Abstract

Hafnium Oxide’s (HfO₂) compatibility with the CMOS process and its ferroelectric phase make it a desirable material for the gate of a transistor in order to create more efficient memory. However, its response time when it switches polarization may limit its application in certain high-performance devices. By introducing an induction term in the Landau-Khalatnikov equation, which describes the dynamic motion of ferroelectric polarization, we hope to better understand the frequency response of HfO₂ and its limitations. The classical damped oscillator model also can model polarization and be fitted to optical data to determine its coefficients. Together, these two models can predict an internal resistance that determines the fastest switching time of HfO₂.

Ferroelectricity

- Asymmetric distortion of molecules creates separation of charge (left). The two polarization states of a ferroelectric result from the two orientations (above).
- Two energy wells represent the two polarization states
- Unstable region is the barrier between the states
- Q = CV
- Negative capacitance in unstable region
- Coercive field needed to switch states

RLC and Damped Oscillator

\[ L\ddot{P} + \rho \dot{P} + V_P F = E \]

- The LK equation (above) models a ferroelectric as a RLC circuit [1]
- Each series RLC represents a domain
- Displacement of oxygen shows change in polarization state and is the source of kinetic inductance
- Classical model of oscillating dipoles. It can be fitted to optical measurements to determine coefficients.
- Predicted mass of 13.5 amu (oxygen has 16 amu) [3]

\[ m\ddot{x} + \beta \dot{x} + kx = eE_x \]

Conclusion and Future Work

We were able to find the phonon resonance of PZT and determine the maximum allowable resistivity to achieve terahertz switching with the LK equation. Future work includes repeating the procedure with HfO₂ and further investigating parameters controlling the resistivity to evaluate whether our prediction is realistic for a ferroelectric thin film. Success could entail faster switching for ferroelectric transistors.

Results

- Frequency response given by the damped oscillator model using fitted parameters.
- Resonance is around 5 THz.
- RLC surface plot showing whether switching is possible for different inputs
- PZT coefficients used because HfO₂’s were not available
- Limit of .003 Ω*cm to switch at 1 THz for PZT

Acknowledgements

I would like to thank my PI, Prof. Sayeef Salahuddin for his guidance on this project and for the opportunity to spend a summer in his group. Also, I am grateful for the help of my mentor Korok Chatterjee and Justin Wong in their explanations and suggestions for my project.

References


Support Information

This work was funded by National Science Foundation Award ECCS-0939514