

Photoconductivity and photoconversion at a photorefractive thin crystal plate



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ABSTRACT

We report on the photoconductivity and the photoelectric conversion measured on a thin photorefractive sillenite crystal plate, between transparent electrodes, in the longitudinal configuration where the current is measured along the same direction of the light beam through the sample. Its behavior is based on the already reported light-induced Schottky effect. The wavelength for optimal photoconductivity is determined. A specific parameter is formulated here for quantitatively determining the photoelectric conversion efficiency of the sandwiched material.

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1. Introduction

Photorefractive materials are photoconductive and electro-optics and are particularly suited for almost real-time reversible optical recording by transforming a spatially modulated illumination into a corresponding volume index-of-refraction modulation that can be read using an auxiliary probe beam [1–3]. These materials are also useful as high capacity volume memories [4–7], optical components fabrication [8] and for mechanical vibration modes detection in 2D [9,10] and various nondestructive metrology applications [11]. In this paper we shall focus only on the photoconductive properties and photoelectric conversion performance of photorefractive Bi₁₂TiO₂₀ crystal.

Light-induced Schottky effect at a transparent conductive electrode-bulk photorefractive crystal interface was already reported [12] before and shown to be due to the large density of electron-filled Localized States in most photorefractive materials [13] that allow to produce a large density of free electrons in the conduction band (CB), close to the illuminated transparent conductive electrode, by the action of light of adequate wavelength. Free electrons in the CB diffuse to the electrode until a sufficiently large depletion layer and associated electric barrier is build up to

stabilize the process. The same barrier but of opposite polarization is build up at the rear photorefractive-electrode interface. As light is strongly absorbed while going through the photorefractive plate thickness, the electric potential barrier is much weaker at the less illuminated rear interface than at the more illuminated front one, as schematically illustrated in Fig. 1.

Such an unbalanced voltage difference produces an overall drift of photoelectrons through the ITO-sandwiched photorefractive slab. Photorefractive materials of the Sillenite family are known to have a large forbidden bandgap (BG) in the range of 3.2 eV (corresponding to a light of $\lambda \approx 388$ nm) that makes them quite transparent in almost the whole visible range. The action of light on nominally undoped sillenites excites mainly electrons from Localized States in the BG to the CB. The energy gap between the Fermi level and the bottom of the CB in these materials being about 2.2 eV [13–15] (corresponding to $\lambda \approx 564$ nm), this one should obviously be the minimum photonic energy for photoelectron generation in the sample's volume, at least in thermally relaxed conditions. Most materials however, and particularly sillenites, have plenty of empty Localized States in between the Fermi level and the CB [15], that may be filled by optical pumping (with light of photonic energy equal to or higher than 2.2 eV, for sillenites) thus allowing light of photonic energy lower (or even much lower) than 2.2 eV to effectively participate in the photoelectric process too. On the other hand, such large number of empty centers makes

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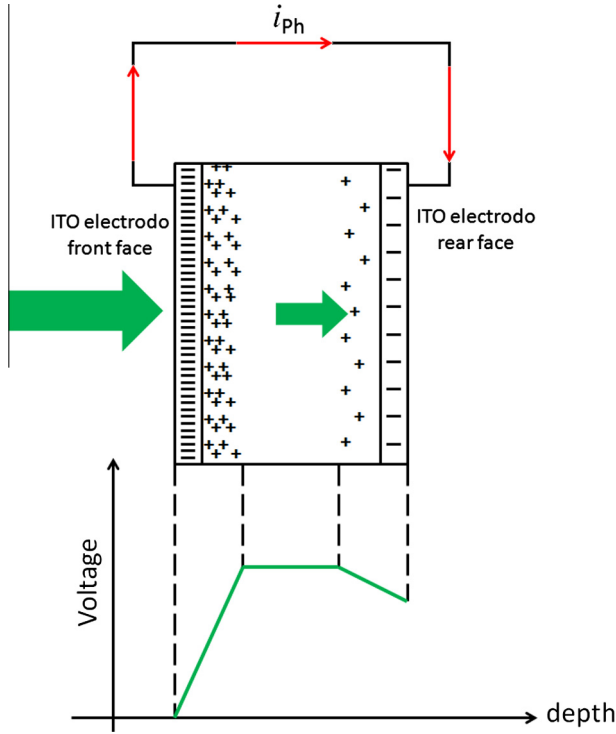


Fig. 1. Schematic representation of the device operation under illumination, in the longitudinal configuration, including a schematic voltage diagram along the device's thickness, without externally applied voltage. The arrows represent the light intensity.

free electrons to be easily retrapped thus reducing the overall photoelectric conversion efficiency.

2. Wavelength-Resolved Photoconductivity

Wavelength-Resolved Photoconductivity measurements [16] were first carried out in the transverse configuration where the light is perpendicularly incident on the input crystal face and the photocurrent is collected in the transverse direction (along crystal axis [100] in the sample of Fig. 2) with silver glue electrodes painted on the lateral opposite faces. This configuration was already shown [14,15] to be adequate for studying the position of the photoactive centers inside the material bandgap even using discrete wavelength illumination. The longitudinal configuration instead, where a thin photorefractive crystal slice is sandwiched between transparent conductive ITO electrodes and the photocurrent is measured along the same direction of the incident light, is here shown to be adequate for studying the photoconductivity and photoelectric conversion performance.

2.1. Photoconductivity measurement

Both transverse and longitudinal configurations will be here mathematically described and compared to each other in terms of their interest for studying the material and its performance.

2.1.1. Transverse configuration

Transverse configuration leads us to a convenient specific photonic energy dependent specific photoconductivity parameter $\underline{\sigma}^t$ that was already defined as [16]:

$$\underline{\sigma}^t(h\nu) = \frac{i_{ph}}{Hd} \frac{\ell}{V} \frac{h\nu}{I(0)} \frac{\alpha d}{1 - e^{-\alpha d}}, \quad (1)$$

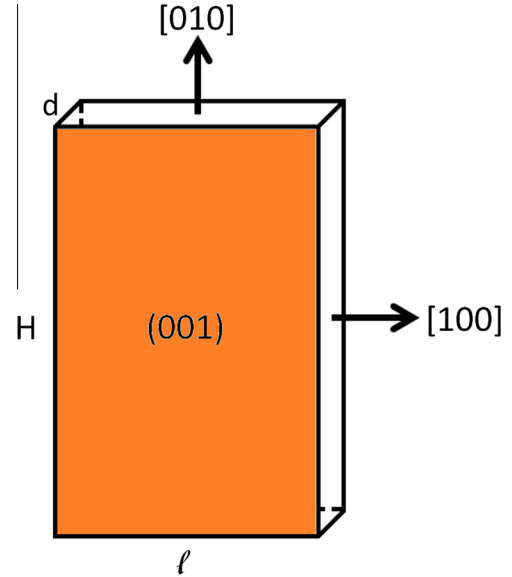


Fig. 2. Undoped photorefractive $\text{Bi}_{12}\text{TiO}_{20}$ crystal sample with H being its height, d its thickness, and ℓ its width. In the longitudinal configuration the front and rear surfaces are coated with transparent conductive ITO electrodes that are separated by the crystal thickness d . In the transverse configuration instead, silver ink glue electrodes are painted on the opposite lateral (100) surfaces and their separation is the width ℓ . (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

where V is the applied voltage through the sample's width ℓ with H being the height and d the thickness of the crystal as represented in Fig. 2. $I(0)$ is the irradiance of photonic energy $h\nu$ as measured inside the crystal at its input face of surface $H\ell$. The overall optical absorption coefficient including light-induced effects if ever present is α with $\Phi\alpha$ representing the fraction of absorption coefficient giving rise to electrons excited to the CB. The parameter in Eq. (1) can be also written, in terms of material properties, as:

$$\underline{\sigma}^t(h\nu) = q\mu\tau \sum_i (\Phi\alpha)_i, \quad (2)$$

where q , μ and τ are the electric charge value, mobility and lifetime of the photoexcited charge carriers (electrons in the CB for sillenite crystals) in the extended state. The summation at the right-hand side in the equation above is carried out on all Localized States (photoactive centers in the Band Gap) found at an energy gap of $h\nu$ from the bottom of the CB and its representation as a function of $h\nu$ is characterized by discrete steps each one of them indicating the position of a filled Localized State in the BG, as reported elsewhere [15].

2.1.2. Longitudinal configuration

Experimental results in this paper for this configuration are all referred to the crystal sample described in Fig. 2 with $H = 9.75$ mm, $\ell = 5.10$ mm and $d = 0.81$ mm. In this configuration the photoelectric current i_{ph} and the light irradiance $I(0)$ are both flowing parallel to each other along the coordinate z and perpendicularly to the input crystal surface. We should therefore write

$$i_{ph} = \sigma(z)E(z)H\ell, \quad (3)$$

$$\sigma(z) = q\mu\tau\Phi\alpha \frac{I(z)}{h\nu}, \quad (4)$$

$$I(z) = I(0)e^{-\alpha z}. \quad (5)$$

Because of the continuity of the current (i_{ph} independent of z) it is

$$E(z)\sigma(z) \propto E(z)I(z) = E(0)I(0), \quad (6)$$

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