Proceedings of Symposium on Ultrasonic Electronics, Vol. 36 (2015)
5-7 November, 2015

Development of a Metal Bonded Langevin Transducer Using $LiNbO_3$

$LiNbO_3$を用いた金属接合型ランジュバン振動子の開発

Hiroshi Ito†, Hikaru Jimbo, Koichi Shiotani, Nagahide Sakai (Olympus Corporation)
伊藤寛、神保光、塩谷浩一、坂井長英 (オリンパス株式会社)

1. Introduction

Bolt clamped Langevin transducers (BLT) are widely used as a high power ultrasonic source. In BLTs, ring shaped piezoelectric elements made of Lead Zirconate Titanate (PZT) and two metal blocks between which the piezoelectric elements are arranged are joined to a single unit by tightening a bolt. PZT is the most common piezoelectric material, however, some resarch reported Langevin transducers using Lithium Niobate ($LiNbO_3$, LN)[1-4] because of its superior features such as lead-free, high Curie temperature (1210 degree) and high fracture limit for ultrasonic vibration[5]. In those papers, two type of Langevin transducer are investigated, one is BLT and the other is bonding type Langevin transducer in which expoxy resin is used as a bonding material.

The BLTs using LN showed good performance, however, LiNbO3 is brittle material and has difficulties in making a ring shape by machining process. That leads to much increase in the cost of making the piezoelectric elements and is not suitable for a commercial application. On the other hand, in the bonding type, the difficulties in LN processing decrease, but the vibration performance need to be improved for practical application.

In order to realize a practical high power LN Langevin transducer, we developed a metal bonded LN Langevin transducer as a low cost and robust assembly method. It utilize lead-free solder as a bonding material by which each elements such as piezoelectric elements and metal blocks are bonded together.

2. Transducer Structure and Fabrication

The schematic diagram of transducer structure is shown in **Fig. 1**. 36° Y-Cut lithium niobate is choosen for the piezoelectric material since it is suitable for thickness vibration mode [6,7]. The shape of piezoelectric elements is square, not a ring. Adapting the square shape make it possible to use a conventional dicing process used in semiconductor and/or MEMS industry and to reduce the process cost of making the piezoelectric elements from a LN wafer.

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hiroshi3_ito@ot.olympus.co.jp

Each elements in the transducer is bonded with a lead-free solder. In order to improve the wettability and the bond strength among the elements of the transducer, a underlying metal, Ti/Pt/Au thin film, is deposited on the bonding surface of the elements. The metal bonding is expected to be more rigid and robust than a adhesive bonding, then the vibration characteristics of the bonding type LN Lagevin transducer is expected to be improved.

One of the difficulties in realizing the metal bonded LN Langevin transducer is to prevent a crack of LN chip caused by thermal stress. The solder bonding process require heating the entire transducer to about 220 degree Celsius at least, which result in large thermal stress on LN chips adjacent to metal blocks after cooling to the room temperature. In order to decrease the thermal stress on LN chips, buffer layers made of ZrO2 are arranged between the metal blocks and the LN chips. Duralumin is choosen as a material of the metal blocks for its high thermal conductivity and its high mechanical strength.

The dimensions of the elements are as follows, a cross section of the transducer perpendicular to vibration direction is 10mm square, thickness of LN chips and buffer layers is 1mm, the length of duralmin is 24.4mm. Twelve LN chips are stacked and the resonant frequency of the transducer is 45.0kHz.

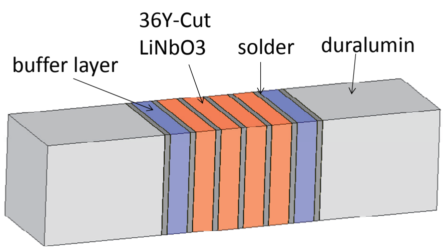

Fig. 1 (a) Schematic diagram of metal bonded LN Lagevin transducer.

The solders and the underlying metals are also used as electrodes to apply drive voltage to the LN chips. Electrical wires are attached to the side of the transducer and electrical contacts between the wires and the solders are made with electrically conductive paste.

The bonding process is conducted in vacuum to prevent bubbles from getting involved in the bonding area. The transducer work well without a polarization process even after the solder bonding. **Fig. 2** is a picture of the transducer fabricated in this study.

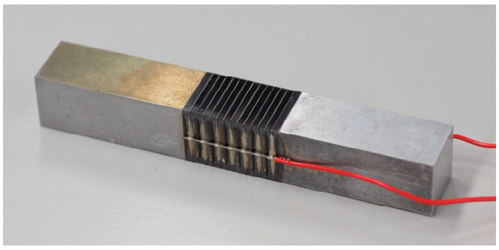

Fig. 2 Picture of metal bonded LN Langevin transducer fabricated in this study

3. Characterization of the transducer

Fig. 3 shows a typical impedance curve of the transducer. The resonance resistance is as low as a few tens ohm and Q value is about 1700.

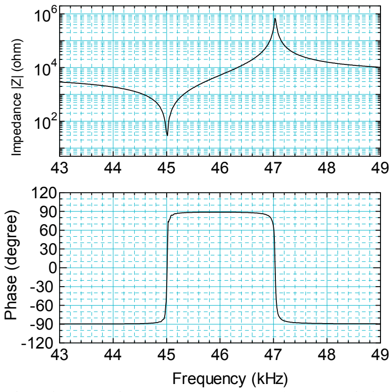

Fig. 3 The impedance curve of metal bonded LN Lagevin transducer.

Fig. 4 shows the driving voltage dependence of the resonance of the vibration velocity, the relationship between the vibration velocity and the current and the dependence of the resonance frequency on the vibration velocity. These data is obtained by downward frequency sweeping of the drive signal with constant voltage.

The resonance curve is symmetry up to over high vibration velocity of 1.0m$_{(0\text{-}p)}$/s. The skew in the resonance curve or the so-called "jump phenominon", which is normally observed in the case of PZT Langevin transducer, does not appear. The resonance frequency is quite stable. The rigid structure by the metal bonding in addition to the linearity of LN material characteristics itself would result in these stable and linear characteristics of the transducer.

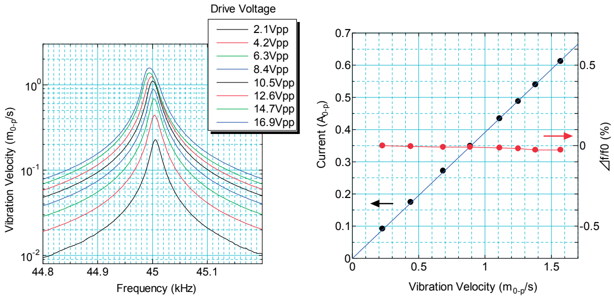

Fig. 4 Driving voltage dependence of the resonance of the vibration velocity(left) Relationship between the vibration velocity and the current, and resonance frequency change (right)

4. Conclusion

In this study, the metal bonded LN Langevin transducer is developed, and the dependence of impedance and resonant characteristics on the vibration velocity are evaluated. It shows that the metal bonded LN Langevin trasnsducer is able to achive stable operation up to high vibration velocity of 1.0m/s(0-p) and that the metal bonded LN Langevin trasnsducer has a good perfomance as a high power ultrasonic transducer.

Acknowledgment

The authors would like to thank Associate Prof. Takeshi Morita of the University of Tokyo for helpful suggestion and discussion on this work.

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