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Domain Reversal in Er:LN by External Field Poling

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Periodic poled $LiNbO_3$ (PPLN) is an extensively used ferroelectric material with various applications. Er^{3+}ion doped $LiNbO_3$ can combine the properties of optics nonlinearity of $LiNbO_3$ and spectral properties of Er^{3+}. Previously Er:PPLN was fabricated using Czochralski technique and demonstrated the function of frequency doubling and laser activity. In this paper, we present our results on fabrication of Er:PPLN by using external electric field poling technique. The poling properties of Er: LN was studied and compared with those of the congruent $LiNbO_3$. The differences on poling properties between doped − and undoped − $LiNbO_3$ were analyzed and studied. Some probable explanations to these differences were given. Meanwhile the fluorescence property in our Er:PPLN were also studied, which show that our samples really possesses strong up-conversion emission.

INTRODUCTION

Congruent $LiNbO_3$ is extensively used ferroelectrics with various field of application. In particular it has recently attracted much attention as key crystals for quasi-phase matched devices which realize compact blue light sources[1,2,5]. As is well known that there are considerable number of useful optical processes taking place in Er^{3+} doped materials. Combing the

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nonlinear optical property of congruent LN and spectral properties of Er^{3+} has been attracted much attention recently[3]. Lu, etc, doped Er^{3+} ions into $LiNbO_3$ crystal, growing optical super-lattice Er:LN crystal. The crystal combined QPM function of super-lattice and the laser properties of Er^{3+}. Pumped by an adapted infrared light, this crystal is able to emit the up-conversion light as well as the second harmonic light at the same time. Because their super-lattice crystals were fabricated by the Czochralski crystal growth technique, the periodic fluctuation is very severe, which directly effects the efficiency of frequency conversion. By means of the external electric field poling, the optical super-lattice crystals of LN and LT have been successfully fabricated. In this technique the periodicity of the super-lattice, defined by lithographic metal electrode, consequently has higher accuracy. In this paper we studied the poling property of Er:LN by means of external electric field poling at the room temperature, compared these basic poling properties of Er:LN to those of congruent LN, it can be found that there are many differences between them. Probable reason to explain these differences is also studied. Based on above work, we fabricated periodic poled Er:LN (PPEr:LN) with 80-μm-domain period.

EXPERIMENT

Our poling setup is similar to the one reported early[6]. The Er:LN crystal was obtained by Czochralsiki (CZ) method, the starting material was a congruent Lithium Niobate melt doped with Er 0.5 mol% in the form of oxide. Crystal was treated by standard single-domain process before poled. The crystal was cut to many 500- μ M-thick wafers, whose C axis was perpendicular to the surface of sample. Pure AL was evaporated on both surfaces as electrodes (the area is 4.0×3.0 mm^2). Rectangular pulse electric fields of various magnitude from 0 to 22.0 KV/mm and its width from 10 ms to 2.0 s applied to the samples immersed in oil bath at room temperature. The voltage signal across a resistance in the electric circuit traces a waveform proportional to the switch current. When the electric field is higher than coercive field, the poling current can be found clearly in our experiment. Fig.1 shows the typical waveform of the switching current i corresponding to a complete polarization reversal in the region covered by electrode. Switch time is also shown in this figure. The area under the curve in Fig.1 is directly proportional to the spontaneous polarization P_s and the area A of domain reversal. The relation among them is:
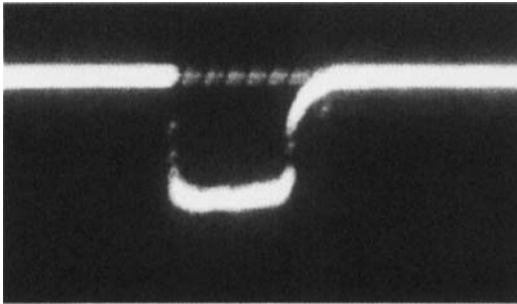
t_s

FIGURE 1   Waveform of switch current I versus t.

A   B
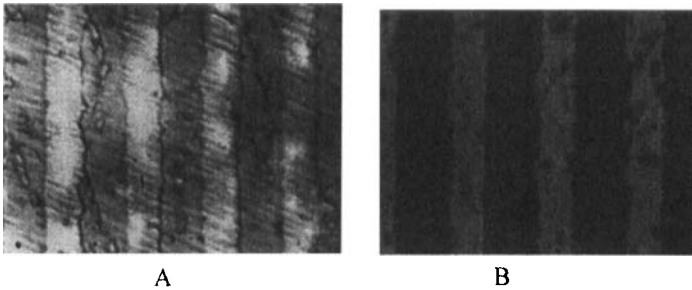
FIGURE 2 Etched photograph of PPEr:LN (a).+c face, (b).-c face

$$Q = \int i dt = 2P_s A \qquad (1)$$

So we can measure P_s of Er:LN through this equation. Therefore by means of poling current waveform, the basic poling property can be obtained in our experiment. A photograph of the etched +C face and −C face of a PPEr:LN which period is 80 μm is shown in Fig.2(a) and Fig.2(b), respectively. Because this sample period is so large that we can only

pickup four period limited by the scope of the light microscopes. It can be seen from these figures that PPEr:LN is can be fabricated by external electric field.

RESULTS AND DISSCUSSION

When the electric field was higher than 12.5 kv/mm, the poling current was found clearly in our experiment As the same as happens in un-doped LN[4], there is a large asymmetry of the ferroelectric A hysteresis loop in Er:LN due to the existent of the internal field. In this paper the direction of higher coercive field is defined as forward direction, and the other direction is set as reverse direction. The internal field can be determined as:

TABLE 1 Main poling property coefficients in Er:LN and those in congruent LN are shown in this table.

Material	E_{for} (kv/mm)	E_{res} (kv/mm)	E_{in} (kv/mm)	P_s (c/m^2)
Congruent LN	22.8 ± 0.2	16.3 ± 0.3	3.25 ± 0.25	0.75
Er:LN	12.0 ± 0.5	8.0 ± 0.3	2.0 ± 0.4	0.81 ± 0.03

$$E_{in} = (E_{for} - E_{res})/2.0 \qquad (2)$$

where E_{in} is the internal field, E_{for} and E_{res} are the coercive fields of forward and reverse directions measured in experiment, respectively. The data in Table.1 shows the spontaneous polarization, internal field, and the coercive field in both directions comparison between un-doped LN and Er:LN. The data of un-doped LN were copied from previous paper[4]. It can be seen that the coercive fields in Er:LN are lower than that in un-doped LN, either to forward or to reverse direction. They are about 0.55 of coercive fields in the undoped LN, while the spontaneous polarization of Er:LN is almost the same as that in un-doped LN. It is worth noting that the internal field in Er:LN is lower than that in un-doped LN. Because the internal field comes from the defects in LN[4], the relationship between doping Er^{3+} and the lower internal field should be studied further. In Figure 3, we plotted the switching current i versus the applied field E for a set of Er:LN under different poling fields. The relation between switch

time t_s and electric field E is shown in Fig. 4. These data can be fitted well by

$$t_s = c \exp\left(\delta/E\right) \qquad (3)$$

where δ is a constant dependence on the temperature and c is a coefficient of proportionality. To see the relation Eq.(3) clearly, we draw a logarithmic plot of t_s versus $1/E$.
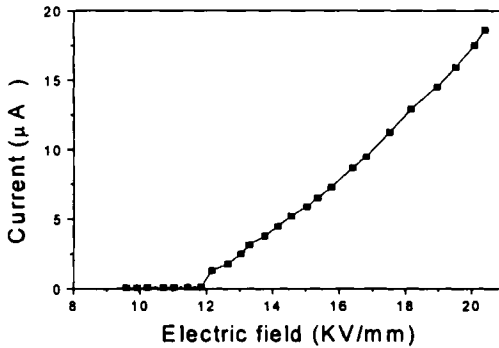

FIGURE 3 Diagram of switching current I versus the applied field E.

As is well known that there are excess Nb ions in congruent LN, which are thought to replace the Li vacant in some ways, Some results show that Er^{3+} ions occupy the Li vacancies and induced more oxygen vacancies in oxygen layers in Er:LN[4] to realize electric balance, which could lead to metal ions passing through the oxygen layers easier during the polarity reversed by application of a field. This is a possible reason to make the differences of poling features between the Er-doped and un-doped LN.

Because the super-lattice sample is lamina, whether up-conversion beam can be effective generated is an important issue. We measured the emission spectra of a periodically poled Er:LN sample. The experimental set up for up-conversion measurement is the same as that of previous report[3]. In our experiment, when the super-lattice sample was pumped by a laser diode of 980 nm, remarkable green fluorescence light could be

observed even with a incident power lower than 200 mW. The fluorescence spectrum of up-conversion is recorded as displayed in Fig.5. It shows that our lamina sample really possesses strong up-conversion emission, at least for the green light of wavelength 550 nm-570 nm. The central peak of up-conversion was at 550nm. There was another
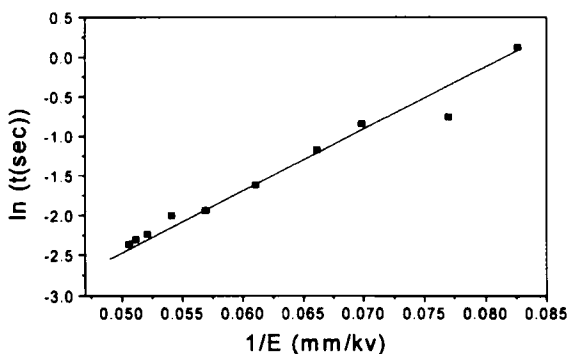
FIGURE 4 Logarithmic plot of t_s versus $1/E$.

weaker peak located at 660 nm. These two peaks corresponded to transitions between the states of $^4S_{3/2}$ - $^4I_{15/2}$ and $^4F_{9/2}$ - $^4I_{15/2}$, respectively[3]. The peak of 550 nm was approximately five times larger than that of 660 nm. That is why only green fluorescence can be observed with the naked eyes. Because we used a super-lattice with 80 μm period in the optical observation, an effective second harmonic generation could not be realized through QPM process as using a 980 nm diode as a pump source. In order to realize emitting the second harmonic blue light by QPM process and the green light through up-conversion simultaneously at room temperature, the poled period of a super-lattice needs to be shrunk to approximate 6μm. Therefore the realization of small period super-lattice Er:LN is a key factor.

SUMMARY

The poling properties of single crystal LN doped with 0.5 mol% Er_2O were studied by the application of an external field at room temperature.

The probable reason making these differences of poling properties between Er-doped LN and un-doped LN crystals is discussed. Moreover, up-conversion emission spectrum of periodically poled Er:LN crystal was measured, verifying no detectable discrepancy in these spectra compared with un-poled Er:LN crystal. Our results show the Er:LN crystal can be poled by application of a external field at room temperature, therefore, the periodically poled Er:LN crystal may be a candidate material used to generate dual-wavelength emission.
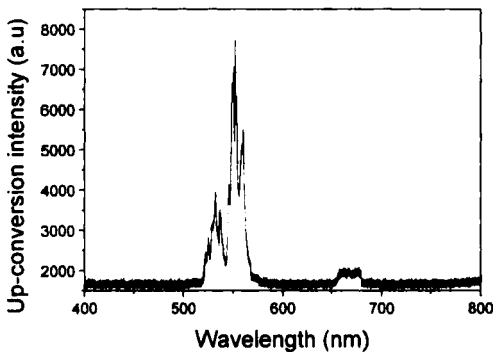

FIGURE 5 The fluorescence spectrum of up-conversion pumped by 980nm.

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