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Far East Journal of Electronics and Communications

Published Online: September 2014
Available online at http://pphmj.com/journals/fjec.htm
Volume 13, Number 1, 2014, Pages 71-78

I-V CHARACTERISTICS VERIFICATION OF SIMPLE ANALYTICAL CALCULATION MODEL WITH EXPERIMENTAL DATA OF Al/$Ba_{0.5}Sr_{0.5}TiO_3$/Al STRUCTURE DIODE

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Abstract

Current-voltage (I-V) characteristics of simple analytical calculation model of ferroelectric $Ba_{0.5}Sr_{0.5}TiO_3$-based diode have been verified with experimental data for bias voltage in the range of –10V to 10V. $Ba_{0.5}Sr_{0.5}TiO_3$ ferroelectrics layer used in the experiment was doped by varied Nb doping level. The simple analytical model used based on Shockley ideal diode model, while the experiment used simple I-V meter for the current measurement. The verification results show that the values of calculation current are similar to that of experimental data for low bias voltage. However, for higher bias voltage, the values tend to be slightly different with the experimental data.

I. Introduction

Ferroelectric thin films are widely used in applications for optoelectronic and electronic devices. Some of the most important electronic applications of

Received: June 16, 2014; Accepted: July 14, 2014
Keywords and phrases: Al/$Ba_{0.5}Sr_{0.5}TiO_3$/Al structure diode, I-V characteristics, simple analytical calculation model, I-V meter.

ferroelectric thin films include: non-volatile memory using high polarization capability, thin film capacitor using the dielectric properties, sensor pyroelectric using the dielectric constant, and piezoelectric actuators using the piezoelectric effect. This sensor drives a lot of attention because of the possibility in replacing SiO_2-based memory as ferroelectric random access memory (FRAM) [1]. With the polarization value of approximately $10\mu C.cm^{-2}$, FRAM is able to produce charge up to 10^{14} electron per cm^{-2} for reading process memory [2]. Ferroelectric materials such as $BaSrTiO_3$, $PbTiO_3$, $Pb(Zr_xTi_{x-1})O_3$, $SrBiTaO_3$, $Pb(Mg_{1/3}Nb_{2/3})O_3$ and $Bi_4Ti_3O_{12}$. $BaSrTiO_3$, $PbTiO_3$, $Pb(Zr_xTi_{1-x})O_3$, $SrBiTaO_3$, $Pb(Mg_{1/3}Nb_{2/3})O_3$ and $Bi_4Ti_3O_{12}$ are very important for memory device applications. Among others, $Ba_xSr_{1-x}TiO_3$ is chosen in this study because it can be yielded in laboratory with simple equipment and there was no group studying the doped $Ba_xSr_{1-x}TiO_3$ material systematically. Thin film processing technique that has been widely used in the growth of $Ba_xSr_{1-x}TiO_3$ is the sol-gel, sputtering, pulsed laser ablation deposition (PLAD), metal organic vapor deposition (MOCVD), and chemical solution deposition (CSD) [3]. Meanwhile, the growth technique used in this study is CSD.

Verification of I-V characteristics of calculation results with experimental data conducted in this study is to test the validity of the simple analytical calculation model of electrical conductivity. Calculation model of the electrical conductivity can be approached by experimental data of Shockley diode, while the electrical conductivity of diode is characterized by Ampere-Volt (I-V) characterization. Here, we verify the I-V characterizations calculation results and the experimental data for different level of doping into $Ba_xSr_{1-x}TiO_3$ layer.

II. Simple Analytical Calculation Model

There are two models to construct a simple analytical calculation model in this study: ideal diode model and Shockley diode model.

A. Ideal diode model

The ideal diode model is used in this study based on its similar characteristics with $Ba_{0.5}Sr_{0.5}TiO_3$ p-n junction, where ideal diode junction acts as a short circuit for forward bias ($V_d > 0$ (positive anode)) [4], as is shown in Figure 1. Meanwhile, the ideal diode junction acts as an open circuit for reverse bias ($V_d < 0$ (negative anode)) [4], as is shown in Figure 2.

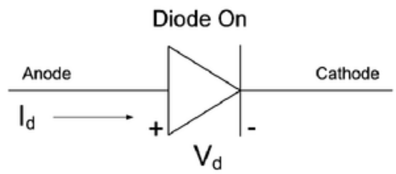

Figure 1. Diode junction when forward bias is applied [4].

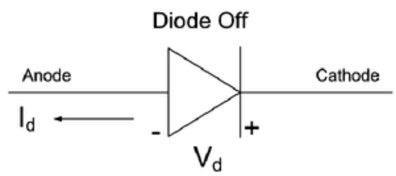

Figure 2. Diode junction when reverse bias is applied [4].

B. Shockley diode model

The Shockley diode equation relates to the diode current I and diode voltage V_d, of p-n junction diode which known as I-V characteristics as follows [4]:

$$I = I_s(e^{V_d/nV_T} - 1), \tag{1}$$

where I_s is the saturation current of the diode that proportional to the cross-sectional area. The magnitude of the saturation current that flows for negative V_d in an excess of V_T is typically in the range of 10-12A. V_T is the thermal voltage that equals to kT/q which is approximately of 26mV at room temperature, and n is the diode ideality factor (for silicon diode, n is approximately of 1 to 2). The ideality factor is derived from the slope of the dark I-V, the open circuit voltage V_{oc} and the light I-V curve.

The basic cell equation in the dark condition is:

$$I = I_0(e^{qV/nkT} - 1) \quad (2)$$

while the basic cell equation in the light condition is:

$$I = I_0[(e^{qV/nkT} - 1)] - I_{ph}, \quad (3)$$

where I is the current through the diode, V is the voltage across the diode, I_0 is the dark saturation current, T is the temperature, q and k are both constants, and I_{ph} is photocurrent resulted when the light is applied to the photodiode. For $V > 50$ mV, the -1 term in equation (2) can be ignored, therefore the basic cell equation in the dark condition reduces to:

$$I = I_0(e^{qV/nkT}) \quad (4)$$

taking the logarithmic for both sides of the equation gives:

$$\ln(I) = \ln(I_0) + \left(\frac{q}{nkT}\right)V. \quad (5)$$

By plotting the natural logarithmic of the current against to the voltage, the slope gives q/nkT and the intercept gives $\ln(I_0)$. In real cells the ideality factor depends on the voltage across the cell. The ideality factor can either be plotted as a function of voltage or it can be given as a single value. Deviation in the ideality factor from one indicates that either there are unusual recombination mechanisms taking place or that the recombination is changing in magnitude. The measurement of I_0 is only valid when the ideality factor is stable.

III. Experiment

$Ba_{0.5}Sr_{0.5}TiO_3$ materials with various doping levels of neobium were grown on n-type silicon (100) substrate using chemical solution deposition (CSD) method. $Ba_{0.5}Sr_{0.5}TiO_3$ materials were obtained from a powdered barium acetate [$Ba(CH_3COOH)_2$, 99%], a powdered strontium acetate

[$Sr(CH_3COOH)_2$, 99%)], a solution of titanium isopropoxyde [$Ti(C_{12}O_4H_{28})$, 99%], and a solvent2-methoxyethanol [$H_3COOCH_2CH_2OH$, 99%]. All materials in solid form were previously crushed for 3 hours in order to obtain refined grains, and then shaken manually for 1 hour to produce precursors, as published in our previous paper [5]. Finally, to obtain the ingredients perfectly mixed and to obtain a more homogeneous solution, the precursor was heated on ironing surface with temperature of ±120°C for 5 minutes, followed by filtration using filter paper.

Furthermore, substrate was placed on top of spin coating reactor, and the center of *n*-type silicon (100) substrate was etched with 2 drops of precursor solution. The reactor was then rotated at 3000rpm for 30 seconds. Followed by the heating of silicon (100) substrate on ironing surface for an hour at temperature of ±120°C. This process then continued by annealing using Vulcan™3-130 furnace at temperature of 900°C for 15 hours. The final stage was the furnace cooled to room temperature. The I-V characteristic measurements of $Al/Ba_{0.5}Sr_{0.5}TiO_3/Al$ structure diode was performed using an I-V meter.

IV. Verification Process

To verify the experimental data with an ideal Shockley diode model, the software of simple analytical calculation was developed using MATLAB R2009a. The software takes the experimental data as the input and uses a curve fitting technique to verify the experimental data with the Shockley diode model. Verification was conducted for bias voltage in the range of –10V to 10V in step of 0.5V.

V. Results and Discussion

In this study, $Al/Ba_{0.5}Sr_{0.5}TiO_3/Al$ structure diode was used with different doping levels into $Ba_{0.5}Sr_{0.5}TiO_3$. The voltage bias in the range of –10V to 10V in step of 0.5V was applied to the structure and the output current of the diode is measured using I-V meter. The experimental data were then compared with the calculation results. Figure 3 to Figure 5 show that the calculation results are similar to the experimental data for low bias voltage (–6V to 6V). However, fitting results will increasingly diverge for the higher bias voltage.

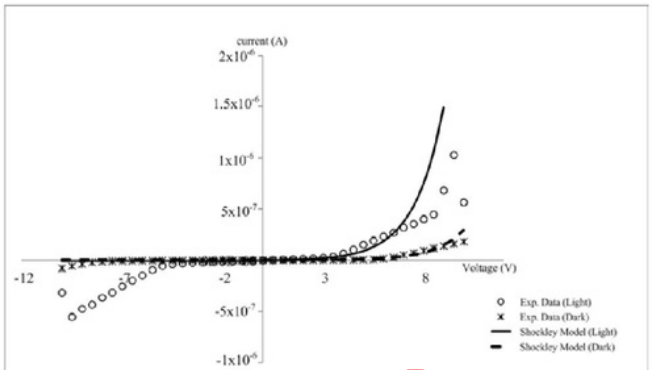

Figure 3. The fitting of calculation results with the experimental data of $Al/Ba_{0.5}Sr_{0.5}TiO_3/Al$ structure diode without doping (0%).

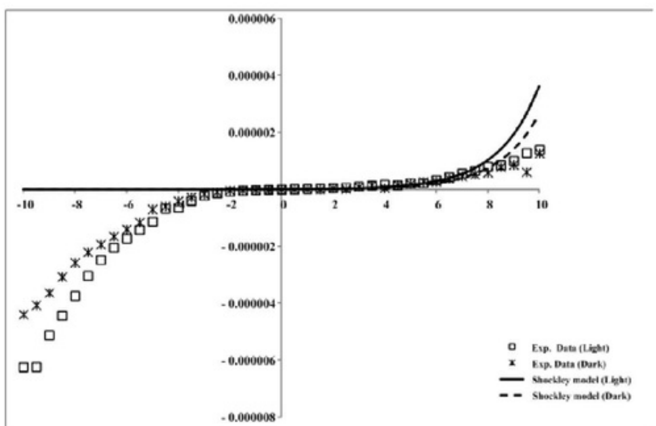

Figure 4. The fitting of calculation results with the experimental data of $Al/Ba_{0.5}Sr_{0.5}TiO_3/Al$ structure diode with 5% of Nb doping level.

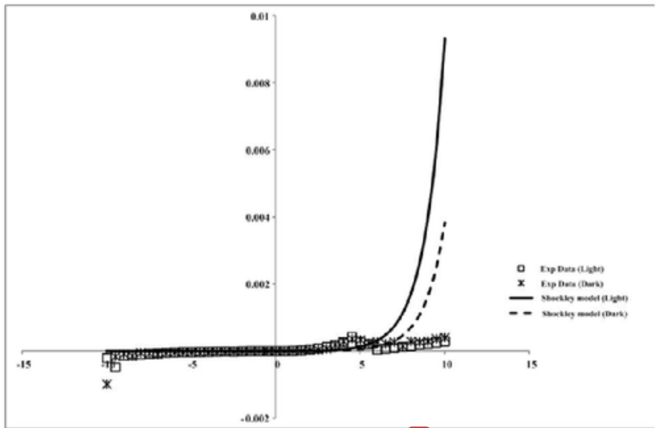

Figure 5. The fitting of calculation results with the experimental data of $Al/Ba_{0.5}Sr_{0.5}TiO_3/Al$ structure diode with 10% of Nb doping level.

The verification between the experimental data and calculation results shows that there is no difference in the current value for low bias voltage in the range of –6V to 6V. However, for higher bias voltage, the calculations results tend to be slightly different with the experimental data. The difference is appeared to be quite large at the reverse bias voltage of –6V.

From the three I-V characteristics resulted, we can see that by applying the same range of voltage on all of the structures, the current results are different. I-V characteristics of $Al/Ba_{0.5}Sr_{0.5}TiO_3/Al$ structure diode without doping level show the lowest current values. Meanwhile measurement results in the dark and light conditions did not show any differences. I-V characteristics of $Al/Ba_{0.5}Sr_{0.5}TiO_3/Al$ structure diode with doping level of 10% show the greatest current values. However, slight differences are shown for measurement results of dark and light conditions. The structure with doping level of 5% yields moderate current values. These due to the increase of valence electrons saturation that caused the difficulties on electron to move in the device. From Figure 4, it can be seen that at 5% of doping level, the bias voltage yields more distinguishable current values for dark and light conditions compared to the other I-V characteristics.

VI. Conclusion

In this research, the software for verification of I-V characteristics of Al/$Ba_{0.5}Sr_{0.5}TiO_3$/Al structure diode of the calculation and the experimental data has been resulted. From the verification, there are no differences in I-V characteristics at bias voltage of –6V to 6V, in both dark and light conditions. The calculation results tend to be slightly different with the experimental data for forward bias voltage >6V and reverse bias voltage <–6V.

Acknowledgement

We gratefully acknowledge to Indonesia University of Education for financial support through "Program Stimulasi Penelitian untuk Pusat-Pusat di LPPM".

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