Polarization Rotation by Barium Titanate (BaTiO$_3$) Thin Film with an External Electric Field

N. A. Razilam*, S. H. Najamudin, W. S. W. Ramli, P. Poopalan
School of Microelectronic Engineering, University Malaysia Perlis (UNiMaP), Pauh Putra Campus, 02600, Arau, Perlis, MALAYSIA.

*amira_razilam@yahoo.com

Abstract. Barium Titanate (BaTiO$_3$) thin films are suitable for many applications especially photonic due to its large electro-optic (EO) coefficient where the EO effect causes a change of optical refractive index in a film due presence of an electric field. The first step towards the development of thin film based EO modulators is to study its EO properties. The thin film BaTiO$_3$ was prepared by a sol gel process and annealed at 900°C and then subjected to EO interrogation via the Sénarmont technique. It shows that the technique affected the electro-optic properties of the thin film and the electro-optic behaviour. The Sénarmont technique also utilized the EO measurement of BaTiO$_3$ thin films from negative 20V up to positive 20V by connecting the electrical and optical domain with different angles of polarizer that are from 0° up to 180°. The results show that the power measurement is much higher between 30° to 50° with positive 20V. It is found that electric field disrupts the EO behaviour of the film.

1. Introduction

Nowadays, the measurement of electro-optic (EO) is a very critical issue. Specific and valid measurement of the EO behaviour of a thin film sample should be repeated with various angles in order to obtain more precise results. Ferroelectric ceramic or ferroelectrics allude to the gathering of dielectrics having the property of unconstrained polarization where they hold a dipole significantly after an applied voltage has been evacuated. The key attributes of a ferroelectric precious stone are that the heading of the polarization can be switched by utilization of an electric field and that a hysteresis circle results. Ferroelectrics primarily have two qualities that are asymmetry and high dielectric consistent or high permittivity. The perovskite family, having a structure of the kind of ABO$_3$ is the most well-known sort of ferroelectrics. Numerous ferroelectric materials, for example, barium titanate (BaTiO$_3$), lead titanate (PbTiO$_3$), lead zirconate titanate (Pb(ZrTi)O$_3$), lead lanthanum zirconate titanate (Pb(LaZr)TiO$_3$), and relaxor ferroelectrics like lead magnesium niobate (MgNb2O9Pb3) have this perovskite type structure [1].

1.1. Barium Titanate (BaTiO$_3$)

BaTiO$_3$ is one of the most widely used ferroelectric materials due to its properties which make it interesting for fundamental science and is isostructural with the mineral perovskite (CaTiO$_3$) as is alluded to as ‘a perovskite’. Over its Curie point (around 130°C) the unit cell is cubic while beneath the Curie point the structure is somewhat mutilated to the tetragonal structure with a dipole minute along c heading. Different changes happen at temperatures close to 0°C and - 80°C, the unit cell is orthorhombic
with the polar pivot parallel to a face corner to corner and beneath - 80°C it is rhombohedral with the polar hub along a body diagonal [2].

BaTiO₃ is an appealing contender for thin film EO modulators because of its dielectric properties and ease of preparation as well as deposition [3]. From the perspective of practical applications, it is artificially and mechanically exceptionally steady, and it shows ferroelectric properties [4] at or above room temperature. From the optical applications’ perspective, BaTiO₃ is exceptionally intriguing as a result of its linear and nonlinear EO coefficients. This makes BaTiO₃ a superb material for use as a modulator. It exhibits a large EO coefficient, such as of r=100pm/V and huge birefringence because of its atomic structure, Δn=0.05, in its bulk crystalline structure. Thin film BaTiO₃ is coated by various strategies and their optical properties have been generally researched and utilized in EO waveguides and modulators. It has a tetragonal crystal structure with an ordinary index, n₀=2.412, comparing to the shorter a-axis bigger than the phenomenal record, ne=2.36, along the c-pivot. Ferroelectric areas structure when the film is cooled underneath the Curie temperature (~120°) and their last direction is influenced by film stress just as cross section and warm extension bungle. Ferroelectric spaces in BaTiO₃ can be described by their direction in-plane (a-pivot) or out-of-plane (c-hub). BaTiO₃ thin film deposited on oxide thin films electrodes have been described by piezoresponse force microscopy and show both-in-plane and out-of-plane spaces. These spaces can be controlled by applying an electric field over the element and in-plane areas can be compelled to change out-of-plane under an applied field more noteworthy than the coercive field. This area exchanging occasion is joined by a huge change in the file of the BaTiO₃ thin film because of the birefringence in the element [5].

The techniques to prepare BaTiO₃ such as solid-state reaction techniques, chemistry-based techniques and many more. For solid state procedure, a wide number of fabricated methods have been created for the formation of BaTiO₃ powders however it is every now and again dependent on solid state responses of varied powder and the advantage of this technique is it single process and it is low cost. For chemistry-based technique, the main objective is to form large purity of BaTiO₃ fine powder at a small temperature and the most widely used is sol-gel method because of it exceptionally powerful in forming ceramic powder of high purity, little size and great consistency at low temperature. This process suggests a stable colloidal (Sol) solution, which gels into film when dried and this solution is customarily founded on dissolved organomettalic sub-atomic precursors. The sol-gel method is beneficial for depositing process since it permits the control of composition, structure morphology, low temperature preparing, and this procedure used for the formation of thin films.

At optical frequencies, thin films are transparent to light, and refraction can be amazingly tuned by actualizing an electric field. Besides, it can be produced as an epitaxial single precious crystal on silicon, making it an ideal material for fused optical modulators. Epitaxial deposition of BaTiO₃ films on silicon substrate was lately recorded. Consequently, the integration of BaTiO₃ in silicon is a standout amongst the most encouraging alternatives for the utilization of electro-optic functionalities with the best execution, especially modulation, which will push forward the cut off purposes of present silicon photonics innovation. However, epitaxial deposition is expensive and complicated due to the use of large-scale machine. Alternatively, a sol which could be spun-on onto a substrate is highly desired. The EO coefficients of a spun-on thin film is not well documented and is the main aim of this research.

1.2. Sénarmont method
In the Sénarmont procedure, the obscure impediment is arranged at 45° from end and followed by a quarter wave plate, parallel to the laser polarization direction. In this configuration, the light transmitted by the quarter wave plate is linearly polarized and the polarization angle is directly related to the phase retardation of the unknown wave plate. Rotating the analyzer until extinction occurs allows the determination of the unknown retardation [6]. Figure 1 shows the Sénarmont schematic. The advantage of the proposed strategy is that a total elliptical polarization will be obtained at the output which is easily interrogated by an analyzer.
The most understood explanation of the Sénarmont technique may be created in the most part circulated monograph [8]. From the monograph, it is expressed that using the Sénarmont method it is possible to evaluate arrange differentiates inside a singular wavelength, or the excess over a crucial number of waves, in any case, the technique is sensible only for organize contrast not outperforming (180°).

Prior to spin coating the glass substrate was subjected to RF Sputter deposition of Indium Tin Oxide (ITO). Argon was used as the sputtering gas and the substrate was maintain at 300°C. The reason for choosing ITO instead of other material is because of it high melting point and high optically transparent conductor. After BaTiO₃ together with the bottom electrode had been annealed, the top electrode, ITO...
is then sputtered on. The top electrode is important because the electrical characterization itself needs some electrically conductive contact to conduct the electrical power to the sample. The magnitude of the electric field was estimated using the relation:

\[ E = \frac{V}{s} \]  

(1)

where \( V \) is applied voltage bias on BaTiO\(_3\) and \( s \) is the width of the gap which is 0.8mm.

![Schematic diagram of the sample.](image)

**Figure 3.** Schematic diagram of the sample.

3. **Experimental Setup**

Figure 4 showed the schematic design that was used been setup. The electro-optical measurement under consideration were carried out on the basis of the Sénarmont-type optical setup. At the end of the setup before photodetector, the analyzer is placed and is oriented with its axis at an azimuthal angle.

![The schematic design setup.](image)

**Figure 4.** The schematic design setup.

A dc voltage is applied to the sample which varies from -20V to 20V to see the influence of the electric field on the optical characteristics of the BaTiO\(_3\).

4. **Results and Discussion**

Figure 6 shows X-ray diffraction pattern of BaTiO\(_3\) thin film prepared by spin coating on silica glass substrate for 5 layers and annealed at 900°C for 2 hours. The results show the XRD peaks at (21.9°), (31.2°), (38.6°) are the BaTiO\(_3\) thin film. The thickness of BaTiO\(_3\) is 250 nm for 5 layers.

The voltage is applied to BaTiO\(_3\) with different angles of the polarizer from 0° to 180°. Figure 7 shows the result for angle of polarizer against the voltage bias. As can be seen from the graph the highest peak occurs at the 40° and 130° for each voltage. For voltages below -5V, the variations reduce with -20V giving an almost nil response. This could be due to residual polarization from the application of 20V or in short hysterical response of the film.
The method is copied with the polarizer turned over a scope of angles depending on the order of magnitude of the retardation to be measured. The recorded power is then investigated to figure out which angle created termination. Both the precise scopes of the polarizer and the analyzer can be diminished if the retardation order of magnitude is known. From the test, the most extreme power estimation is 45°. The estimation blunder utilizing by deciding the angular estimation vulnerability which is characterized as the angular range over which the yield light power diminishes past the base quantifiable power. So it is almost similar to result angle of polarizer against the voltage bias BaTiO3.

![Sample when applied dc voltage.](image)

**Figure 5.** Sample when applied dc voltage.

![XRD diffractogram are resulting after annealed at 900°C for 2 hours.](image)

**Figure 6.** XRD diffractogram are resulting after annealed at 900°C for 2 hours.
The electric field dependence of the voltage bias is shown in Figure 7. Electric field has been calculated using Eqn 1. It is seen that the electric field increases as the voltage bias increases. The highest electric field is 0.25kV/cm which is achieved when voltage bias is 20V. This field is a lateral field whereby only fringe fields are expected to affect the thin film.

Figure 8. Electric field against voltage bias of BaTiO₃.

5. Conclusion
In conclusion, the power measurement against variation angle of polarizer and voltage bias of BaTiO₃ showed the highest peak is at 40º for different voltage bias. However, 20V gives the highest measurement compared to other voltage bias. When the voltage bias increase, the electric filed also increase linearly. For the compensator angle, the angle that give the higher intensity output is at 45º. The EO measurement of BaTiO₃ can be used for optical modulator application.

Acknowledgement
The author would like to acknowledge the support from the Long Term Research Grant Scheme (LRGS) Wide Band Gap Semiconductor Special Focused Industry Driven Program under Long Term Research Grant Scheme (LRGS/1/2016) with Grant No. 9012-00007 in carrying out the research work.
References

[1] Osman K I 2011 Synthesis and Characterization of BaTiO3 Ferroelectric Material (Faculty of Engineering, Cairo University Giza, Egypt)

[2] Sahoo G K 2008 Synthesis and characterization of BaTiO3 Prepared by Molten Salt Synthesis Method (Department of Ceramic Engineering National, Institute of Technology, Rourkela)

[3] Zgonik M, Bernasconi P, Duelli M, Schlesser R, Günter P, Garrett M H, Rytz D, Zhu Y and Wu X 1994 Dielectric, elastic, piezoelectric, electro-optic, and elasto-optic tensors of BaTiO3 crystals Phys. Rev. B 50 5941–9

[4] Xu Y 1991 Ferroelectric materials and their applications (North-Holland Amsterdam)

[5] Dicken M J, Sweatlock L A, Pacifici D, Lezec H J, Bhattacharya K and Atwater H A 2008 Electrooptic modulation in thin film barium titanate plasmonic interferometers Nano Lett. 8 4048–52

[6] Montarou C C 2005 Low-Level Birefringence Measurement Methods Applied to The Characterization of Optical Fibers and Interconnects (School of Electrical and Computer Engineering, Georgia Institute of Technology)

[7] Abel S, Stöferle T, Marchiori C, Rosse C, Rossell M D, Erni R, Caimi D, Sousa M, Chelnokov A, Offrein B J and Fompeyrine J 2013 A strong electro-optically active lead-free ferroelectric integrated on silicon Nat. Commun. 4 1671

[8] Chmyrev V I and Skorikov V M 1999 Analysis of the ellipse of polarization by the senarmont method as the phase difference varies in the range 0–2π Measurement Techniques 42 22–5

[9] Kumar N D and Chandra S 2003 Dielectric and ferroelectric by the sol-gel process properties of BaTi & thin films grown process J. Electroceram. 5679 1993

[10] Namsar O, Watcharapasorn A and Jiansirisomboon S 2012 Structure-property relations of ferroelectric BaTiO 3 ceramics containing nano-sized Si 3N 4 particulates Ceram. Int. 38 S95–S99