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Photo-magnetic assisted ferroelectric polarization in magneto-electric $BiFeO_3/BaTiO_3$ thin film

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ABSTRACT

We examined the effect of light illumination on the magneto-electric behavior of the $BiFeO_3$ thin film which deposited onto $BaTiO_3$ piezoelectric layer by the aid of pulsed laser deposition technique. The ferroelectric polarization of the sample has been measured under electric field bias and illumination of different power of laser diode with a center wavelength of 406 nm in the presence of magnetic field. The photo-magnetic assisted ferroelectric polarization of the sample has been observed when the sample illuminated with light under magnetic field. Our results show the linear dependence of this answer with the power of light. This effect can possibly open a research development in photoassisted ferroelectric behavior properties for next generation devices.

1. Introduction

Magneto-electric (ME) materials has attracted considerable attention for their unique simultaneously ferroelectric and magnetic orders. These materials are promising for the multifunctional device applications [1–3]. One of the best candidate for these applications is $BiFeO_3$ (BFO) in bulk form due to its coupling between ferroelectric and anti-ferromagnetism order at room temperature [4–6]. Although BFO has been known for a long time, its properties such as photovoltaic, photostrictive, magnetism order and modulated spin flop remains a subject of intensive investigation in bulk form of it [7–9]. However the weak magnetism order at room temperature due to a residual moment from a canted spin structures and also new technological possibilities, drift researchers to the thin film state of this material [10]. Conversely, magnetostrictive, magnetic, photoconductive and magneto-electric behavior of these thin films has been investigated [11].

On the contrary, Narrow band gap in BFO structures lead to high spectral response located in the ultraviolet to visible region and a high conversion efficiency from the light to the electron–hole pairs which is separated by the internal electric field arising from the ferroelectric polarization of it. This high conversion efficiency lead to light induced phenomena such as photostrictive [12] and photovoltaic [13–15] effects which are arranged by the aid of ferroelectric polarization (FEP). Control of FEP in BFO based structures can be achieved by the aid of many factors such as substrate [16], ferroelectric-electrode interface [17], and also stimulated strain from the bottom piezoelectric layer [18].

Management of FEP and subsequently control of coupling between BFO and piezoelectric layer such as $SrRuO_3$ [19], $BaTiO_3$ (BTO) [20] and $PbZrTiO_3$ (PZT) [21] can be changed the ME answer of the system. In the recent work on BTO buffer layer, improved ferroelectric properties, as well as induced ferromagnetism, reduced leakage current, coercive field and increased ferroelectric saturation of BFO/BTO bilayer films were observed were obtained and compared with those of BFO films.

As mentioned above, to improve the ME coefficient of BFO thin films, their FEP needs to be enhanced. Now according to the photovoltaic effect of BFO thin films and use of piezoelectric layer, an effective and economical way of FEP engineering is use of light illumination.

In the present work, photoassisted FEP and photo-magnetic assisted ME effect have been measured in the $Au/BiFeO_3/BaTiO_3/Si/Al$ capacitor configuration with an electric field positive and negative bias poling under illumination of 406 nm.

2. Experimental details

$BiFeO_3/BaTiO_3$ heterostructure has been deposited onto Si (100) substrate using a 355 nm pulsed laser beam produced from third harmonic of Nd:YAG laser, which was focused on a target rotating at a frequency of 3 Hz at a distance of around 2 cm from the substrate. Typical laser parameters applied for deposition were as follows: pulse frequency of 10 Hz, laser fluence of 3 J/cm^2. All depositions were carried out in a vacuum chamber evacuated down to 4×10^{-5} mbar and the oxygen ambient gas pressure was

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120 mbar. The substrate was not intentionally heated and after deposition, each film was crystallized with rapid thermal annealing procedure at 600 °C for 60 min. The $BaTiO_3$ and $BiFeO_3$ thin films have thicknesses about 60 nm and 240 nm respectively that measured by the aid of mechanical thickness monitor.

The crystalline phases of thin films were measured by means of x-ray diffraction (XRD). After that, we use the thermal evaporation method to prepare the Au contact at upper edge (on BFO layer) and Al contact at bottom edge of the sample (on Si) with thickness of 50 and 200 nm respectively as depicted in Fig. 1. Also, silver paste is used in electrical connections.

Current that passes from the sample was measured after poling the structure with pulsed bias electric field under illumination of laser beam with the wavelength of 406 nm. This bias field was generated by function generator with pulse duration of 40 μs, repetition rate of 20 Hz and 5 ns rise time. This measurement have been done in two configurations consist of Al/Si and Al/Si/BTO/BFO/Au capacitors with forward and backward electric field polling.

Finally, the ME coefficient of the sample has been measured under light illumination at frequency of 7 kHz. Simultaneously we apply and sweep a DC magnetic field from −4 to 4 kOe to the sample and the output of lock-in amplifier recorded as the voltage between contacts, which is converted to the ME coefficient.

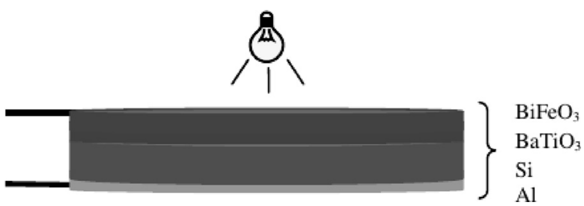

Fig. 1. Schematic diagram of heterostructure.

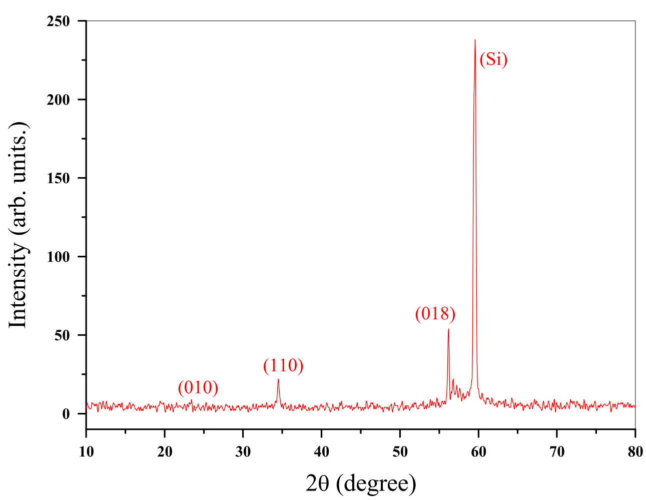

Fig. 2. XRD pattern of BFO/BTO configuration.

3. Results and discussions

Fig. 2 shows the XRD pattern of the sample, from which, we can see that the BTO and BFO film are well crystallized and impurity peaks such as Bi_2O_3 or $Bi_2Fe_4O_9$ do not appear.

From Fig. 3, one can see the passed current of the sample in backward and forward biases of electric field with and without light illumination. As shown in this figure, the sample has a capacitor and polarization current behavior. Consequently we observe sharply increase in the current of sample, Al/Si/BTO/BFO/Au capacitor, in each of on and off states which can be attributed to the FEP of the sample. In fact, charging the capacitor by the pulse of electric field yield to the sharply increase in the current for about 0.2 μs due to the increasing in FEP and then because of the leakage current, we have decreasing current.

As mentioned in the figure, one can observe that in the capacitor irradiated by light we have 18.56 times larger current in backward bias state which is named as photoassisted FEP (PA-FEP). In the irradiated sample, the PA-FEP yield to the again enhance in the current after the half of the pulse because decrease in the resistance of the sample. Also the discharge current of the pulse give in to enhance in the FEP and also PA-FEP of the sample.

As we expected, the photoassisted manner of the sample in the forward bias have the lower FEP with the decrease in rise time of the pulse and PA-FEP have the enhancement factor equal to the ideal p–n junction diode working voltage, 0.7 V.

Dependence of the PA-FEP on the power of light was performed and one can see that the maximum FEP in the sample has been enhanced linearly by power of light (Fig. 4). It has been shown that distribution of polarization in our polycrystalline layer can be arranged in order to increase the average PA-FEP by the aid of illumination with light and hence enhanced photoconduction and leakage current in the BFO layer of the sample.

With the purpose of investigate the Si substrate, our measurement repeated for the Al/Si sample. In this specimen, we have enhanced passed current in all of the electric field's pulse duration due to light illumination that is attributed to the semiconductor behavior of the Si sample (Fig. 5). Also as it expected, we do not have any contribution of FEP in this configuration.

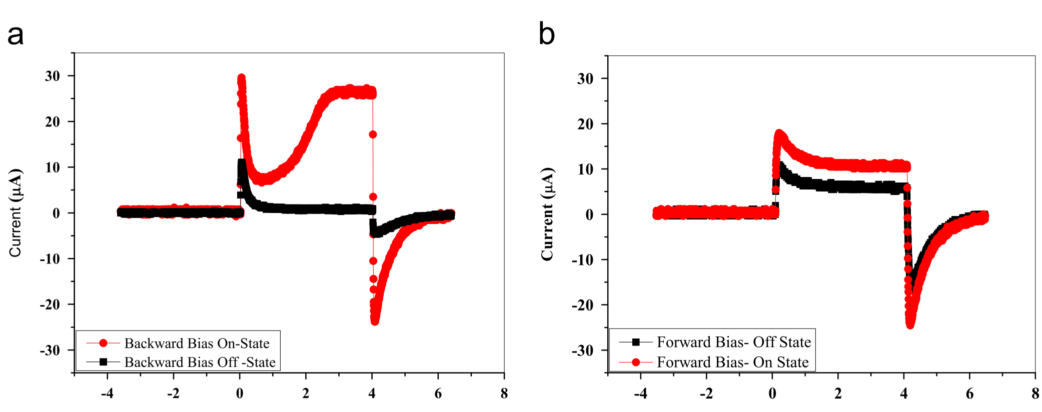

Fig. 3. Photoassisted response of the Al/Si/BTO/BFO/Au sample in on and off state for (a) backward and (b) forward bias.