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POLARIZATION HYSTERESIS CURVE MEASUREMENT FOR AN Au/PZT/YBCO DEVICE BY DOUBLE PULSE TECHNIQUE

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Abstract

Polarization for Au/Pb($Zr_{0.52}$ $Ti_{0.48}$)O_3/$YBa_2Cu_3O_{7-x}$ ferroelectric capacitor has been studied and measured by pulse method. A sequence of pulses with amplitudes varying from 0 to 10 volts in 2 volt steps is applied and a conventional polarization curve is obtained by integrating the charge flow from the polarization switching induced by the voltage ramp. A value of 25 $\mu C/cm^2$ is measured for the saturated polarization from the hysteresis curve. The polarization retention is also measured at 200°C for the device and the polarization change over 24 hours was about 5.7%.

Introduction

Ferroelectric memory cells have been extensively used in devices like nonvolatile memories [1,2,3], pyroelectric detectors [4,5,6], integrated optical modulators, infrared detectors and switching devices [7,8]. The fast polarization reversal phenomena in the electric field is the main reason of the ferroelectric thin films as a nonvolatile computer memory element. One of the properties which is required of ferroelectric memory cells is long term stability. The degradation of the polarization caused by fatigue [9], retention [10] and aging are basically the main reasons that limit the application of ferroelectric thin films in the microelectronics industry.

Therefore, measuring and monitoring the polarization state of ferroelectric devices play a major role in characterizing the electrical and optical properties of such devices. The magnitude and direction of the polarization can be measured and monitored through the pyroelectric current measurement of the device made from such ferroelectric materials. In the ceramics, the direction of the remnant polarization and therefore the polarity of the photo-emf's can be switched with voltage pulses [11]. Therefore, one can retrieve the information stored in the direction of remnant polarization within a ferroelectric element by sensing the polarity of the photovoltage across the element.

Among the ferroelectric materials, Pb($Zr_{0.52}$ $Ti_{0.48}$) O_3(PZT) is of particular interest due to its high dielectric constant and relatively high Curie temperature. Thin film ferroelectric PZT and thin film superconducting $YBa_2Cu_3O_{7-x}$(YBCO) have been used for this study. The YBCO is not used as a superconductor in the application, but only as an operating oxide electrode. The choice of YBCO for the bottom electrode is partly due to its good conductivity at room temperature [4], but mostly because of its proper lattice constant match with PZT which makes it possible to grow an oriented PZT thin film on top of YBCO [11]. In this paper, the double pulse technique for monitoring and switching the polarization state of PZT

Keywords: Ferroelectrics; Polarization; Retention

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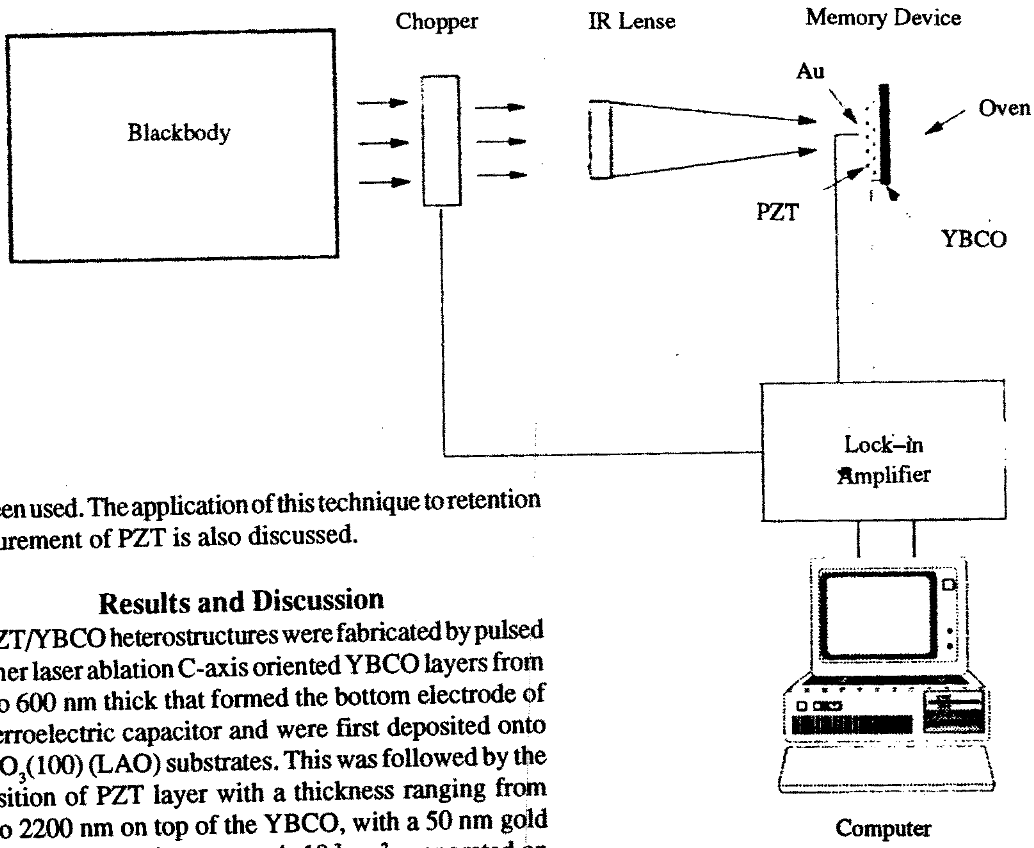

Figure 1. The schematic diagram of the set-up for a pyroelectric current measurement

has been used. The application of this technique to retention measurement of PZT is also discussed.

Results and Discussion

PZT/YBCO heterostructures were fabricated by pulsed excimer laser ablation C-axis oriented YBCO layers from 300 to 600 nm thick that formed the bottom electrode of the ferroelectric capacitor and were first deposited onto $LaAlO_3(100)$ (LAO) substrates. This was followed by the deposition of PZT layer with a thickness ranging from 300 to 2200 nm on top of the YBCO, with a 50 nm gold electrode of approximate area 4×10^{-3} cm^2 evaporated on top of the PZT to complete the ferroelectric capacitor. The structural properties of this heterostructure have been studied previously and show an orthorhombic YBCO that is C-axis oriented normally to the surface, on top of which is formed a crystallographically ordered PZT film in the Perovskite structure with (001) orientation normally to the surface [12, 13].

The polarization of PZT was measured by monitoring the pyroelectric current from the device. The pyroelectric current is measured by using a set-up consisting of a standard blackbody source of infrared radiation, a chopper and a lock-in amplifier (Fig. 1). The pyroelectric current for the device is obtained directly from the lock-in amplifier output, and its direction is reflected by the phase measurement. It is known that almost all ferroelectrics are pyroelectric with the pyroelectric current proportional to the time derivative of the polarization. This can be expressed by the following equation:

$$I = -AdP_s/dt \qquad (1)$$

This equaiton can also be expressed as the following:

$$I = -A(dp_s/dT)(dT/dt) \qquad (2)$$

where A is the area of the device, P_s is the spontaneous polarization of the device [14], dp_s/dT is the pyroelectric coefficient and dT/dt is the rate of temperature change. The device itself is maintained at a constant temperature throughout the experiment. However, it can receive heat through incident infrared radiation and therefore the temperature change of the polarization can be monitored through pyroelectric current measurements.

The conventional method uses a double positive and double negative pulse train to switch a ferroelectric memory cell as shown in Figure 2. If the polarization of a ferroelectric memory cell has been stored in such a way that its direction is pointing out of the surface, it can be defined as state "1". The "0" state of the memory cell is then defined for the polarization direction pointed into the surface. When a double pulse train is applied to the device, the first positive pulse (P1) switches the polarization vector. A displacement current proportional to $(\partial/\partial t)(\varepsilon_0 E+P)$, where ε is the dielectric constant, E is the electric field and P is the polarization, then flows through the device. The second positive pulse (P2) will generate less current since it is proportional to $(\partial/\partial t)(\varepsilon_0 E)$. Similarly, the first applied negative pulse (N1) should generate the

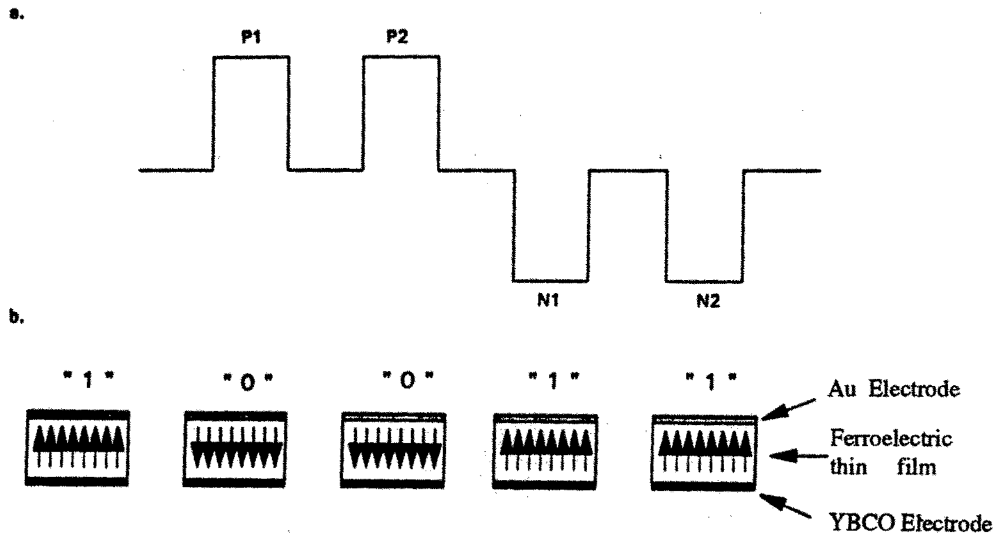

Figure 2. (a) The diagram for a typical double pulse train. (b) The polarization field measured by a double train for an Au/PZT/YBCO memory cell

same amount of current as the first positive pulse, but with the opposite sign. The second negative pulse (N2) again should produce only the $(\partial/\partial t)(\varepsilon_0 E)$ part of the current similar to the second positive pulse. By integrating the current versus time curve for both the first positive and the first negative pulses, the total polarization switching charge flowing through the device can be obtained.

The state of polarization of the device with any polarity and at any stage can be monitored from the hysteresis loop of the polarization. To obtain hysteresis curves for the polarization, a sequence of pulses with amplitudes varying from 0 volts to 10 volts in 2 volt steps is applied. The charge flow from the polarization switching is measured for each voltage by evaluating the area under the corresponding charge flow curve. The curves for the positive (P1) and the negative pulses (N1) are shown in Figures 3 and 4. The area under each curve is an indication of the amount of polarization left in the device. Therefore, the integration of each charge flow curve would give us a point on the hysteresis polarization curve. Such a curve is shown in Figure 5. The values for the saturation polarization (Ps) and the remnant polarization (Pr) can be

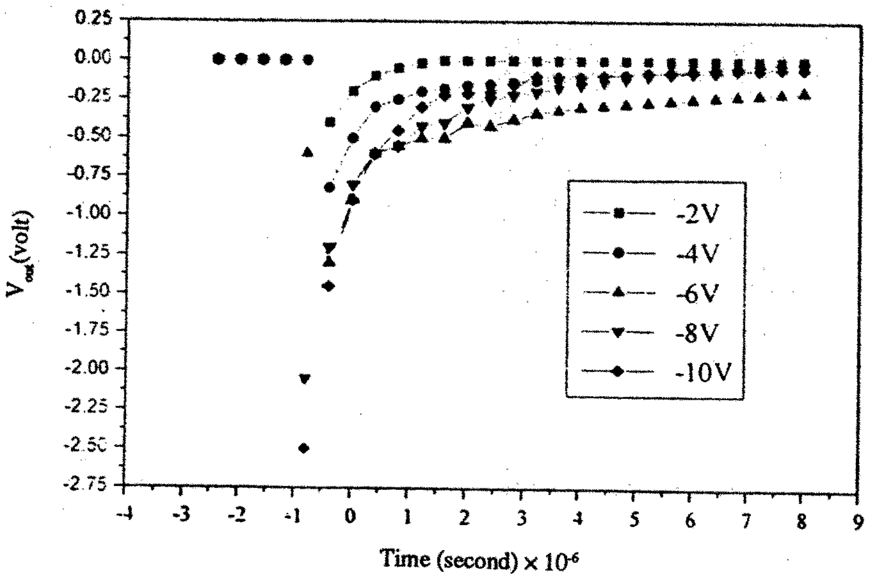

Figure 3. Charge flows from the polarization switching of PZT by P1 pulses in each step

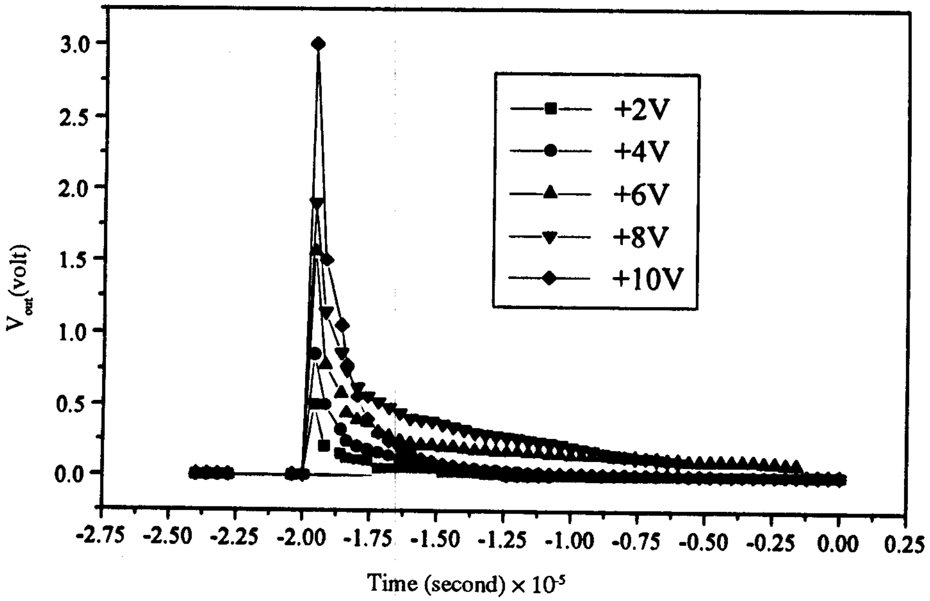

Figure 4. Charge flows from the polarization switching of PZT by N1 pulses in each step

deducted directly from this curve and are normally higher when compared to the same quantities from a conventional Sawyer-Tower curve [12], the reason being that the polarization states are forced to the maximum values by using the pulse method.

Using this pulse method, one can investigate the retention behavior of the device at any stage of polarization of the dielectric material used in making the device. Retention is the ability of the device to retain its original state of polarization for a certain period of time. It is an important property for the commercial uses of such devices. Recently, the application of such devices at high temperatures has opened new areas of research which include investigating the retention, fatigue and aging of such devices at temperatures above room temperature. Figure 6 shows the retention behavior of an Au/PZT/YBCO device at 200°C. The measurement was taken twice, once at t=0 and again at t=24 hours. The polarization change over 24 hours obtained by this technique was about 5.7% with a systematic error of about 5%.

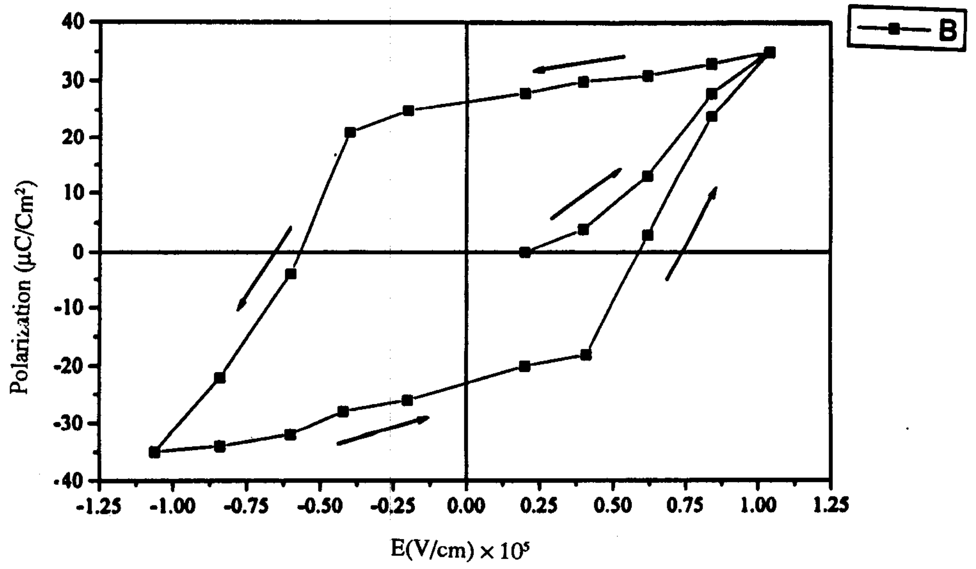

Figure 5. The polarization hysteresis curve for an Au/PZT/YBCO memory cell measured by a double pulse technique

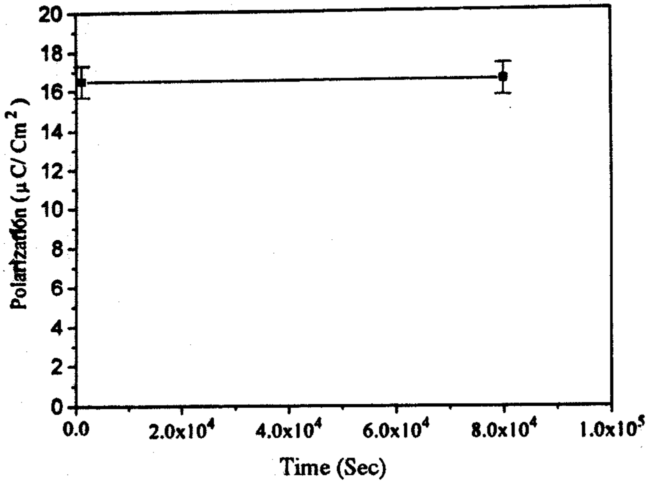

Figure 6. Retention measurement of PZT thin film measured in an AU/PZT/YBCO device

Conclusion

In conclusion, the polarization of a device made from PZT thin film is measured using pulse method. The hysteresis curve of the polarization is obtained by integrating the charge flow of the polarization through the device by switching the polarization in 2 volt steps. The retention behavior of the device is also measured at 200°C which shows an almost negligible degradation of the polarization at this temperature.

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