the next. Thus the piezoelectric tensor, being a third-rank one, is no longer a constant through the ASL, but a two-value function of the spatial coordinate z (FIGURE 1b). Under the action of an alternating electric field, the domain walls, where the piezoelectric coefficient shows discontinuity, can be regarded as sound δ-sources as shown in FIGURE 1c. The ultrasonic waves excited by these sound δ-sources interfere with each other. Those satisfying the constructive interference will appear as resonant peaks in the ultrasonic spectrum. This is the physical principle for ultrasonic excitation with ASL. One of the unique features of ASL is that the fundamental working frequency is determined by the modulation period as $f_0 = v/\Lambda$, where Λ is the modulation period of ASL and v is the velocity of shear wave. Thus ASL LN could be considered to consist of 2N individual crystal plates and each oscillates independently. The response frequencies are very high for the modulation period is several microns long. Though ASL with a periodic laminar domain structure is a candidate material for high frequency acoustic devices, with sharp resonance peak and narrow bandwidth. A new method has been proposed to widen the bandwidth of ASL.[6, 7] It may be assumed that there is a one-to-one correspondence between the response frequency and the modulation period. Therefore, if the modulation periods vary linearly, the resonance peak can be widened, offering advantages for many acoustic applications.

CRYSTAL GROWTH

To fabricate such a unique structure, a modulated Czochralski method was employed. A specially designed asymmetric temperature field causes a periodic temperature fluctuation on the solid-liquid-interface, which results in a periodic yttrium concentration distribution along the growing direction. The concentration distribution then builds up a periodic space-charge-field (SCF). When cooled through the Curie temperature, a paraelectric to ferroelectric transition will take place. The periodic ferroelectric domain structure was fabricated in LN by the periodic SCF. In the present work, LN melt was doped with 0.5wt% yttrium and the LN crystals were grown in the asymmetric temperature field. The modulation period of ASL is determined by the pulling rate v_{pull} and the rotation rate n_{rot} as $\Lambda = v_{pull}/n_{rot}$ without considering the decrease in melt surface in the crucible during crystal growth. Thus the modulation period changes with v_{pull} or n_{rot}. In this work, the rotation rate n_{rot} is computer-controlled. Thus the ASL LN crystals with various ferroelectric domain structures can be fabricated through program control. To obtain ASL LN crystals with several hundred megahertz bandwidth, a program for the modulation periods ranging from 6.7μm to 10.6μm was designed. The ASL LN crystals were then fabricated successfully.

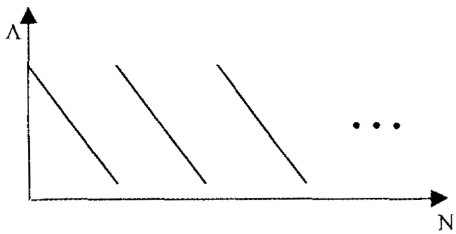

FIGURE 2 A schematic diagram showing the programming relationship between the modulation period and the sequence number N

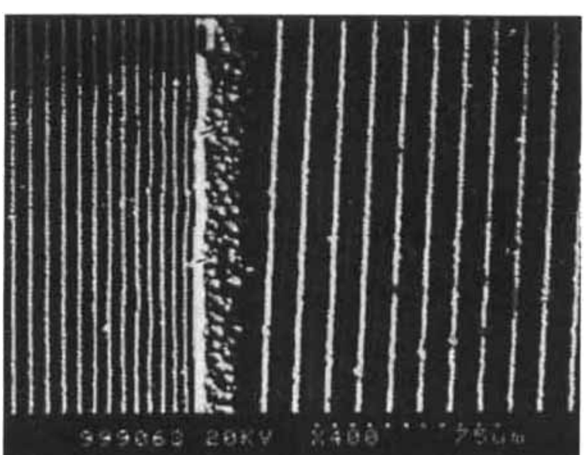

FIGURE 3 An SEM micrograph showing the ferroelectric domain structure

Samples were then cut from the ASL LN crystals grown along the z-axis and shaped into z-cut plates (about 10mm×5mm×1mm). The ferroelectric domain structures were revealed by optical photomicroscope when the samples were polished and etched in the mixture of 1 part HF and 2 parts HNO_3 (by volume) for 10 minutes at 100°C. FIGURE 2 shows the programming relationship between the modulation period and the sequence number N. FIGURE 3 shows the SEM micrograph of ferroelectric domain structure. Each modulation period is composed of one dark striation and one bright striation. Between two long-range periods, a growth striation was made by stopping the rotation of pulling rod. In the photomicrograph, the modulation periods decrease almost linearly and continuously with the sequence number N. The modulation periods vary from 6.7μm to 10.6μm.

ULTRASONIC WAVE EXCITATION

To investigate the acoustic properties of the ASL, an HP8510C network analyzer was used. The z-cut plates of ASL samples were painted with a pair of electrodes of Ag glue on the z-faces. The area of the electrodes was about 10mm×5mm. Thus a prototype resonator was constructed. This excited scheme is defined as in-line field scheme (FIGURE 4), a name derived from interdigital surface wave transducers. The relationships between the reflection coefficient r and the response frequency were measured as a resonator reflects the electrical energy if the impedance is not equal to that of the electrical measurement system. When a resonator is in oscillation, its impedance varies with the frequency. In the vicinity of resonator, the impedance changes greatly. The insertion loss is another important parameter concerning the transducer. If the "dissipation loss" of measuring the acoustic power absorbed due to internal dissipation from dielectric, sound absorption, and other losses is ignored, the insertion loss (IL) can be expressed as $IL = -20\log(1-r^2)$,[8] where r is the magnitude of the reflection coefficient. FIGURE 5 shows the IL-Frequency curve in a resonator. In FIGURE 5, the frequency response range is extended from 680MHz to 1100MHz, for comparison with our previous results on periodic ASL. It agrees with the theoretical prediction based on $f_0 = {}^{v}/_{\Lambda}$, *i.e.* the bandwidth is from $f_1 = {}^{v}/_{\Lambda_1}$ =680MHz to $f_2 = {}^{v}/_{\Lambda_2}$ =1100MHz. A potential application of the high-frequency resonator with broad bandwidth is for the bulk wave dispersive delay line devices.

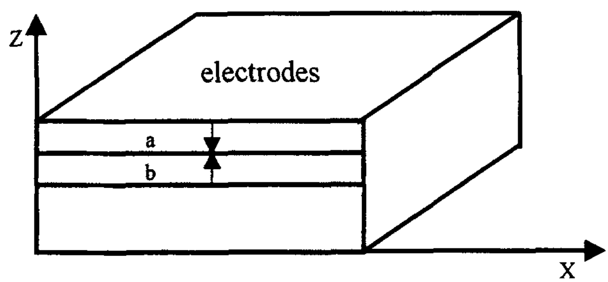

FIGURE 4 Diagram of the "in line" scheme with an ASL

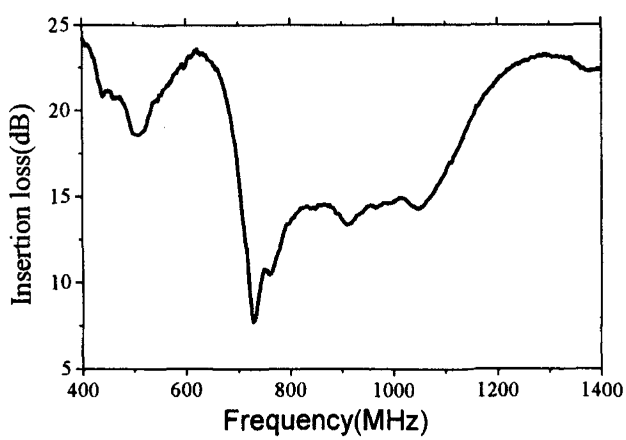

FIGURE 5 The curve of insertion loss vs resonator frequency

CONCLUSIONS

ASL LN crystals with linear taper of period were grown successfully. A sample with the periods varying from 6.7μm to 10.6μm was selected for acoustic measurement, where HP8510C network analyzer was used to evaluate the reflection coefficient. A frequency response in the range of 680MHz to 1100MHz was achieved, which agrees well with the theoretical prediction. Based on there results, a prototype high-frequency resonator with broad bandwidth has been constructed.

Acknowledgement

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