Femto-second Laser Triggered Ultra-fast Switching Dynamics in Thin Film Ferroelectric Capacitors

B.Nagaraj, J.Li, W.Cao, H.Y.Liang, C.H.Lee and R.Ramesh
Materials Science Research and Engineering Center, University of Maryland, College Park, MD 20742

The application of ferroelectric capacitors in non-volatile ferroelectric random access memories (FeRAMs) is due to their switchable remnant electric polarization which can be reversed by the application of a short voltage pulse. The significant progress in the past few years notwithstanding, a fundamental understanding of the broadband polarization dynamics in these materials is still not complete. Specifically, the physics of polarization switching, involving nucleation and growth of reverse domains, with short electrical pulses needs to be understood better.

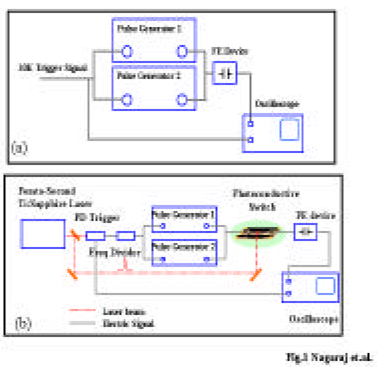

Fig. 1 (a) Measurement setup with optically triggered electrical pulse generators ; (b) Measurement setup with optically triggered GaAs photoconductive switch.

The Merz model, further elaborated by Ishibashi describes this process as a power exponential function of the applied field and switching time, with two important parameters : (a) α, the activation field and (b) t_0, the characteristic switching time. α is a time-averaged measure of the ease of switching, representing the energetics of switching while t_0 is a measure of ultimate switching speed. Our earlier studies, using a conventional electrical setup showed that α is relatively invariant to systematic changes in the circuit parameters[2]. However, t_0 changed dramatically with the above parameters, suggesting that it is convoluted with the circuit parasitics. Further, the measured t_0 was significantly larger than the theoretically predicted switching times of ~ 50ps[3]. We therefore initiated a careful and systematic study of the switching behavior of fully integrated $Pb(Nb,Zr,TiO_3)$ capacitors using two novel femtosecond laser experimental setups. A novel, femtosecond laser technique has been used to probe the ultra-fast polarization switching dynamics in ferroelectric thin films Our models of the switching transients show that the activation field α, which is a measure of the ease of switching is essentially constant.

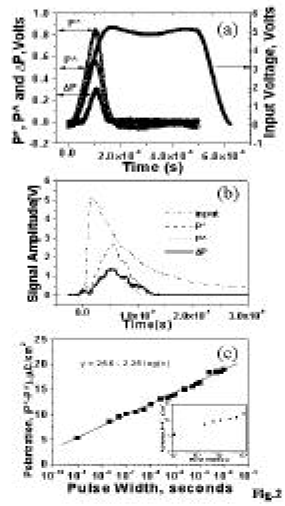

Fig. 2(a). Input signal using an optically triggered electrical generator and switched (P*), non-switched (P^) and the remanent (DP) responses of LSCO/PNZT/LSCO capacitor ; (b). Input signal using GaAs photoconductive switch and switched (P*), non-switched an and (DP) responses of LSCO/PNZT/LSCO capacitor.

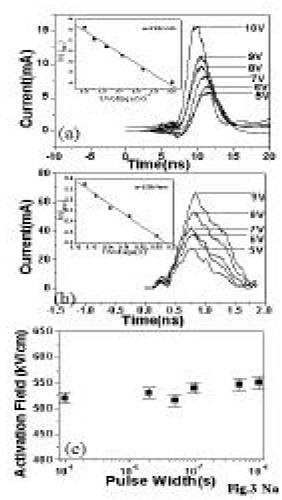

Fig. 3 Switching current response of LSCO/PNZT/LSCO capacitor as a function of pulse voltage : (a) from the optically triggered pulse generator; (b) from the GaAs- optical switch. The insets show the corresponding plots of ln(imax) vs 1/V, whose slopes give slopes give the activation field a.

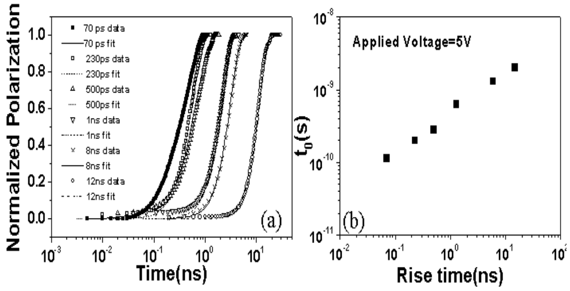

Fig. 4 4 (a) Plots of normalized DP vs transient time of LSCO/PNZT/LSCO capacitors for 5V pulses of various rise times. (b) Calculated value of t0 vs rise time of the input pulses. Note the linear dependence down to a rise time of ~70ps

Modeling of the switching transients using the Merz-Ishibashi model of switching kinetics yields a quantitative estimate of t_0, the characteristic switching time, in the range of 100-200psec. This nugget summarizes the key results of this study. For the first time, MRSEC researchers have demonstrated the ability to switch ferroelectric capacitors with pulses shorter than 1 nsec and rise times smaller than 100psec. These studies have enabled us to establish a lower limit on the intrinsic switching time in these capacitors to a value of about 100-200psec.