Fast lateral photovoltaic effect in ferroelectric $LiNbO_3$ single crystals

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We report the fast lateral photovoltaic effect in pure congruent $LiNbO_3$ crystal induced by pulsed laser and continuous wave laser with wavelengths of 355, 532, and 1064 nm. A typical ultrafast photovoltage can be observed on the surface perpendicular to the c axis, with the rise time of 1.5 ns and the full-width at half-maximum of 1–2 ns, when the laser pulse inhomogeneously irradiates on the crystal. The peak open-circuit photovoltages show a linear dependence on the incident laser intensities. The mechanism of the photovoltaic characteristics is proposed.

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Since lithium niobate ($LiNbO_3$) was firstly discovered to be ferroelectric in 1949[1], it has attracted great attention and been studied extensively for decades. It is well known that $LiNbO_3$ is a multifunction material including piezoelectric, pyroelectric, electro-optic, photoelastic, photovoltaic, and photorefractive properties[2,3], and is widely used in applications such as acoustic wave transducers, optical phase modulators, holographic data processing devices, and so on[4−6].

In the past few years, various types of photodetectors were proposed, such as photoconductor, Schottky barrier detector, p-i-n junction photodiode, and heterogeneity junction[7,8]. Photovoltaic effect plays an important role in the investigation of these photodetectors. Photovoltaic effects in $LiNbO_3$ were observed by Chen in 1969[9]. Then $LiNbO_3$ was found to be in response to ultraviolet, visible, and infrared radiation of laser[10,11]. And it is a promising material for photodetector because of its high responsibility, good dielectric properties, and low cost.

However, most of the studies were focused on the photovoltaic effect in doped $LiNbO_3$ along c axis. In this letter, we investigat the characteristics of the fast lateral photovoltaic efects in pure congruent $LiNbO_3$ crystal. The photovoltages, proportional to the incident light intensity, are observed when the sample is irradiated by pulsed laser and continuous-wave (CW) laser at diferent wavelengths. The mechanism is discussed based on the ferroelectric and pyroelectric properties of $LiNbO_3$ crystal.

In our experiments, we used commercial optical grade z-cut $LiNbO_3$ single crystal which was double polished with a dimension of 5×5×0.5 (mm) in the a, b, and c directions, respectively. Two silver paste electrodes were separated about 1.5 mm on the surface perpendicular to the c axis. The laser beam passed through the crystal along the c axis and irradiated normally at the back of one electrode, as shown in Fig. 1. Here the $-c$ and $+c$ faces were identified by an etching technique. The resulting photovoltage signals were recorded by a digital storage oscilloscope with 350-MHz bandwidth.

An actively/passively mode locked Nd:yttrium-aluminum-garnet (Nd:YAG) laser (with pulse duration of 25 ps, repetition rate of 10 Hz, and spot diameter of 2 mm) was used to irradiate the sample at the wavelengths of 1064, 532, and 355 nm at room temperature. Typical ultrafast signals can be observed as shown in Fig. 2, with the rise time of about 1.5 ns and the full-width at half-maximum (FWHM) of 1−2 ns. For mode 1, the signals were negative and positive when the laser pulse irradiated the positive and negative electrodes, respectively (Fig. 1(a)). While the reverse signals were recorded for mode 2 (Fig. 1(b)).

Due to inhomogeneous illumination in $LiNbO_3$ crystal, the concentration of photoelectrons is larger in the illumination region than in the dark region. And the photoelectrons will drift toward the $+c$ face of the crystal because of the existence of a permanent electric feld in the direction from $-c$ to $+c$ faces[12], then diffuse toward another electrode. Thus we can get the negative (positive) signals when the sample is irradiated at the back of positive electrode for mode 1 (mode 2). The same results can be also obtained when the CW laser is used to irradiate the crystal, as shown in Fig. 3.

The dependence of the peak open-circuit photovoltages on the incident light intensity is studied experimentally. The results are summarized in Fig. 4. We can see that

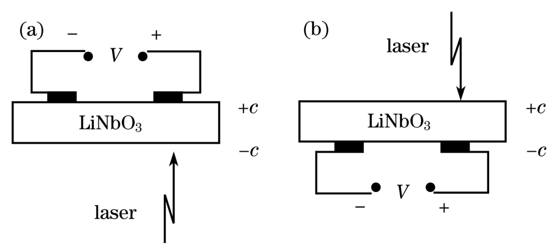

Fig. 1. Schematic of measurement for sample irradiated by laser through (a) $-c$ face (mode 1) and (b) $+c$ face (mode 2).

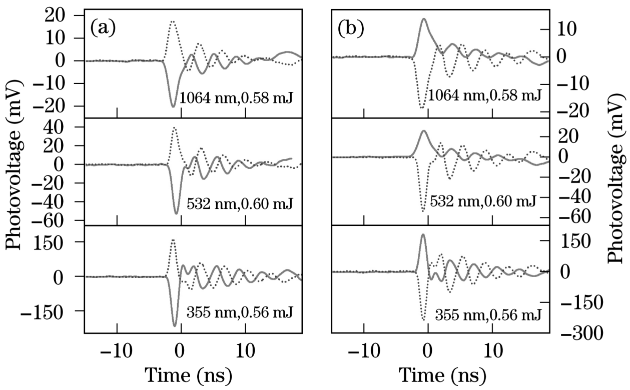

Fig. 2. Typical ultrafast photovoltages recorded for (a) mode 1 and (b) mode 2. Solid and short dot lines are for the signals when the laser pulse irradiates the positive and negative electrodes, respectively.

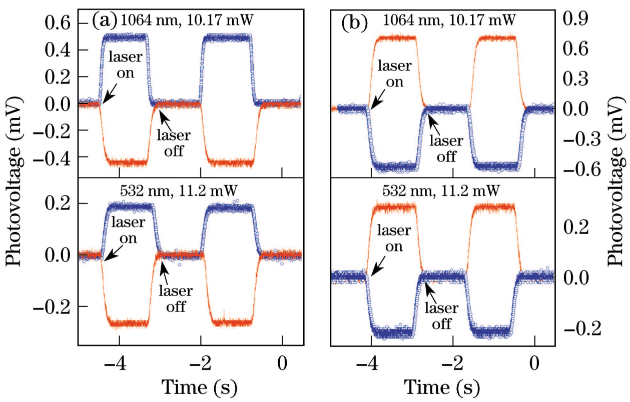

Fig. 3. Photovoltages for (a) mode 1 and (b) mode 2 under the irradiation of CW laser of 532 and 1064 nm. Solid line and open circle point are for the signals when the laser pulse irradiates the positive and negative electrodes, respectively.

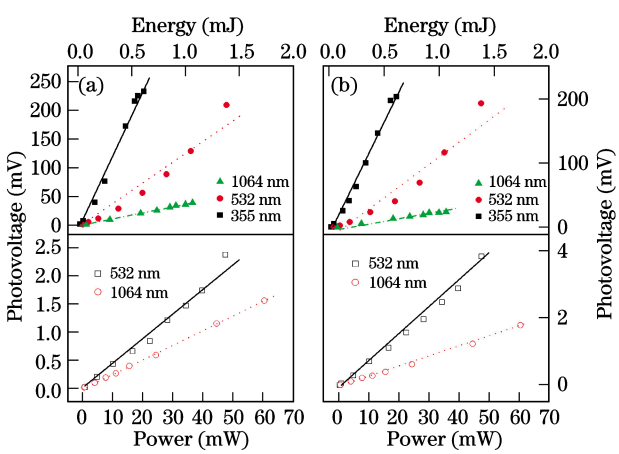

Fig. 4. Peak open-circuit photovoltages as functions of pulsed laser energy (solid point) and CW laser power densities (open point) for (a) mode 1 and (b) mode 2.

the photovoltages increase linearly with the laser intensity, which can be well explained by the photovoltaic efects in $LiNbO_3$ crystal[13−16].

About 1 mol% of intrinsic defects in pure congruent $LiNbO_3$ crystal is the main reason of the photovoltaic efect[17,18]. Electrons in deep center can be excited into the conduction band when the lasers of 355 nm (photon energy of 3.5 eV) and 532 nm (photon energy of 2.3 eV) irradiate the sample[19,20]. In addition, these electrons can also be excited by heating from the deep center. Under the irradiation of 1064-nm laser, the temperature of the crystal increases and the deep center is dissociated and releases electrons.

In summary, we investigate the lateral photovoltaic efects in pure congruent $LiNbO_3$ crystals by using pulsed and CW lasers with back inhomogeneous irradiation, respectively. A typical ultrafast signal under the pulsed laser can be observed. The peak open-circuit photovoltages increases linearly with the intensity of the incident laser.

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