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Multiferroic domain based photovoltaic behaviour of $BiFeO_3$ – a review

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ABSTRACT

Semiconductor photovoltaic materials have high conversion efficiency and mature technology but photo-induced voltage is limited to the height of their barrier. Ferroelectric photovoltaic effect has attracted a great deal of attention due to many unique features such as extremely large photo-voltage, a photocurrent proportional to the polarization magnitude and charge -carrier separation in homogeneous media. So, we wish to club the idea of above two reference in on the basis of domain in multiferroic materials. It has been found that in multiferroic based photovoltaic effects, domain of the material plays a very important role. It has been found that bismuth ferrite ($BiFeO_3$) single crystals exhibits a switchable diode behavior having a periodic array of 71° domain walls.A 71° domain wall corresponds to an interface separating two adjacent ferroelectric whose respective polarization directions make an angle of 71° with one another. There are two configurations, electrodes parallel to the domain walls (PLDW) exhibits no photovoltaic effectand PPDW (electrodes perpendicular to the domain walls) shows photovoltaic effect. The photovoltaic current-voltage properties associated with directional step of the electrostatic potential at 109°and 71° domains. The magnitude of the potential step at the 109° domain walls is larger than that of step at a 71° domain wall.

***Keywords:Domain, Multiferroics, Photovoltaic*.**

1. INTRODUCTION

Multiferroic materials have been received a renewed attention because these materials exhibit simultaneously two or more ferroic orders, i.e., ferroelectricity, ferromagnetism along with strong magnetoelectric coupling. Nowadays these materials getting much attention to be used in photovoltaics due to their fascinating domain structure.

The photovoltaic effect in ferroelectrics was first observed in 1956 in $BaTiO_3$, and it remains as dead many decades until 2009. Afterwards, ferroelectric photovoltaic effect has attracted a great deal of attention due to their unique properties such as extremely large photovoltage, a photocurrent is proportional to the polarization magnitude, charge - carrier separation in homogeneous media. However, the relationship between electronic transport and ferroelectric polarization in semiconducting ferroelectrics has been studied very little so far [1] due to the complexity associated with impurity interactions, grain boundaries and ferroelectric domains and domain walls [2–5]. The conversion process of light energy to electrical energy in photovoltaic devices relies on some form of built-in asymmetry structure that results in the separation of charge carriers. The anomalous

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photovoltaic effects in ferroelectric materials have been found to arise from two mechanisms (i) granularity [6, 7] and (ii) the inherent non-Centro-symmetry, i.e., the absence of an inversion centre of symmetry [8–11]. This can also be achieved by separation of charges in homogeneous ferroelectrics under illumination. The oxygen vacancy accumulation at the domain walls is a characteristic of perovskite oxides due to multidomain channels with diffusive switching characteristics.

$BiFeO_3$ (BFO) is one of the most important Multiferroics that exhibits ferroelectricity, anti-ferromagnetism, band gap in visible spectrum of light, possess rhombohedral structure (R3*c* space group) is promising for photovoltaic effect.

2.EXPERIMENTAL

BFO thin film has been fabricated using metal organic chemical vapour deposition (MOCVD) [12]. The microstructure of the thin film is characterized by Piezoresponse force microscopy (PFM) measurements. The two structural configuration, i.e., out-of-plane and in-plane domain images have been shown in Fig 1a and1b. Current-voltage (I-V) curves have been measured using a pA meter/DC voltage source (Hewlett Package 4140B). The light source was a Halogen lamp and the illumination energy density was 20 mW/cm^2.

3. RESULTS AND DISCUSSIONS

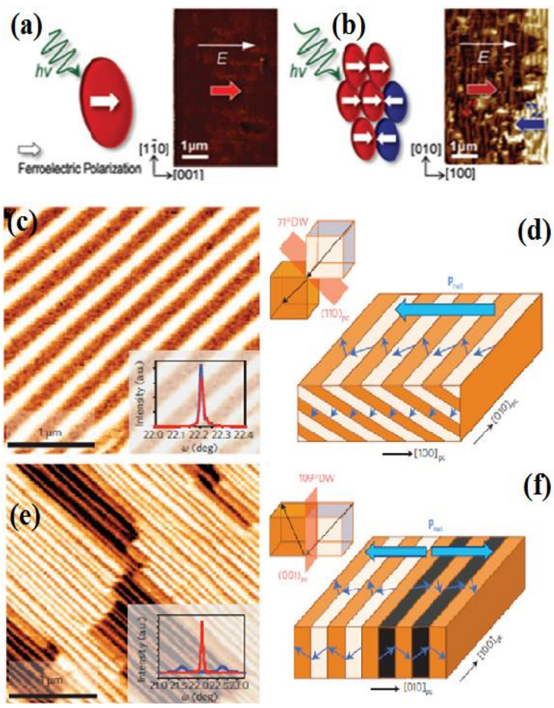

Figure 1:(a) shows in-plane PFM images of (110) BFO single domain and(b) (100) BFO multi-domains, net polarization directions are indicated by red and blue arrows (c, d) PFM image and x-ray curves of 71° domain walls (e, f) PFM and x-ray curves of the 109^o domain wall arrays (adopted with permission from ref. 12,15).

It has been found from TEM images of the two different domain structures that 71^{o}and 109 ^{o} domain lie along walls lie along (101) and (100) planes respectively [13]. BFO thin film of 100nm is fabricated on symmetric platinum top electrodes by photolithography in two type's geometries first electrodes for electric transport measurements perpendicular domain walls (DW⊥) and parallel domain walls (DW║), andcurrent-voltage (I-V) measurements of the two samples have been illumination in dark and white-light along 71^{o}and 109^o domain walls[12]. It has been found from Figure 2 c and d, that with 28.5 mW cm^{-2} white light and in the perpendicular domain walls direction a large photo induced V_{oc} of 16V has been found, with in-plane short-circuit density J_{sc} = 1.2×10^{-4} Acm^{-2}. Therefore, in parallel to the domain walls (PLDW) configuration shows photovoltaic effect, while the perpendicular to the domain walls (PPDW) shows none as shown in Figure 2 a and b[12].

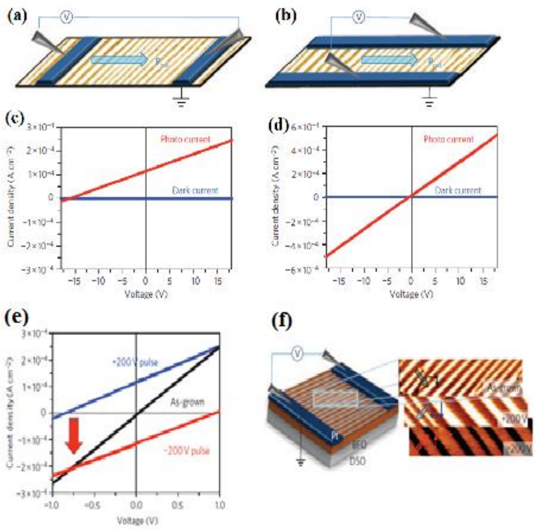

Figure 2:Schematics of the (a) perpendicular (DW⊥) (b) the parallel (DW║) device geometries, (c) I–V measurements of the (DW⊥) (d) and(DW║)devices, (e)domain-wall switching effect (f) corresponding PFM images of the as-grown (top panel), 200 V poled (middle panel), and 200 V poled (bottom panel) device structures (adopted with permission from ref. 12, 15).

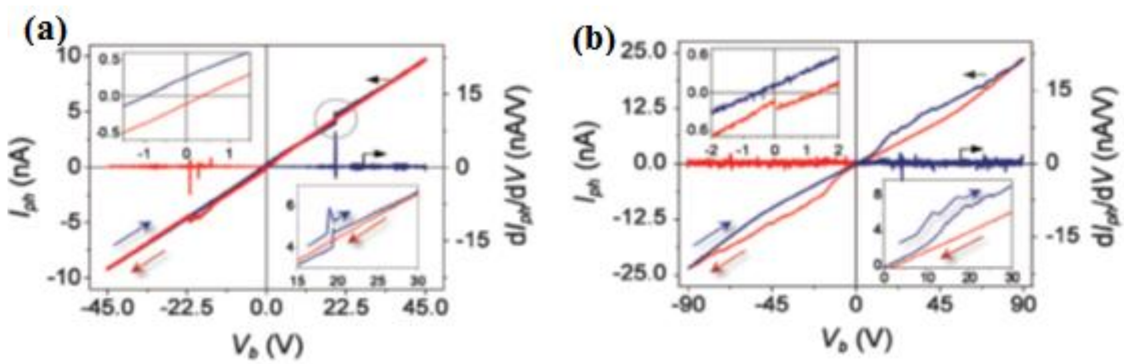

Figure 3:(a) I-V characteristics under global illumination on single-domain (b)and multidomain BFO(adopted with permission from ref. 15).

I-V characteristics have been studied under illumination in dark and white-light. The parallel domain walls shows no photovoltaic response Figure 2 (e, f) [12]. By applying a voltage pulse of 200V between the two in-plane electrodes, ferroelectric domain switching is observed. For a pulse of 100 µs, 200KVcm^2 is applied, and thatproduce a corresponding rotation of the ferroelectric domain structure that creates a system with the perpendicular domain walls geometry. The domain structure has been rotated by 90^0 which creates a potential drop necessary for anomalous Photovoltaic effect in PFM image of +200V pulse. The application of -200V/100ms pulse flips the polarity of photo-induced voltage and current(as shown by red curve, Figure 2f) [12]. Figure 1 a and b show in-plane PFM images that has been obtained after poling with 90V, indicated by white arrows. This observation represents a transient current characteristic in ferroelectrics that is associated with the change in capacitance at the electrode contacts because of net polarization variation under an applied field [14], while, I_{ph} increases upon a single abrupt switching in the single domain of BFO. TheI_{ph} increases in continuous minute steps for multi-domains, as shown in Figure 3b, reminiscent of the Barkhausen effects of magnetization.Figure 1 a and b inset show photovoltaic effect in the low electric field region [15].The inset shows the variation of the transient current associated with the switching characteristics of each domain. The magnified views of the low electric field region, shows photovoltaic effects [15].

4. CONCLUSIONS

This study verified the role of domains, domain walls and electrode parallel and perpendicular to domains walls in ferroelectric Photovoltaic effect.

5. ACKNOWLEDGEMENT

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