Detection of domain structure in Periodically Poled Lithium Niobate waveguide by acoustic microscopy.

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Abstract

PPLN waveguides are new optical materials for frequency conversion of laser beam from the domain structures of ferroelectrics patterned by applying an electric field via lithographicaly-defined electrodes. To optimize domain structure elaboration and comprehension, Acoustic microscopy can be a complementary tool. First investigations have been performed at 130MHz to visualize the gratings pattern. From the defocused acoustic amplitude images, large stripes are visible. Acoustic signatures performed on them have revealed different velocity values at first associated to mechanical property variations. However, this interpretation is somehow refuted by the presence of a complicated microscopic network. So, using a 600MHz sensor, we performed amplitude and phase acoustic images (100x100µm). Thus, on a sample previously etched for optical control, this method has revealed the 0.8µm depth topography inducing fringe patterns on amplitude images and also shielding the domains. At the contrary, on the virgin opposite side, amplitude image displays few microns thick parallel structures.

Introduction

Periodically Poled Lithium Niobate waveguides are optical devices for frequency conversion of laser beam. They are fabricated using a classic IC wafer manufacturing process: a photoresist resin is deposited and insulated with the appropriate lithographically pattern. High electric field poling is followed to permanently reversing the Lithium Niobate/Tantalate nonlinear property according to the designed pattern. After the poling, the wafer is diced and polished to form the chips. Acoustic Microscopy has been previously used to control the reticulation process of the resin by acoustic velocity measurement and acoustic imaging. In this work, the same ultrasonic technique is used to display the domain structure of these PPLN chips from the detection of local variations of mechanical properties.

1 Investigation of material properties by Acoustic microscopy

Ultrasonic techniques such as "Acoustic microscopy" measure the velocity of ultrasonic waves and their attenuation. These two parameters define propagation conditions of ultrasonic waves in samples. They are linked to the material mechanical properties and also to the presence of heterogeneities such as dislocations, cracks, grain boundaries, impurities, porosity...

Ultrasonic techniques are considered as non-destructive means to study the mechanical properties of samples because they used extremely low amplitude mechanical vibrations to stress mechanically the sample under test. Classic ultrasonic echography is suitable to measure materials properties but it needs at least few square millimeters surfaces and samples with a thickness greater than one millimeter. With Acoustic Microscopy, this investigation size can be highly reduced using an ultrasonic focused beam and specific surface waves using the associated "acoustic signature" technique. Moreover, from the sweep displacements (C-Scan) of this sensor, this device can produce images with a lateral resolution as small as one micron. The contrast levels revealed on these acoustic images reveal the sample topography and local variations of mechanical properties.

1.1 Acoustic signatures

Acoustic signatures are provided by an acoustic microscope using a spherical acoustic lens to focus a plane acoustic wave towards the sample surface. When the acoustic focused beam reaches the sample surface, its energy is partially transmitted inside material while the remaining part is reflected towards the lens where its amplitude is recorded by the piezoelectric cell of the acoustic sensor. Due to high attenuation level for ultrasounds in gas, coupling fluid as water is used to ensure an efficient propagation of acoustic waves between sensor and sample.

By acoustic microscopy, velocity of surface waves is measured from the interferential pattern present on "acoustic signatures". Indeed, when the amplitude “V” of the reflected acoustic wave is recorded as function of the distance “Z” between the sample and the sensor, the resulting curve shows damped oscillations due to phase delay between different specific waves. This interference effect is linked to the propagation velocity of a Rayleigh surface wave in the material. The period "ΔZ" of the oscillations contained in an acoustic signature is given by the following equation:

$$\Delta Z = V_{liq} / \{2.f.[1-\sqrt{1-(V_{liq}/V_{surf})^2}\ ]\}$$

with "f" the wave frequency, V_{liq} the wave velocity inside the coupling fluid and V_{surf} the velocity of the wave propagating at the surface of the sample. This period "ΔZ " is measured from the V(Z) curves by a Fast Fourier Transform.

1.2 Acoustic Imaging

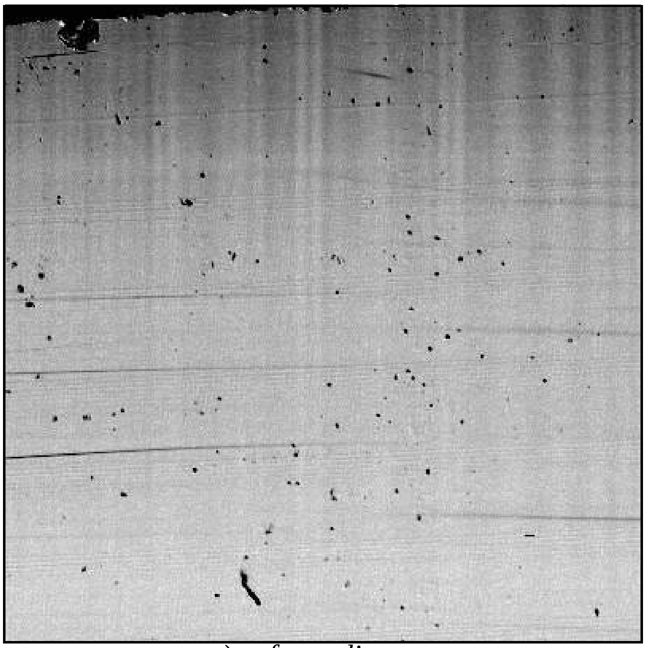
Acoustic images are constructed from the sweep movement of the lens parallel to the sample surface. Each pixel of this image corresponds to the reflection echo amplitude for a small area of the sample. Thus, using a 600 MHz lens with an half opening aperture of 50 degree, diffraction limits image resolution to 3 µm. In our acoustic microscope, we used high precision motors to move the lens with a minimal displacement step of 0.1 µm.

The reflected amplitude is coded on a gray scale. The same surface can be scanned for various defocusing distances. At focal distance, the sample roughness effect on the reflection level is enhanced whereas variations of local mechanical properties become more and more visible for suitable defocusing. Level contrasts on acoustic images display variations of acoustic wave propagation conditions. To quantify these variations, acoustic signatures are performed on the detected areas to get their characteristic velocities and next their elastic constants.

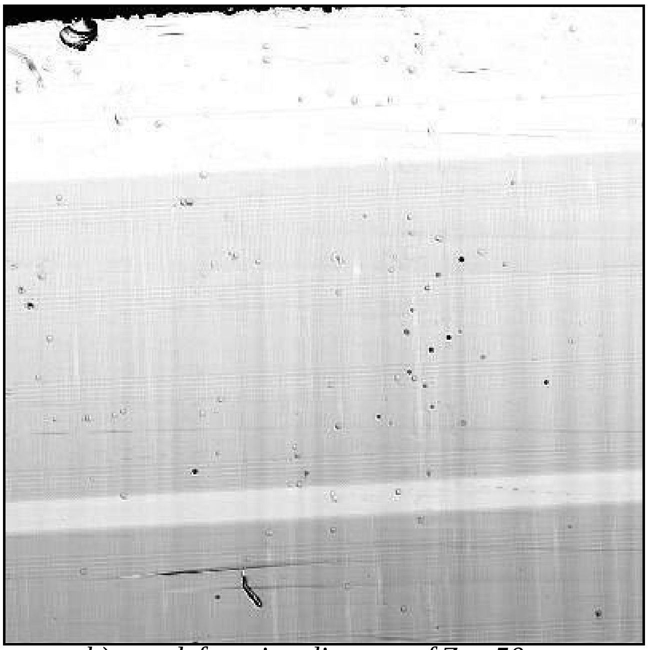
2 Application to Detection of magnetically formed cells by acoustic imaging

2.1 Amplitude acoustic imaging at 130MHz

This acoustic investigation has been done with a 130MHz lens. The lateral resolution of this device can reach 10µm for surface image. The figure 1 presents acoustic images of the same area using two different defocusing distances. At focus distance, very small contrasts are visible but it does not display clearly any domain patterns. The black points on these images are dust and could have been removed. These defaults are mainly visible on the image performed with the lens adjusted at focus distance. On the second picture (cf. figure 1 b)), thanks to the defocusing of the sensor, quasi-horizontal large stripes appear clearly while thin vertical lines are distinguishable. These patterns apparently correspond to the grating periods of the poled structure.



a) at focus distance



b) at a defocusing distance of Z= -50µm

Acoustic images at 130MHz (4x4mm)

Figure 1: effect of the defocusing distance for detection of magnetically formed structures

These contrasts can be attributed to topography and/or mechanical property variations. To investigated their origins, acoustic signatures have been performed to individually characterized these large stripes.

2.2 Investigation of contrast origins by acoustic signatures

Each detected stripe has been analyzed by a single acoustic signature materialized by a reference number and a black circle corresponding to the sounded area on the left side of the figure 2. For one of these V(z), this investigation size includes a stripe and its neighborhood. The right side of figure 2 represents the superposition of the corresponding

V(Z) curves. The wavelength of ultrasonic waves used at 130MHz is roughly equal to 30µm.

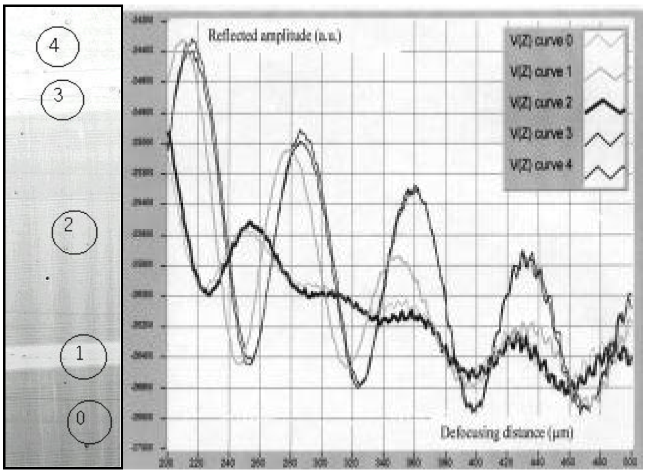
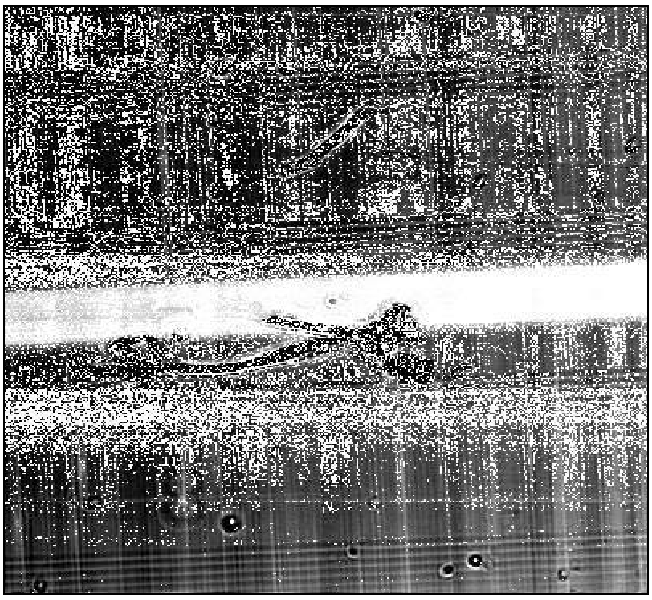


Figure 2: V(Z) curves at 130MHz and their localisations on the acoustic image (1x4mm)

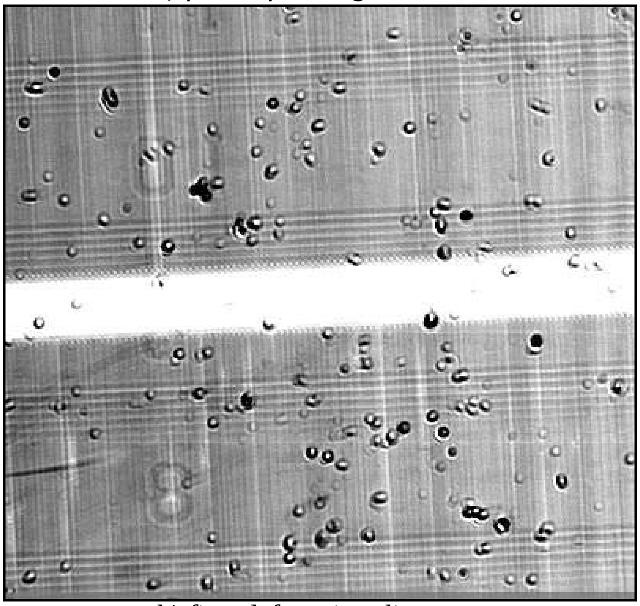
Globally, these acoustic signatures present different oscillation periods and attenuation. This figure shows that the acoustic signatures numbered 3 and 4 are the same, whereas all the others places have different shapes. Moreover, the FFT analysis of these V(Z) curves indicates that only curves 3 and 4 exhibit a mode corresponding to the Rayleigh velocity of the bulk material (3810m/s). At the opposite, other acoustic signatures have yielded to a multiple mode result. For the curve 1, this fact is probably due to an investigation size superior to the white stripe width. Consequently, different propagation modes are mixed into the same signature.

In fact, these velocity differences are not only linked to mechanical variations because acoustic images with a higher magnification (2x2mm) reveals a sophisticated network of structures. Indeed, the figure 3 shows different domains as function of different acquisition settings. Gratings are now visible in vertical and also on vertical directions. The figure 3 b) also displays figures corresponding to underground structures created during the device elaboration.

The size of these patterns seems to be smaller than 50 microns. For this reason, acoustic imaging at an higher frequency will be done using a 600MHz acoustic microscope. Nevertheless, the investigation size used by an acoustic signature at this frequency has a diameter around 50µm which is too large. For this reason, phase analysis seems to be the only way to instigate the contrast origins of the domains displayed on the previous amplitude acoustic images.



a) first defocusing distance



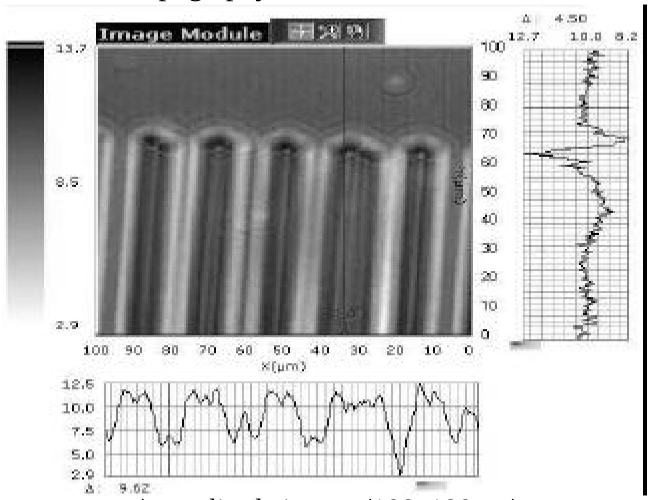
b) first defocusing distance

Figure 3: acoustic images (2x2mm) of the same area for different defocusing distances and settings.

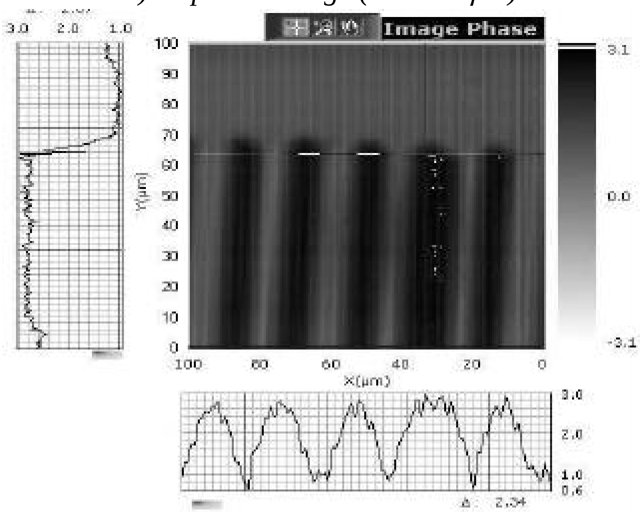
2.3 Amplitude and phase imaging at 600MHz

Amplitude and phase images are calculated conjointly from the reflected echo digitized at a rate of 4 Gech/s using the Hilbert's transform and mean vector analysis. Phase measurement is a powerful tool to detect fine variations of topography. For instance, our device accuracy is around 50 nm at 600MHz. One side of the PPLN sample had been etched to reveal the domains for optical investigation. On this surface, amplitude acoustic image reveals a domain structure apparently surrounded by fringe patterns (cf. figure 4 a). The corresponding phase image on figure 4 b) confirms that these contrasts are mainly due to the sample topography. From these phase measurements, a 3D graph of the sample surface is obtained (cf. figure 5) showing 0.8µm deep rectangular cavities. The other side of the specimen should be quite flat.

This is confirms on the phase image (cf. figure 6 b) except in the vertical direction where the sample is found curved. Anyway, this phase analysis demonstrates that the structures visible on the amplitude image (cf. figure 6 a) have been detected due to their mechanical property differences and not because of topography effect.



a) amplitude image (100x100µm)



b) phase image (100x100µm)

Figure 4: acoustic images and profile examples of the etched side of the PPLN device

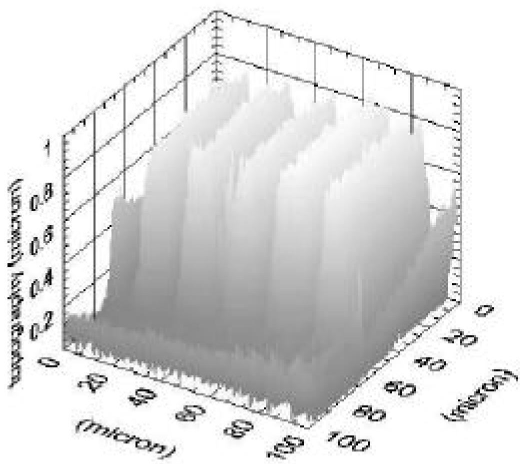
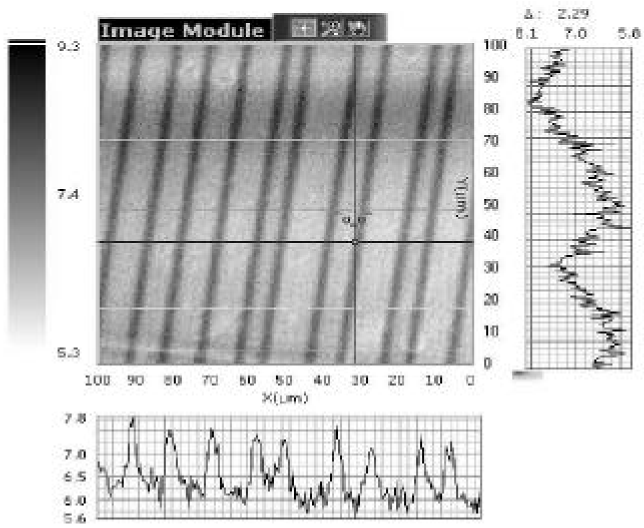
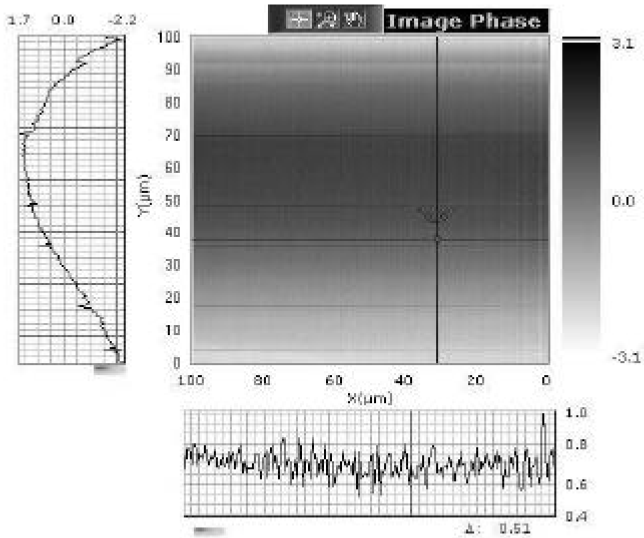


Figure 5: topography detected form acoustic phase measure at 600MHz



a) amplitude image (100x100µm)



b) phase image (100x100µm)

Figure 6: acoustic images and profile example of the virgin side of the PPLN device

Conclusion

The domains of the PPLN chip seem to have been detected on amplitude acoustic images performed with a 600MHz acoustic microscope due to their mechanical properties different from the substrate ones. For this study, Phase analysis has been a powerful tool to identify the real contrast origins providing an accurate topography measure. The exact origin of contrasts on these acoustic images has to be further investigated to understand the effect of high electric field on ferroelectrics materials. Extensions of this work could concern the study of switching phenomena and the dynamic of domain walls in order to improve the characteristics of FeRAM memories.