2021「中技社科技獎學金」

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研究獎學金

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鐵電氧化鉿鋯應用於多位元非揮發性記憶體及深度神經網絡

Ferroelectric $HfZrO_2$ for Multibit Nonvolatile Memory and Deep Neural Networks

國立臺灣師範大學 光電工程研究所 博士班 二年級 廖俊宇

指導教授: 李敏鴻 教授

研究重點

本研究使用鐵電氧化鉿鋯($HfZrO_2$, HZO)作為鐵電電晶體之閘極氧化層，並利用鐵電材料的雙穩態特性，將其應用於①非揮發性記憶體及②深度神經網絡。第一部分：使用雙層非等厚度之堆疊HZO，因上層與下層矯頑場(Coercive Field, E_C)不同，進而獲得多位元非揮發性記憶體操作。第二部分：使用超薄(5 nm) HZO在相等脈衝(Identical Pulse)進行深度學習，可望解決後續複雜的電路設計，並得到非線性度(non-linearity) = 1.25，電導比(Conductance Ratio) > 1000x的結果。

研究成果

Multibit Nonvolatile Memory with Nonidentical Double-HZO

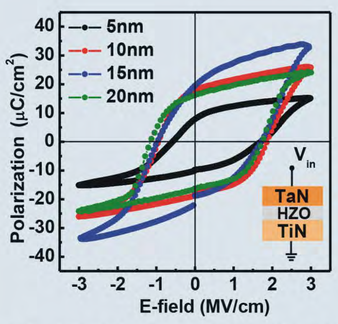

Fig.1 P-E loops of TaN/HZO/TiN with 5-nm, 10-nm, 15-nm, and 20-nm HZOs.

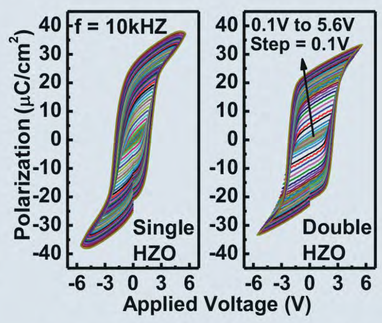

Fig. 2 Ferroelectric characteristics single-HZO and double-HZO with a total physical thickness of 15 nm.

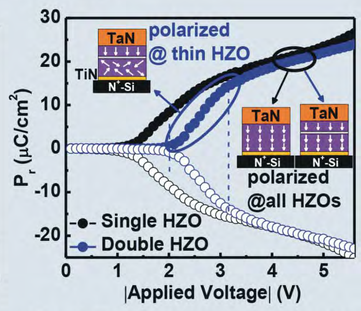

Fig. 3 The two stage slopes of the double-HZO indicate the polarization flipping mechanisms at different E_C, providing stable multilevel states.

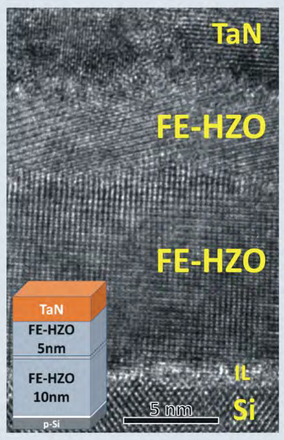

Fig. 4 HR-TEM of the double-HZO FeFETs. The top and bottom HZO layers are clearly identified with two different crystalline structures.

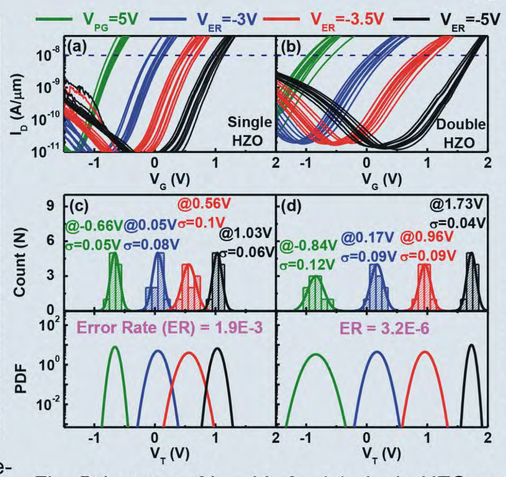

Fig. 5 4-states of $I_D - V_G$ for (a) single-HZO and (b) double-HZO FeFETs. The corresponding statistics count of the V_T distribution and converted PDF (probability density function) of (c) single-HZO and (d) double-HZO FeFETs at selected erase conditions.

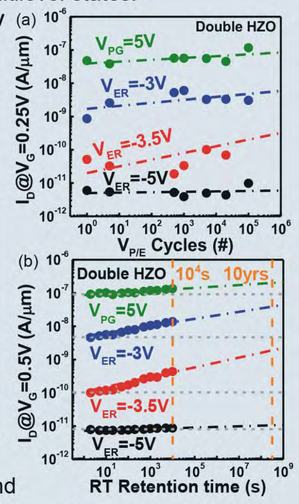

Fig. 6 Reliability of double-HZO with (a) endurance and (b) retention.

Identical Pulse with Potentiation Learning Trajectory by Ultra-Thin HfZrO2

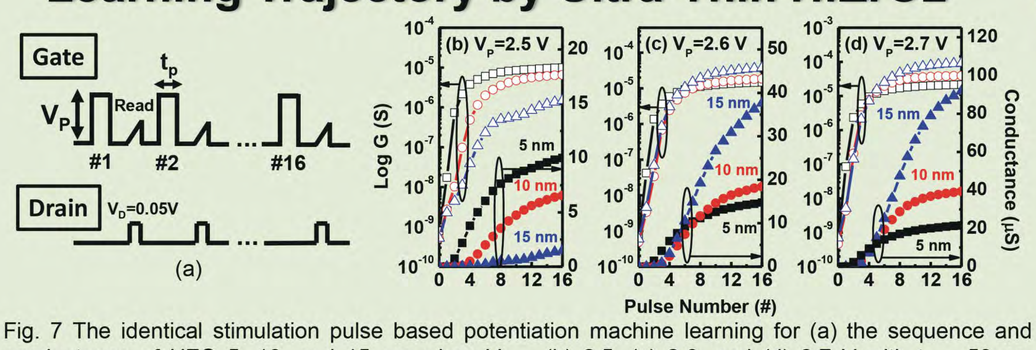

Fig. 7 The identical stimulation pulse based potentiation machine learning for (a) the sequence and conductance of HZO 5, 10, and 15 nm when V_P = (b) 2.5, (c) 2.6, and (d) 2.7 V with t_P = 50 ns, respectively.

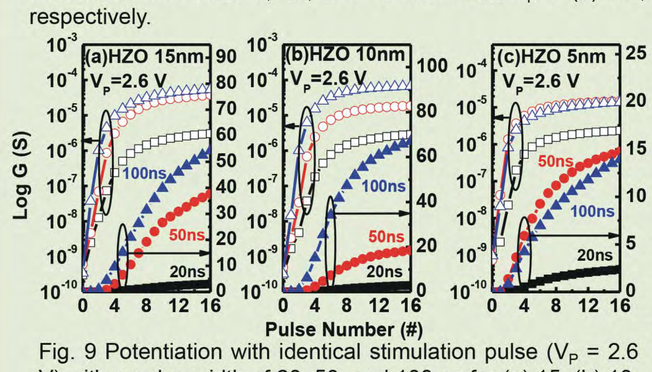

Fig. 9 Potentiation with identical stimulation pulse (V_P = 2.6 V) with a pulse width of 20, 50, and 100 ns for (a) 15, (b) 10, and (c) 5 nm HZO FeFET.

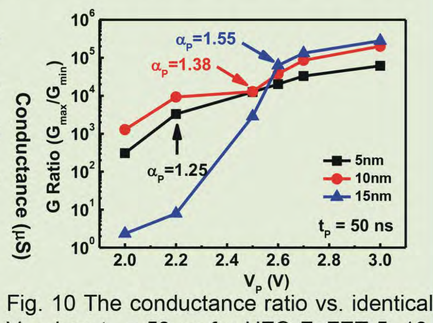

Fig. 10 The conductance ratio vs. identical V_P when t_P = 50 ns for HZO FeFET 5, 10, and 15 nm. The potentiation non-linearity α_P is also marked with the optimized value for each thickness.

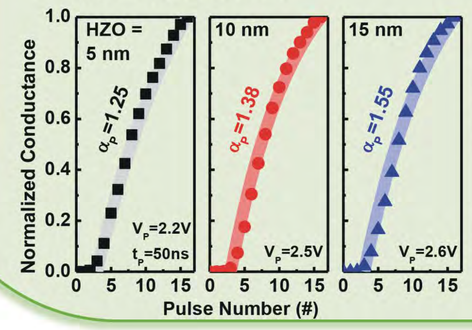

Fig. 11 The optimized potentiation non-linearity of 5, 10, and 15 nm HZO FeFET. (left figure)

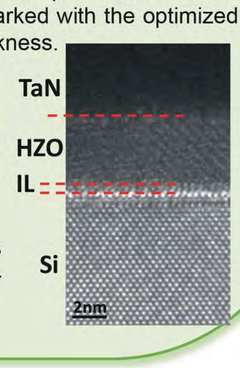

Fig. 12 The FeFET in this study for HR-TEM of 5 nm-thick HZO. (right figure)

研究生活及心得

就讀博士班所受的壓力及辛勞肯定只有博士生自己能感受到，看著同齡的朋友們在科技廠奮鬥，甚至娶妻生子，自己卻還在校園中，讓我覺得在人生階段晚人家一節。但每當看到自己發表的期刊或研究受到注目時，就堅信未來的自己肯定也能發光發熱。這次的獲獎，謝謝中技社對我的肯定，也非常謝謝我的指導教授-李敏鴻教授，這幾年從碩士班到博士班，不僅在學術上的指導，也在我求職及求學的生涯中提供我不同的目標及方向。最後謝謝一路無私支持我的父母，在我身旁為我披荊斬棘，讓我能專注在學術研究上。