Memory Technologies for Machine Learning
Measuring Ferroelectrics
EITP25

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1 Introduction to Ferroelectrics

Dielectric materials are highly attractive as insulators due to there ability to block charges from passing through them. For polar dielectrics with a non-centrosymmetric unit cell structure very interesting properties can arise. In regards to crystalline materials these are divided into crystal classes depending on their properties. One of these crystal classes is ferroelectric materials. A ferroelectric (FE) material is defined by its spontaneous polarization which can be reversed in the presence of an electric field. This polarization change stems from the physical movement of ions in the unit cell structure from one equilibrium to another. Due to the two stable and uniquely defined states of FE materials they are excellent for memory applications storing "1"s and "0"s as the different polarization state of the material. The states are uniquely defined, non-volatile and has a non-destructive readout. All of which are big advantages of FE based memories.

2 Characterizing Ferroelectrics

The metric for benchmarking FE materials is the Polarization-Electric field (PE) curve, from this the remanent polarization P_r and coercive field E_c can be extracted. The remanent polarization P_r represents the displaced charge at zero applied electric field whereas the coercive field E_c provides the minimum electric field required to displace the charge and reverse the polarization direction.

The polarization and hence the PE curve cannot be measured directly, instead it is derived from the IV characteristics. From this we can attain the net *change* in polarization. In the simplest case of a field plate capacitor the stored surface charge at any time t is calculated by the integral

$$Q(t) = \int_{t_1}^{t_2} I dt \tag{1}$$

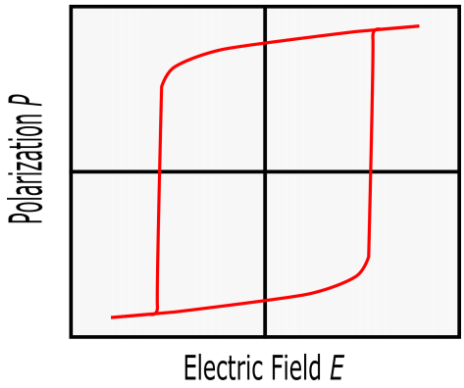


Figure 1: Schematic of P-E curve.

The dielectric displacement D is calculated as the surface charge density by [1].

$$D(t) = \frac{Q(t)}{A} \tag{2}$$

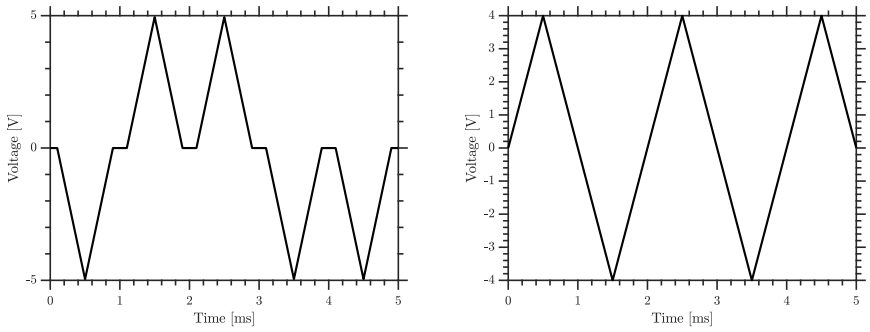
For high permittivity ferroelectrics, $\kappa > 20$, the polarization P is roughly equal to the dielectric displacement D. Note that this approximation is only valid for materials with a large permittivity. The expression for polarization then becomes

$$P(t) = \frac{Q(t)}{A} \tag{3}$$

When trying to characterize FE response there are two different types of measurement schemes used among researchers. The first one is known as the "PUND" method which stands for **P**ositive **U**p **N**egative **D**own. A typical PUND sequence is shown in figure 2a. The second method is the "Virtual Ground" setup where identical pulses of alternating sign is continuously pulsed after each other, depicted in figure 2b. The two measurement schemes are equally common in literature. **Why do you think that is? What are the benefits and drawbacks of the two methods?**. **Hint:** The "Positive" and "Negative" pulses in PUND switch the polarization whereas the "Up" and "Down" pulses do not.

3 Assignments

For this hand in assignment you will derive the corresponding PE curves of three materials in order to benchmark them. You will receive three sets of measured IV-data and your task is to **implement the PUND data analysis**



(a) Example of PUND implementation. (b) Example of VG implementation.

Figure 2: The two pulse sequences used to characterize FE materials.

in MATLAB to derive the PE curves. For more detailed information on the subject please see the lecture slides related to this topic or [1].

All three data sets are measured on a circular parallel plate capacitor with $r = 25\mu m$. The FE material in all the three structures are metal organic oxides with a high permittivity. The dielectric measured in files **A** & **B** are 15nm thick whereas for the third data set, file **C** the dielectric thickness is 10nm.

Finally the PE curve displayed in figure 3 below shows a classical anti-ferroelectric (AFE) response, would it be possible to measure this type of response by implementation of the **PUND** method? If so why or why not?

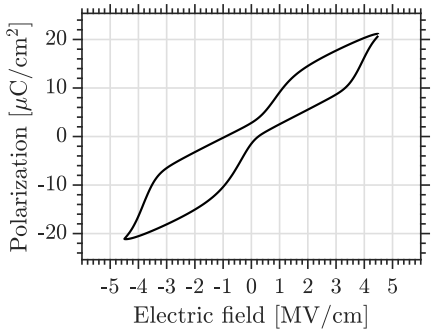


Figure 3: Measured PE curve of anti-ferroelectric response of pure ZrO_2

References

[1] D. Hall, M. Cain, M. Stewart, T. U. K. C. f. M. M. National Physical Lab., and Technology;, "Ferroelectric hysteresis measurement & analysis," in *Minutes of the NPL CAM7 IAG Meeting*, 1998.