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► **To cite this version:**

E. Courjon, N. Bodin, G. Lengaigne, L. Gauthier-Manuel, W. Daniau, et al.. Fabrication of periodically polled domains transducers on LiNbO_3 . International Frequency Control Symposium and Exposition, Jun 2006, Miami, United States. pp.831-834, 10.1109/FREQ.2006.275497 . hal-00194288

HAL Id: hal-00194288

<https://hal.science/hal-00194288v1>

Submitted on 14 Apr 2021

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Fabrication of periodically poled domains transducers on LiNbO₃

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Abstract— The development of piezoelectric transducers based on periodically poled ferroelectrics domains is investigated. Optical quality Z-cut LiNbO₃ wafers have been used for the fabrication of test devices operating in the range 7 – 70 MHz. The fabrication process is detailed and characterization results are reported. A very good agreement between theoretical predictions achieved by periodic finite element analysis and experiments is observed, allowing for a precise identification of the excited modes.

I. INTRODUCTION

The possibility to manufacture elastic wave-guide based on a thin ferroelectrics film deposited on a single crystal substrate and periodically poled to enable the excitation of surface acoustic wave has been demonstrated recently [1,2]. The so-called piezoelectric inter-digital transducer (PIT) simply consists in two electrically conductive media embracing a poled ferroelectrics layer. It has been successfully implemented and tested for the excitation of elliptically polarized waves in the frequency range 1-3 GHz [2].

In this work, the possibility to develop PITs on LiNbO₃ is investigated, since this material is classically identified as well-adapted for very high frequency applications. The first experiments have been performed on 500 μ m thick 3" wafers of optical quality Z-cut answering severe specification on total thickness variation and side parallelism. The fabrication of PITs on such wafers allows for the excitation of symmetrical Lamb modes with an operating frequency twice higher than those obtained using standard inter-digital transducers. A photo-resist pattern is defined on one side of the wafer, enabling the implementation of a poling process using a liquid electrode. A poling sequence [3] (max electric field of about 22 kV.mm⁻¹) was applied to successfully fabricate PITs of period 100 and 200 μ m (50 and 100 μ m line-width respectively). The corresponding devices exhibiting respectively 500 and 200 periods have been tested and the measured admittance are compared to theoretical predictions. The latter were obtained using our

periodic finite element code [4] providing an harmonic admittance considering a synchronous excitation of all the PIT cells comparable to the admittance of our very long implemented PITs. An excellent agreement is found between both results, enabling one to analyze almost all the peaks of the experimental setup response. Even low frequency parasitic signals were analyzed thanks to the theoretical analysis. The LiNbO₃ wafer then was lapped to check the robustness of the PIT to this kind of operation. The PIT still operates after reducing the wafer thickness by a factor of 2. As in the case of classical Lamb waves, the fundamental mode is almost insensitive to the wafer thickness. The frequency control is then totally achieved by the PIT period for that mode, offering attractive perspectives for the development of reliable high frequency devices.

In the first section of the paper, the fabrication process is reported, pointing out specific difficulties related to the use of LiNbO₃. The second part of the paper is dedicated to the characterization of the devices and to theory/experiment assessment. The evolution of the spectral behavior of the device versus its thickness is theoretically and experimentally investigated and the mode shape and polarization is deduced from theoretical calculation. As a conclusion, the possible applications of devices based on PITs on LiNbO₃ are listed and discussed.

II. FABRICATION OF PIT ON Z-CUT LiNbO₃ PLATES

A. Poling bench

We first recall here the overall principle of the piezoelectric inter-digital transducer (PIT). It is fundamentally based on a periodically poled piezoelectric medium. Each side of this medium is metallized, then providing a capacitive dipole in which elastic waves can be excited. Such a periodically poled structure can be advantageously achieved on a ferroelectrics material like PZT [1,2] thanks to the rather small value of its coercitive

electric field (the absolute value of the electric field above which the ferroelectrics poling can be controlled). The principal advantages of PITs compared to standard periodic inter-digital electrode transducer (IDTs) deposited atop piezoelectric materials is first the robustness of the excitation versus defects or surface pollution (no passivation required to avoid short circuit as for standard IDTs) and second the possibility to excite waves exhibiting a wavelength equal to the poling period, contrarily to standard IDTs for which the wavelength is equal to twice the mechanical period (Bragg condition). Figure 1 schematize the general outlook of such a device and points out the interest of the PIT compared to standard IDTs.

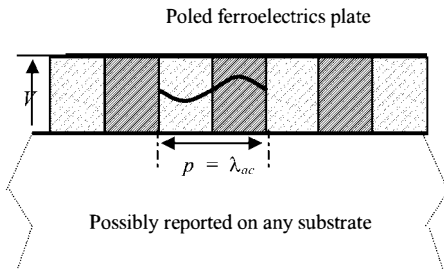


Figure 1. Typical geometry of piezoelectric interdigitated transducer (PIT) based on ferroelectric poling

As mentioned in introduction, the poling process can be rather easily applied to PZT for which the coercitive field is small enough to allow for an efficient control of the domain polarity. In the case of lithium niobate, this situation is quite different because of the large value of its coercitive field (22 MV.m^{-1} compared to 2.5 MV.m^{-1} max. for PZT). As a consequence, the development of a dedicated poling bench was required to control the poling of thick ($500\mu\text{m}$) Z-cut LiNbO_3 plates. This is detailed in ref.[3]. Consequently, only a short recall of the bench principle is reported below.

The poling bench mainly consists in a high voltage amplifier used to submit the LiNbO_3 wafer to an electric field strong enough to invert the native poling of the plate. To achieve such an operation, one needs the use of optical grade Z-cut LiNbO_3 plates. Wafers are cut in the same boule to well control the poling condition. A photoresist mask is achieved atop one wafer surface, which will control the poling location. An lithium chloride electrolyte is used to drive the poling high voltage atop the wafer surfaces. A dynamic poling sequence is then imposed to the wafer, progressively reaching the coercitive field of lithium niobate. An evidence of succesfull poling is obtained by measuring the current of the whole electrical system. Once evidence of transient current measured, the device is considered to be poled. Following this sequence, and providing no short circuit occurs, an almost perfect poling can be achieved. Figure 2 shows a principle scheme of the poling bench.

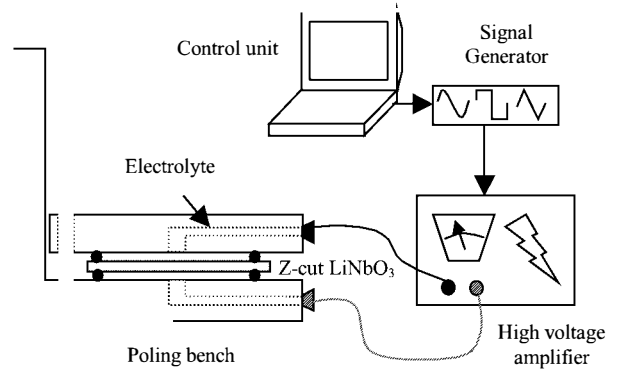


Figure 2. Scheme of the ferroelectric plate poling bench

B. Design of the device

The fabricated devices correspond to periodic transducers exhibiting periods p equal to $400\mu\text{m}$, $200\mu\text{m}$ and $100\mu\text{m}$ respectively, with a volume fraction ideally equal to 50%. The number of period of the corresponding transducers is 100, 200 and 500, yielding quite long transducers preventing the fabrication of more than three devices on a 3" wafer. The acoustic aperture was 10 mm for each device in order to avoid any diffraction effect. This kind of structure is assumed to only exhibit symmetrical modes, as there is no source of geometric nor material-related asymmetries. It is expected to behave in a very close way to the one simulated by our own periodic FEA code which is devoted to the simulation of infinite periodic transducers [4]. We also assume that edge effects should remain small enough to prevent major signal pollution, as there is no in-phase reflection effects on the wafer sides. Figure 3 shows the implantation of the periodically poled sequence on the wafer and of the top side electrodes (the wafer backside is totally metallized). Note that the backside electrical contact is reported on the top surface thanks to the wafer sides metallization naturally generated by the sputtering process.

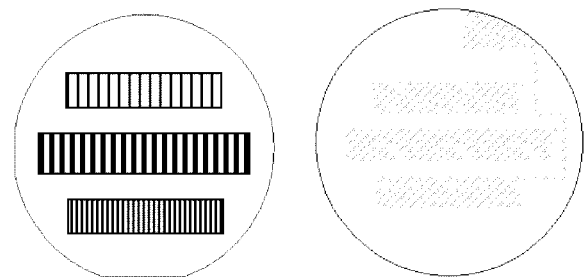


Figure 3. Implantation of the periodically poled sequences and of the top side electrode on the Z-cut LiNbO_3 wafer

The dispersion curve of Lamb modes on a Z-cut LiNbO_3 plate has been computed first along the Green's function

approach and is plotted in fig.4, giving a clear idea of at least the velocity of the first symmetrical mode (the so-called S_0 mode, assumed to be the most suited to be excited by our transducer). This allows us to point out the operating frequency of the first mode for each of our device configuration.

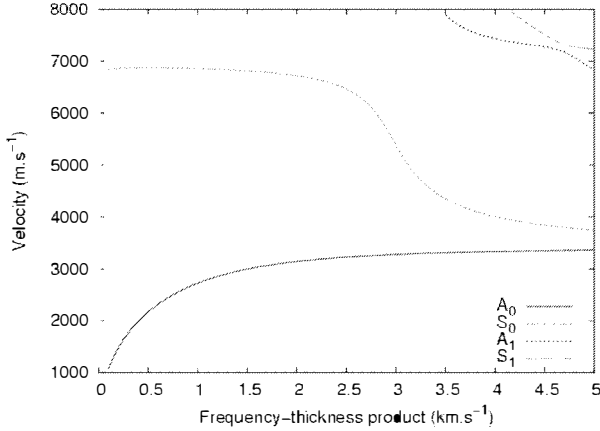


Figure 4. Dispersion curve of Lamb waves on a Z-cut LiNbO₃ plate

A simple geometric construction gives the operating frequencies for each excited Lamb mode. For a plate thickness h , the slope m of a straight line passing through the origin is equal to the wavelength-plate thickness ratio ($m=\lambda/h$). In our case, the values of the slope m are 0.2, 0.4 and 0.8 respectively. Projecting the corresponding line on the Lamb wave dispersion curves allows for the prediction of the wave velocity and hence the operating frequency for each mode. Since the values of m are always smaller than 1 (i.e. the frequency-thickness products corresponding to the test device are in the range 5-20 km.s⁻¹), we could not take advantage of the high velocity of the S_0 mode. As a consequence, the first coupled mode on our device should always exhibit a wave velocity close to 3500 m.s⁻¹, yielding operating frequencies respectively equal to about 8.5 MHz, 17 MHz and 35 MHz. As it will be shown further, this first order prediction nicely meet the experimental values.

III. EXPERIMENTAL RESULTS

In this section, we present the electrical measurements obtained using a Süss Microtec RF probing bench using the so-called Z-probes connected to a Rhode & Schwarz ZVRC network analyzer. The electrical admittances of the test devices have been measured and are compared to the harmonic admittance of the corresponding configuration. These results are reported in fig. 5(a,b,c) for the three considered configurations. In fig.5c, we have reported the response of an un-poled device, as only the bulk wave signature and its odd harmonics appears on the experiments. We have no explanation to propose for that result, since all the transducers were processed at the same time.

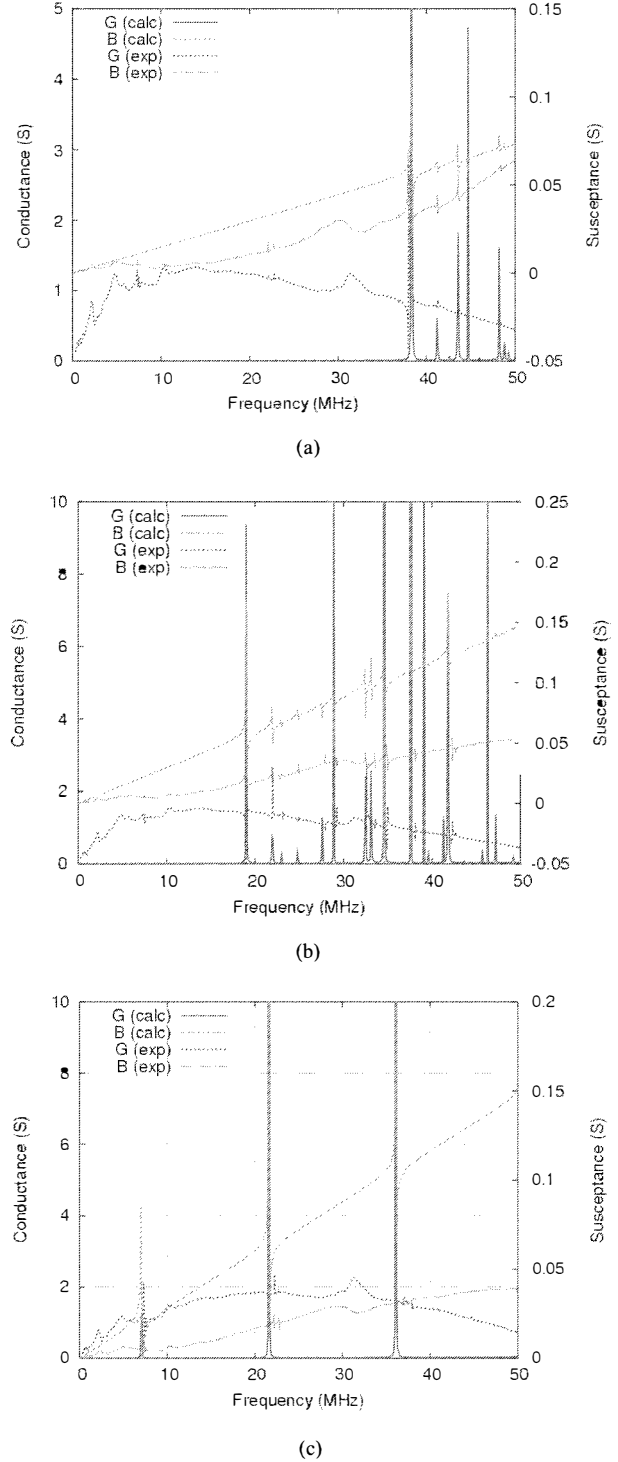


Figure 5. Comparison between theory and experiment for the three test vehicles (a) period $p=100\mu\text{m}$ (b) $p=200\mu\text{m}$ (c) $p=400\mu\text{m}$ (poling failed)

We have related the contribution on the experimental curves near 7 MHz of fig 5a&b to parasitic bulk waves due to the actual volume fraction of positively and negatively poled domains of the period. In the case the volume fraction is not rigorously equal to 50% (for instance 40% Z+ / 60%

Z- within the period), the longitudinal bulk wave and its odd harmonics (see the contribution at 21 MHz on fig. 5a) can be weakly excited. This was simulated for the 100 μ m period device and is reported in fig.6.

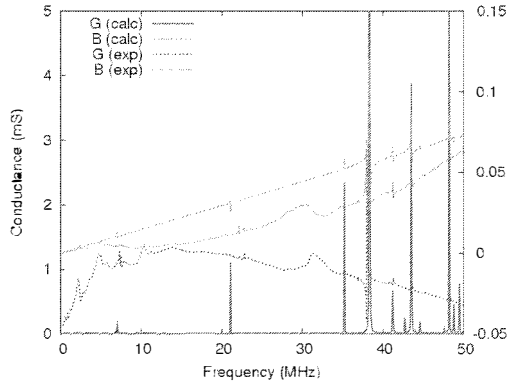


Figure 6. Influence of a volume fraction defect on the transducer response (40/60% instead of 50% as expected)

Thanks to the very good agreement between theory and experiments on fig 5a&b, one can easily identify the shape of the mode of the different Lamb-wave contributions, allowing to select one of those for its particular properties and polarization. Fig.7 (a,b,c) shows some examples of modes excited in the plate for a 200 μ m period transducer. It can be seen on these graphs that elliptically polarized modes as well as almost purely longitudinal waves can be excited in the plate thanks to our PIT.

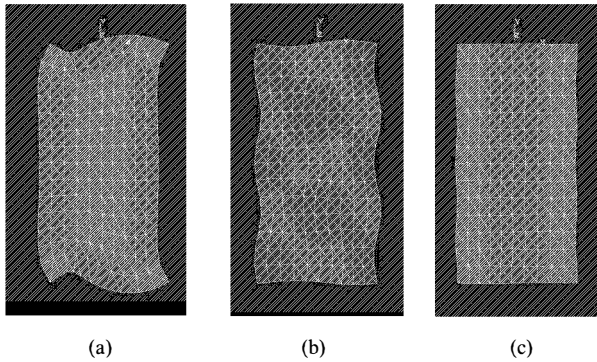


Figure 7. Shape of given modes of the 100 μ m period transducer (fig. 5b) (a) fundamental at 19 MHz (b) mode#6 at 28 MHz (c) mode#8 at 34 MHz

The last experimental work that has been achieved for this paper is to test the robustness of the polarization to lapping and polishing techniques. These operations are required in order to fabricate LiNbO₃/Silicon wave-guides, as expected as a future issue of our work. We consequently have lapped down the plate to a thickness of 250 μ m and then achieved new admittance measurements. Again, the very nice theory/experiment agreement is met as shown in fig.8, proving that the poling is strong enough to persist even after such treatments.

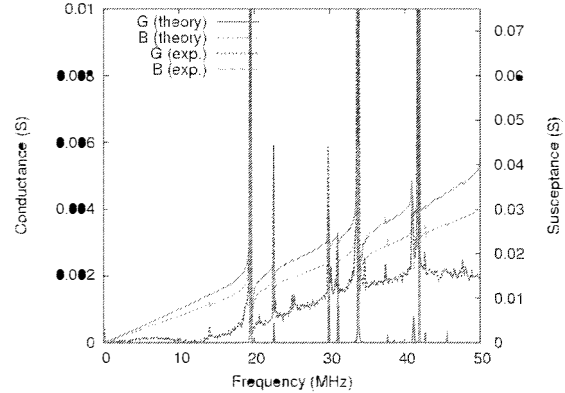


Figure 8. Theory/experiment assessment after lapping the plate down to 250 μ m, 200 μ m period PIT

IV. CONCLUSION

PIT have been successfully manufactured on LiNbO₃ Z-cut plate, allowing for a very nice demonstration of the piezoelectric inter-digital transducer's operation on such material. Almost all the contributions to the electrical admittance of different devices have been predicted by FEA, allowing for the mode shape identification. The poling is found very resistant to different technological treatment, allowing for any kind of process sequencing. This will be exploited for the fabrication of wave-guide consisting of Z-cut lithium niobate plates on silicon.

ACKNOWLEDGMENT

This work has been achieved in the Dominos program framework, funded by the European Community as the InterReg project DOMINOS.

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