Optical Damage Resistance in a Pure Congruent Lithium Tantalate Crystal

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Abstract

The optical damage resistance has been investigated on a pure congruent $LiTaO_3$ crystal by the measurement of the photoinduced birefringence changes as a function of an Ar-laser irradiation time and intensity. From these measurements, the intensity dependence of the saturation value of the birefringence and the photoconductivity have been extracted. The so-obtained results are compared to that of a pure congruent $LiNbO_3$ crystal.

مقاوم الإتلاف الضوئي لبلورة $LiTaO_3$ ليثيوم تانتليت

هيثم لفتة سعدون

قسم الفيزياء -كلية العلوم –جامعة البصرة

الخلاصة

مقاوم الإتلاف الضوئي تم البحث عليه في بلورة $LiTaO_3$ النقية وذلك من خلال قياس تغيرات الانكسار المزدوج الضوئي المحتث كدالة لزمن اشعاع اركون ليزر وشدته. من تحليل النتائج, تم اعتماد الشدة على القيمة المشبعة للانكسار المزدوج ومنها تم اسـتخراج التوصـيلية الضـوئية. النتائج المستحصلة تمت مقارنتها مع بلورة LiNbO3 النقيه.

Introduction

Recently, lithium Tantalate LT ($LiTaO_3$) has become one of the most important ferroelectric materials because of the richness of its physical properties but also due to their good mass productivity, congruent LT crystals, corresponding to a ratio [Li]/[Ta]=0.942. It is widely used in optical and acoustic devices (Cason et al. 2002) due to the large electro-optic (EO) properties. However, a new interest began to use it as a satisfactory alternative of lithium Niobate crystal LN ($LiNbO_3$) in electro-optic modulation (e.g. IM) systems (Saadon et al. 2006) .As laser sources for applications new wavelengths (Gahagan et al. 2001, Saadon et al. 2006).

There are an increasing interest in use of LT for photorefractive and other applications at UV wavelengths (Juvalta et al. 2006). In addition to a lower absorption, congruent LT as compared with other competing oxide crystals such as LN shows higher Curie temperature, smaller birefringence, and smaller photorefractive (PR). The photorefractive effect originates by light-induced refractive index changes and causes optical damage resistance. When the crystal is illuminated with a beam, mobile charge carries generate in the bright region giving space-charge fields that modify refractive indices via the electro-optic effect.

Up to now, there exist no complete data on the photorefractive damage measurements in $LiTaO_3$ crystal, especially the saturated value of the photoinduced changes in the refractive index $\delta\Delta n_s$ which depends on the light intensity and the photoconductivity on the laser intensity.

In this work, we try to investigate the optical damage resistance of a pure congruent LT crystal with different power of Ar-laser. In addition, we present the behavior of the photoinduced birefringence change at saturation and the photoconductivity as a function of the Ar-laser pump intensity. The measurements in question have been performed using a modern technique, namely the modified-frequency-doubling EO-modulation (MFDEOM) method (Aillerie et al. 2000). Finally, the results extracted in this work are compared with those obtained for a pure congruent $LiNbO_3$ crystal.

Photoinduced birefringence measurement

In the present work, we have used a very sensitive technique, based on a modified FDEOM method (Aillerie et al. 2000), for the measurement of the photoinduced birefringence change $\delta\Delta n$. The technique can be explained in Fig. 1. As seen, two concentric laser beams with different wavelengths are used for the pump and for the probe beams, respectively. This technique using a modulation external to the crystal under study presents as main advantages to permit the measurement of induced phase shift instead of corresponding intensity leading to an accurate determination of $\delta\Delta n$ (Theofanous et al. 1997, Aillerie et al. 2000), which is of great importance for the determination of small changes $\delta\Delta n \approx 10^{-6}$.

The optical damage resistance has been characterized by monitoring the photoinduced birefringence caused by Ar-ion laser beam at a wavelength λ=514 nm with various light intensities I=76 Wcm^{-2}, I=121 Wcm^{-2}, and I=242 Wcm^{-2}, respectively, and a spot size 0.06 mm in diameter. A low power He-Ne laser with a wavelength of 632.8 nm was used as a probe beam along the optics axis (c-axis). The probe beam is directly monitoring on an oscilloscope screen, which yields to the value of the light-induced birefringence changes $\delta\Delta n$, via the well-known equation $\delta\Delta n = 2\pi L\delta\Gamma/\lambda$, where $\delta\Gamma$ is the induced phase shift, λ is the wavelength of the probe beam, and L is the width of the electro-optic crystal. The changes have been monitored as a function of irradiation time until saturation and the curves obtained by this technique can be fitted with a first order exponential time response function can be given by

$$\delta\Delta n(t) = \delta\Delta n_S[1 - \exp(-t/\tau)] \quad (1)$$

where $\delta\Delta n_S$ is the saturated value of the birefringence change and τ is the characteristic time constant yields the photocoductivity

$$\sigma_{ph} = \frac{\varepsilon_0\varepsilon_{33}}{\tau} \quad (2)$$

where ε_0 and ε_{33} are the vacuum and relative dielectric, respectively.

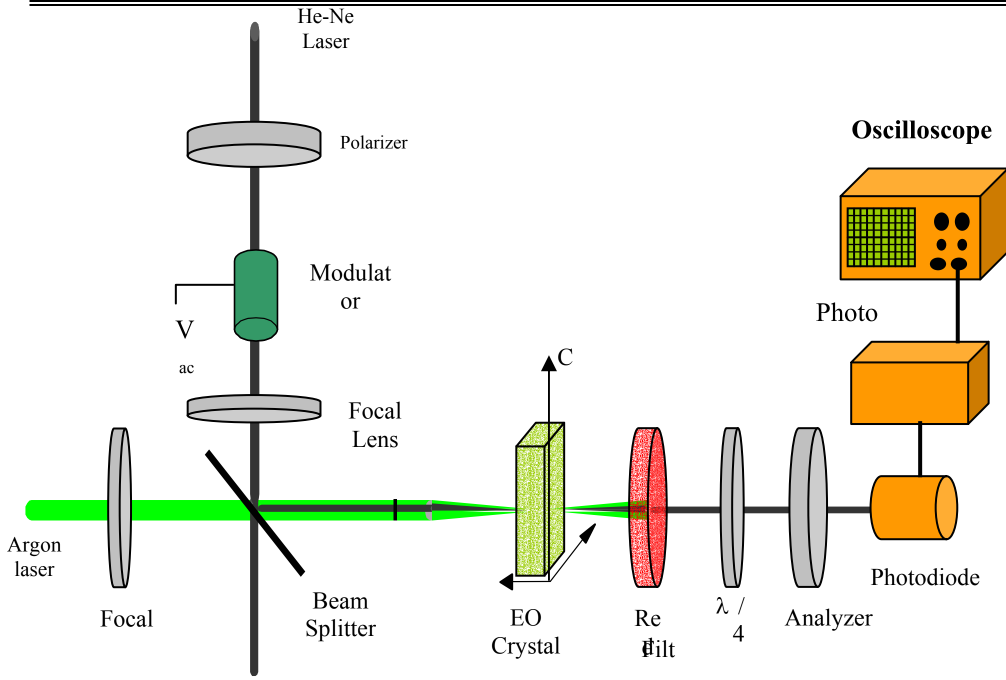

FIGURE 1 Experimental optical damage resistance setup (with a Sénarmont optical arrangement).

Results and discussion

For investigation of the optical damage resistance in a pure congruent $LiTaO_3$, we record in Fig. 2 the photoinduced birefringence change $\delta\Delta n$ as a function of irradiation time for different Ar-laser light intensities I=76 Wcm^{-2}, I=121 Wcm^{-2}, and I=242 Wcm^{-2}, respectively. The continuous curves in this figure represent the graphical plots of the first-order exponential which fit to the experimentally obtained data points. In our measurements, $\delta\Delta n$ is the sum of birefringence change caused by intrinsic optical damage and that caused by the thermo-optic (TO) effect due to the Ar-laser irradiation. Nevertheless, when the Ar-laser irradiation is stopped after illumination, no significant birefringence changes occurred even some hours later. That means that the birefringence change due to the effects is negligible and that the measured $\delta\Delta n$ in this sample is predominantly induced by the photorefractive effect. We can also consider that the relative stability after the end of illumination indicates a weak dark conductivity σ_d

in this crystal in comparison of the photoconductivity σ_{ph}. Thus, the observed effect is mainly due to the photovoltaic space charge field generated along the c-axis (Mostefa et al. 2006). We emphasize that under these experimental conditions, a low intensity probe and high intensity pump focus beams, photorefraction is only due to the photovoltaic mechanism generated by the pump beam.

As a result of that the photoinduced birefringence in congruent LT increases very rapidly and reached saturation in 24.5 min with irradiation time. It is also of note that the photoinduced birefringence of $LiTaO_3$ is larger than that of $LiNbO_3$ crystal (Fontana et al. 2001). That is considered with the results reported at different methods in (Ashkin et al. 1966, Tangonan et al. 1977), in which LT is more resistant to optical damage than $LiNbO_3$.

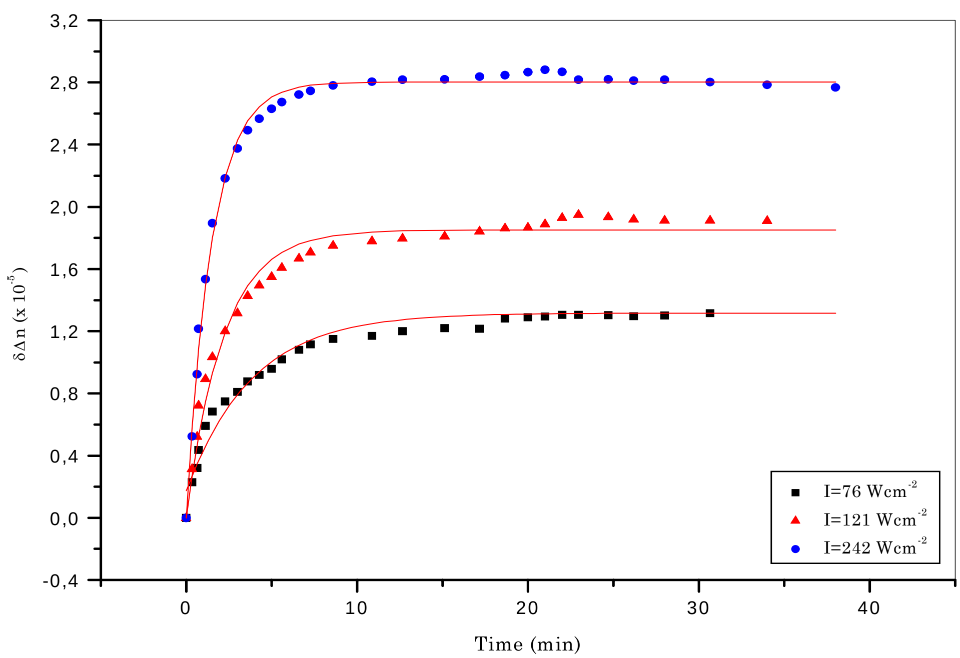

FIGURE 2 Photoinduced birefringence change δΔn of a pure congruent $LiTaO_3$ crystal irradiated with Ar-laser beam at different light intensity. The solid lines are the results of the first-order exponential fit made to the experimental values, which are represented by the undulating dots of the diagram.

Next, we have determined the saturation values $\delta\Delta n_S$ of the photoinduced birefringence on Ar-laser intensity I, using from Fig. 2. Precisely, for various intensities, we determined from figure the corresponding $\delta\Delta n_s$ value of the line least-squares fits of the above curves. The so-obtained results are plotted in Fig. 3. It can be observed that, the $\delta\Delta n_S$ depends strongly on the laser intensity of the pump beam (Ar-laser beam). As it can be seen, $\delta\Delta n_S$ increases with an increase in the laser intensity.

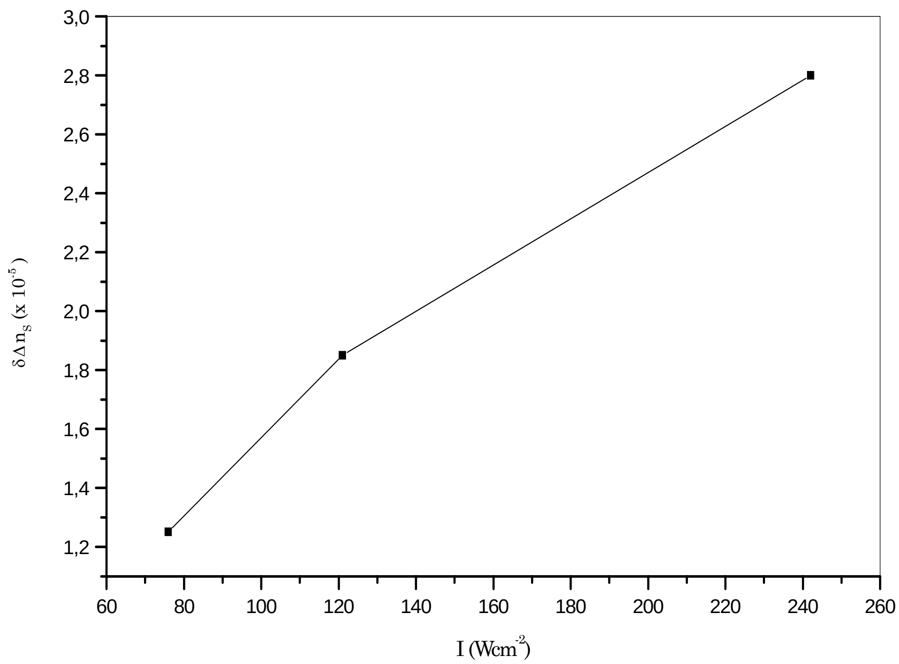

FIGURE 3 Dependence of the saturation values $\delta\Delta n_S$ of the photoinduced birefringence change in congruent $LiTaO_3$ as a function of light intensity I.

Lastly, we have calculated the photoconductivity σ_{ph} for various intensities I, by means of Eq. (2), using for τ the constant derived from the fit curves of Fig. 2 along with the dielectric ε_0 and ε_{33} reported in literature (Saadon 2006), respectively. The so-obtained results are depicted in Fig. 4. The results show that the photoconductivity increases linearly with increasing the light intensity. It is also one note that, an increase in σ_{ph} results by increasing the saturation value of birefringence $\delta\Delta n_S$. Thus, the optical damage resistance is connected with a sharp increase in photoconductivity. That is consistent with those of $LiNbO_3$ crystal (Kostritskii et al. 1997).

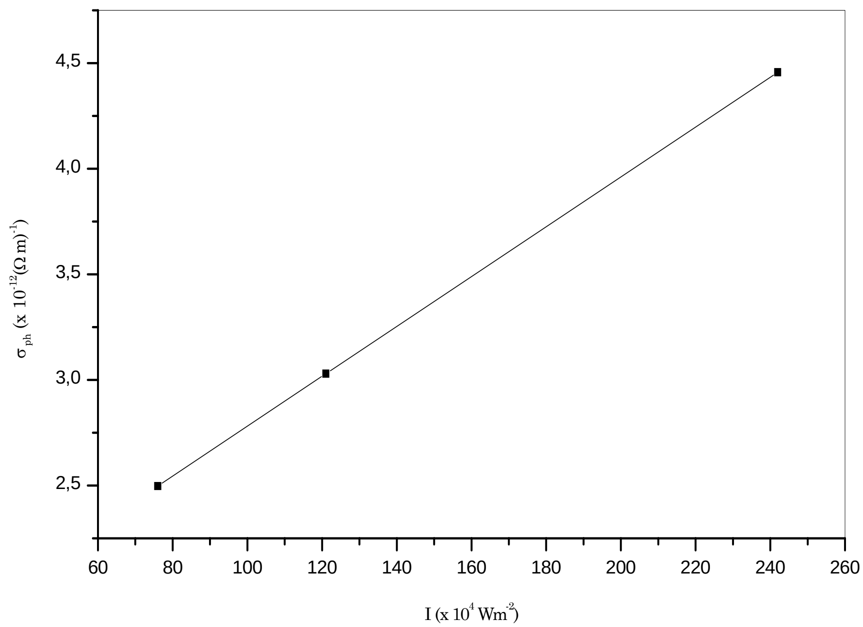

FIGURE 4 The photoconductivity σ_{ph} of $LiTaO_3$ as a function of light intensity I.

Conclusion

The photorefractive optical damage resistance of a pure congruent $LiTaO_3$ crystal has been investigated. With the process develop for photorefraction characterizations and the associated high accuracy of the methods in used, it allows us taking into consideration the thermo-optic effect and the dark conductivity σ_d, which are found negligible compare with the photoconductivity. Also, we have observed that the decrease of the photorefraction is due to an increase in the photoconductivity σ_{ph}. The knowledge of these characteristics could be needed for the use of this material in Q-switching.

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