Direct Probe of Phase Uniformity of High-*k* Ferroelectric Oxides Using X-ray Nano-beam

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Abstract

High-*k* gate oxides have been the workhorse for the semiconductor industry in the last decades. The continuous downscaling of the gate dielectrics due to ever diminishing dimensions of the metal oxide semiconductor field effect transistor (MOSFET) has reached to a point beyond the physical limits of SiO_2. Recent developments in the creation of effective negative capacitance (NC) [1,2] and ferroelectric tunnel junctions (FTJ), have offered a solution in nano-electronics scaling such as reducing supply voltage, heat generation and leakage current, as well as their potential application in low-power electronics, energy storage, and conversion. Extensive research has been conducted on $Hf_{1-x}Zr_xO$ (HZO) based thin films for the development of NCFET and FTJ. While the ferroelectric (FE) nature of the compound is now well established, the length scale of the FE uniformity in relation to the crystallographic phase is less explored. Phase determination in HZO used to rely on cross-comparison between x-ray diffraction (XRD) and polarization-electric (*P-E*) measurements. People use this methodology to examine whether the desired phase is achieved during fabrication optimization. However, this kind of approach is not quantitative and it does not satisfy the higher demand on the accuracy of phase determination when further thinning HZO, particularly less than 5 nm. In this work we introduce a methodology as a solution to the long-standing concern of phase determination in ultra-thin high-*k* ferroelectric gate materials. By scanning x-ray nano-beam over a 10μm x 10μm sample area we were able to construct a two-dimensional (2D) map of the HZO featuring phase uniformity over a large landscape, in which a spatial resolution of 100 nm can be achieved. We interpret the spatial relationship of the multiple phases based on the mapping results, free energy calculation and *P-E* measurements, and found it very helpful to understand the mode of origin of the ferro- and non-ferro phases. Based on this understanding we proposed a second annealing process, and found that it does promote the HZO's FE properties. This proves that this methodology can provide solid guidance to the optimization of the high-*k* ferroelectric gate materials.

Keywords –dielectric, x-ray absorption spectroscopy, semiconductor, field-effect-transistor

References

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