High Speed, Low-power, and Multi-bit Ferroelectric Field Effect Transistor based on Freestanding 3D $SrTiO_3$ Nanomembranes

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Abstract: While ferroelectricity has been observed in layered two-dimensional crystals like $CuInP_2S_6$, In_2Se_3, etc., it has yet to be fully explored in the context of devices based on freestanding nanomembranes of 3D single crystals. In this context, realization of $SrTiO_3$ (STO) nanomembranes using hybrid molecular beam epitaxy has introduced exciting new possibilities. Bulk STO exhibits quantum paraelectricity or so called "incipient ferroelectricity" where quantum fluctuations impede ferroelectric transition. In contrast, thin STO films can display relaxor ferroelectricity in the low-temperature region when subjected to strain, stoichiometric deviation, and alloying. Here we report ferroelectricity in freestanding STO nanomembranes. Furthermore, we develop ferroelectric field-effect transistors (FeFETs) by stacking large-area STO nanomembranes and a monolayer MoS_2 film, allowing us to realize a reconfigurable neuromorphic device capable of functioning as both a synapse and a neuron. We observe ultra-fast polarization switching occurring in approximately 20 nanoseconds, low-switching voltage < 5 V, nonvolatile retention projected to extend beyond 10 years, endurance surpassing 10,000 cycles, and the ability to store 64 distinct synaptic weights or 6-bit memory storage in STO-gated MoS_2 FeFETs at 100 K. While polarization switching is observed in STO nanomembranes even at 300 K, there is significant trade-off in nonvolatile retention. By leveraging the dynamics of polarization switching at room temperature,

we use the FeFET to craft a neuromorphic inference engine, which is capable of distinguishing several distinct patterns. Our findings are particularly significant due to the low-thermal budget of 180 °C associated with the fabrication of such a 3D-STO/2D-MoS_2 FeFET stack, opening up opportunities for integration of diverse set of materials into the back end of silicon complementary metal oxide semiconductor technology for addressing challenges associated with compute-in-memory architectures and neuromorphic applications.