Periodically Poled $LiNbO_3$ transducer on (YX*l*)/128° cut for RF applications

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Abstract — ***Previous studies have shown Periodically Poled Lithium Niobate structures on Z-cut $LiNbO_3$ could be used as acoustic transducers to generate acoustic waves. Investigations on Periodically Poled $LiNbO_3$ (YXl)/128° transducers have been conducted. Simulations have pointed out interesting electromechanical coupling from such transducers. Fabrication of Periodically Poled (YXl)/128° $LiNbO_3$ transducers bonded/thinned on Silicon is presented and confirm the possibilities of rotated cuts poling for new transducers.***

Keywords — ***Periodically Poled Lithium Niobate, acousto-electric transducer, rotated cut, radio-frequency.***

I. Introduction

Ferroelectric properties of Lithium Niobate ($LiNbO_3$) have been actively studied for almost 60 years due to excellent optical properties of this material. In 1980, Feng *et al.* have successfully realized a Periodically Poled Lithium Niobate (PPLN) device for optical purposes [1], consisting of Lithium Niobate domains with periodic reversal of its orientation. In late 90s – early 00s, it has been shown PPLN devices on Z-cut $LiNbO_3$ can be used as acoustic transducers; studies have been made on Z-cut to determine acoustic properties of these devices and to discuss about possible applications of PPLN acoustic devices [2]–[4]. Studies have demonstrated interesting properties of PPLN-based acoustic compared to standard SAW ones such as the robustness of the excitation versus defects or surface contamination, the opportunity to excite fundamental waves exhibiting an operating frequency twice as high for a same spatial period, and the possibility to excite waves of various polarizations. A functional acoustic resonator based on bulk and bonded/thinned Z-cut PPLN transducers operating at 131MHz have been demonstrated [5].

Nevertheless, actual state of art on Z-cut PPLN devices highlights low electromechanical coupling factors ($k^2 < 1\%$) and small quality factors (Q = 300-500) [6]. Ridge-shaped periodically poled acoustic transducers on Z-cut $LiNbO_3$ exhibits high coupling factors higher than 20% [7], but their performances are strongly dependent of edges verticality, and obtaining perfectly vertical ridges are a strong technological challenge.

As state of art on PPLN acoustic devices is limited to Z-cut Lithium Niobate, is it possible to get better figures of merit (k^2, Q factors) by using a different (YX*l*)/θ cut of Lithium Niobate? In this paper, we actively studied a (YX*l*)/128° Lithium Niobate device bonded/thinned on Silicon; a schematic view of this structure is given by Fig.1. P is the acoustic period of the device, λ is the spatial period of the PPLN.

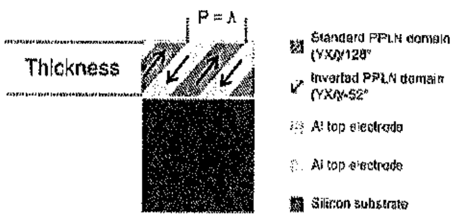

Fig. 1. Schematic profile view of a (YX*l*)/θ PPLN device bonded on Silicon

First of all, main acoustic properties from this device are identified through numerical simulations. Then, realization of (YX*l*)/128° Lithium Niobate bonded/thinned on Silicon resonators is described. Finally, electrical characterization of are made on two different resonators for validation of simulation results and extensive studies of experimental figures of merit of such devices.

II. Numerical simulations on Lithium Niobate rotated cuts

Numerical simulations have been made using a finite element/boundary integral method approach to compute harmonic admittance of PPLN device based on 45µm thick (YX*l*)/128° Lithium Niobate poled and bonded/thinned on Silicon. Simulation results on this device are given by Fig.2.

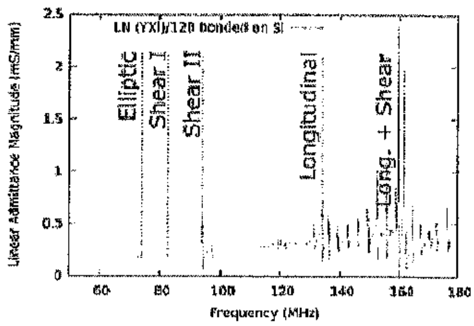

Fig. 2. Simulation on bonded/thinned Lithium Niobate (YX*l*)/*128°* at 45µm thickness and 50µm acoustic period. Modes listed in Table I are reported.

Simulation has been conducted on a 45µm thick Lithium Niobate (YX*l*)/*128°* cut bonded/thinned on silicon where the acoustic period is 50µm. Periodical boundary conditions have been considered on left and right side of our structure, while Dirichlet electric boundary conditions have been imposed on top (1 mV) and bottom (GND) side. Calculations are made considering a 1mm-width (along Y-axis) PPLN.

Numerical simulations have pointed out 5 different waves: an elliptic wave, a longitudinal wave and two shear waves and a longitudinal-shear wave. Pictures of some of these modes taken from numerical simulations can be seen on Fig.3.

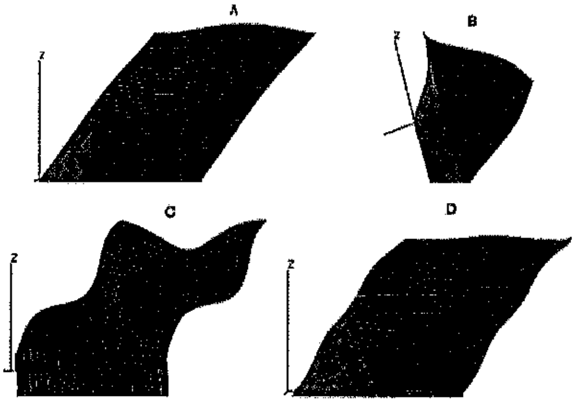

Fig. 3. Illustration of elliptic mode (A), shear-transverse mode (B), shear mode (C) and longitudinal modes (D) seen through numerical simulations

Dispersive effects can be observed between 120MHz and 200MHz, where the main longitudinal peaks are spitted into multiple peaks. Propagation through Silicon of these modes can be observed from numerical simulations, explaining such behavior on bonded devices. Results compilation and results on similar structure on Z-cut Lithium Niobate as comparison are given by Table I. As for longitudinal multiple modes, we only have reported the 2 most relevant peaks.

TABLE I. SIMULATED RESULTS ON (YX*L*)/128° AND Z-CUT PPLN BONDED ON SILICON

Structure	Wave properties		
	Mode behavior	*Velocity* $(m.s^{-1})$	*Coupling factor* (%)
45µm-thick $LiNbO_3$ (YX*l*)/*128°* on Si	Elliptic	3710	0.2
	Shear I (Transverse)	4120	0.15
	Shear II	4700	0.42
	Longitudinal	6700	0.31
	Longitudinal + Shear	7980	0.71
45µm-thick $LiNbO_3$ Z-cut on Si	Elliptic	3790	0.6
	Shear (Transverse)	4750	0.52
	Longitudinal	7860	0.23

It can be observed some similar modes can be both found in Z-cut and (YX*l*)/*128°* devices, but some other ones are only appearing on (YX*l*)/*128°* cut. Coupling factor of the elliptic wave is better on Z-cut, while longitudinal wave has a better coupling factor on (YX*l*)/*128°* cut.

III. FABRICATION OF PERIODICALLY POLED TRANSDUCERS ON (YXL)/128° LITHIUM NIOBATE

Domain reversal is made by applying a strong electric field to the material, which must be greater than coercive field of this material, equal to 21kV/mm for Z-cut congruent $LiNbO_3$. Common poling processes uses liquid electrolytes as electrodes and a photoresist mask to design periodically poled structures on the material, which allows to reach high voltage with reduced electric discharge issues [8].

Although, intrinsic properties of $LiNbO_3$ only allows orientation reversal along Z-axis of the material. Therefore, reverted domains will get tilted with an angle equal to the θ orientation of the material and coercive field will increase. The following formula then gives the coercive field according to the cut angle:

$$E_c(\theta) = E_c(\theta = 90°) / \cos(\theta - 90°) \quad (1)$$

For highly rotated cuts, poling process can become challenging as discharges will more likely happen at higher voltage. For this reason, poling on a 45µm thick (YX*l*)/128° bonded on Silicon has been investigated, as this cut is a good compromise between rise of acoustic performances and rise of coercive field, while the use of bonding/thinning technique allows to achieve very thin Lithium Niobate layers.

Bonding/thinning technique have been used for reducing thickness of a (YX*l*)/*128°* $LiNbO_3$ wafer to 45µm, using a process already validated for Z-cut $LiNbO_3$ PPLN with standard microfabrication processes such as photolithography for domain definition on photoresist mask and sputtering for electrode deposition [5]. Silicon back side is not polished to avoid bulk acoustic waves.

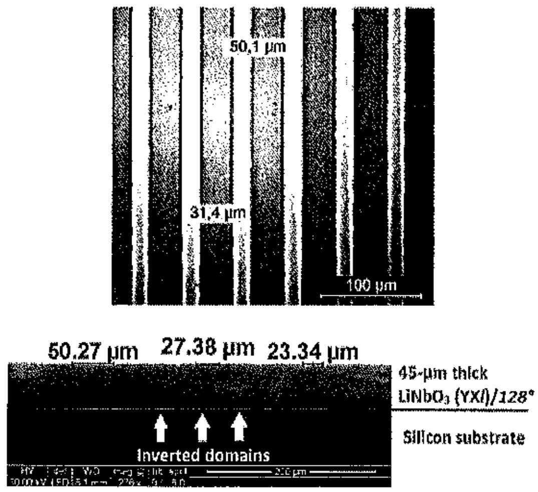

Fig. 4. Top Optical Microscope view and profile SEM picture of Periodically Poled Lithium Niobate Structures on (YX*l*)*128°* $LiNbO_3$ reported on Silicon wafer, with a 50µm period and 45 µm thickness

Fig.4 shows a successful on 45µm thick (YX*l*)/*128°* LiNbO3 wafer which has been bonded on Silicon wafer.

Tilting of inverted domains by the θ orientation of the material is observed. Similar period can be observed between profile SEM view and top optical microscope view.

Aluminum electrodes of two different dimensions (chip #1: 0.5 mm (*W*) x 2 mm (*L*) and chip #2: 2 mm (*W*) x 0.5 mm (*L*)) have been deposited on our devices to create resonators for characterization of our transducers. *W* and *L* correspond respectively to width and length of the electrode.

IV. ELECTRICAL CHARACTERIZATION OF PPLN TRANSDUCERS ON (YXL)/128° LITHIUM NIOBATE

Characterizations have been made using a ZNB 8 Rohde-Schwarz Vector Network Analyzer with 500µm-gap GS Probe from Cascade Microtech. Results are given in terms of admittance and S-parameters for Chip #1 are given by Fig.5.

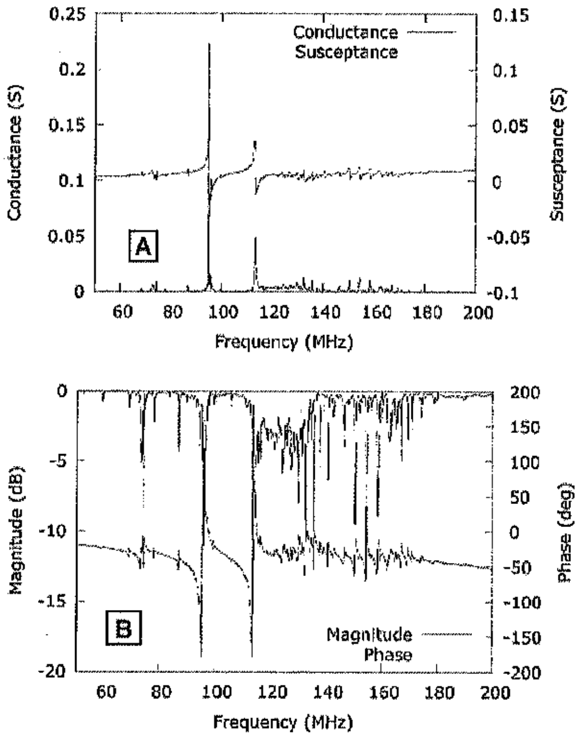

Fig. 5. Electrical characterizations of Chip #1 Lithium Niobate (YX*l*)/*128°* cut in terms of Admittance (A) and S-parameters (B)

Four different modes can be identified from both devices characterizations at 74.5, 86.8, 95.2 and 113.4MHz; the three first ones have been reported from simulations while 113.4MHz mode hasn't clearly been observed from simulations on bonded/thinned Lithium Niobate (YX*l*)/*128°* cut. Moreover, multiple peaks from 120 to 180MHz can also be observed from these electrical characterizations. Figures of merit associated to these modes is reported in Table II.

Comparison between theoretical results obtained from simulation (Table I) and experimental results of chip #1 (Table II) shows relative good correlation in terms of coupling factor for the elliptic mode (Fig.3A) at 74.4MHz (0.2% versus 0.25%) and Transverse-Shear I mode at 86.8MHz (0.15% versus 0.15%). Difference can be observed for chip #2. This difference can be due to the length of electrode and the number of periods of the device. Only ten periods are used on chip #2, while the simulation considers infinite number of periods.

TABLE II. EXPERIMENTAL RESULTS ON BONDED (YX*L*)\128° $LiNbO_3$

Structure	Wave properties			
	Frequency (MHz)	*Mode velocity ($m.s^{-1}$)*	*Q factor*	*Coupling factor (%)*
Chip 1	74.4	3720	1160	0.25
	86.8	4340	960	0.15
	95.2	4760	940	6.3
	113.4	5670	200	4
Chip 2	74.6	3730	3400	0.05
	86.8	4340	3100	0.05
	94.2	4710	< 50	8.3
	113.6	5680	< 50	3.4

Shear mode II at 95.2MHz shows a much higher coupling factor than expected. On the simulation, three sub-modes appear, while on experimental result only one exists.

One interface mode appear clearly at 113.4MHz on electrical measurements. On our simulation this mode exists, but presents low amplitude compare to other modes.

Finally, it appears bulk acoustic waves take place as expected between 120 and 180MHz. Amplitudes are much lower than simulation ones due to the roughness of the Silicon back side.

Coupling factor for modes at 95.2 and 113.4MHz are unprecedented on planar Z-cut PPLN devices, while ridge PPLN structures have reported very high coupling factor but with very poor *Q* factor [7]. These results shows the possibility of increasing the coupling factor when using Lithium Niobate rotated cuts with higher *Q* factor than ridge PPLN structures.

V. CONCLUSION

Numerical simulations have shown interesting results for coupling factor which is improved for some modes on Lithium Niobate (YX*l*)/*128°*.

Experimental poling of a (YX*l*)/128° $LiNbO_3$ using bonding/thinning technique has been achieved. Electric characterizations of resonators done on a Lithium Niobate (YX*l*)/*128°* cut bonded/thinned on Silicon have demonstrated a 6% coupling factor at 95MHz with a *Q* factor of 940.

These results give promising expectations for devices using rotated cut transducers of bulk and bonded/thinned Lithium Niobate. Filtering or wireless interrogation sensors applications could be addressed by such devices.

Transducers done on bulk material could bring smoother acoustic response and avoid wave dispersion, but it still represents a technological challenge due to coercive field rising. Other Lithium Niobate standard cut, such as (YX*l*)/*36°*

or *64°*, could also be explored for realization of PPLN devices to study wave behavior and evolution of figures of merit.

ACKNOWLEDGMENTS

This work has been developed under the support of the FEDER Research Grant No. FC0001257-11002 with SMART-INN project.

This work was also partly supported by the French RENATECH network and its FEMTO-ST technological facility.

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