Investigation of Ferroelectric Properties of Oxide Superlattices at Low Temperatures: How do Strain, Dimensionality, and Polarization Compete in the Low-Dimensional Structure, $(SrTiO_3)_n(BaTiO_3)_mSrO$?

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REU Program: 2017 Platform for the Accelerated Realization, Analysis, and Discovery of Interface Materials Research Experience for Undergraduates (PARADIM REU) Program with Caltech SURF

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Primary Sources of PARADIM REU Funding: NSF Materials Innovation Platform Program, Grant # DMR-1539918; Caltech Student-Faculty Programs Summer Undergraduate Research Fellowship (SURF)

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Abstract:

The oxide superlattice $(SrTiO_3)_nSrO$ has been identified as a promising tunable dielectric for modulating frequency signals, especially at 5G gigahertz frequencies, due to its epitaxial strain to enhance tunability and defect mitigating structure that reduces charged point defects. The next generation of this material, $(SrTiO_3)_n(BaTiO_3)_1SrO$ thin films, combines two ferroelectric materials, $SrTiO_3$ and $BaTiO_3$, in a superlattice broken up with non-ferroelectric SrO layers.

This study explored the in-plane and out-of-plane ferroelectric and dielectric properties of the $(SrTiO_3)_n(BaTiO_3)_1SrO$ thin films at temperatures 80-340 K for *n* = 1, 3, and 5. Understanding the competing $SrTiO_3$'s and $BaTiO_3$'s polarizations' interactions can be useful for optimizing the material for planar and vertical devices. Measurements involved the use of Cr/Au interdigitated electrodes for in-plane characterization and a $SrRuO_3$ bottom electrode with Cr/Au circular top electrodes for out-of-plane characterization. The data was collected by combining ferroelectric and dielectric measurement software with a low temperature probe setup. By investigating dielectric constants with temperature and measuring ferroelectric hysteresis loops at 80 K, we found that in-plane shows a clear ferroelectric transition around 170-180 K and clearly shows ferroelectric properties at 80 K. Out-of-plane measurements show high leakage and did not clearly indicate ferroelectric properties.

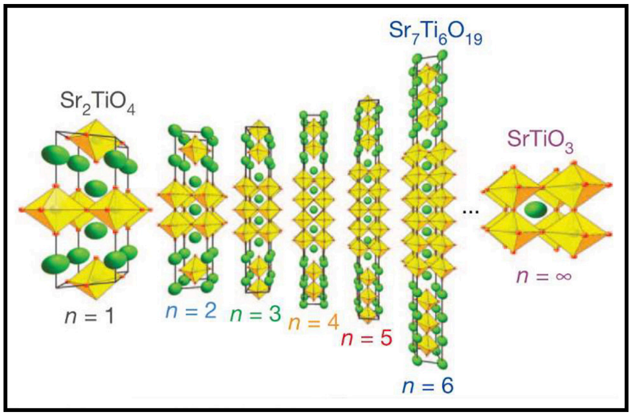


Figure 1: Structure of $(SrTiO_3)_nSrO$ [1].

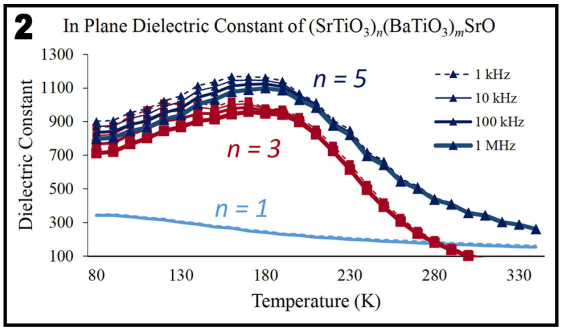
Introduction and Background:

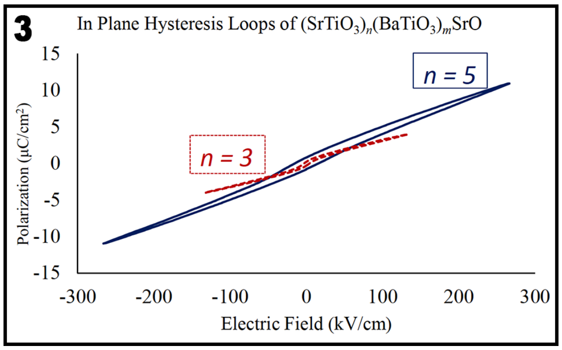
Telecommunications companies have been exploring gigahertz frequencies for 5G cell phone technologies as fertile territory to address our ever-increasing need for more data.

Prof. Darrell Schlom's group at Cornell University identified the Ruddlesden-Popper phase, $(SrTiO_3)_nSrO$ (see Figure 1 for structure), as a candidate for its low loss in bulk and reduced point defects. The resulting paper found $(SrTiO_3)_nSrO$ phases exhibited high performance levels and was highly tunable for *n* > = 3 at frequencies up to 125 GHz. The superlattice periodicity, *n*, can additionally be exploited to achieve high performance at room temperatures [1].

Results:

By investigating dielectric constants between the temperatures 80 K and 340 K and measuring ferroelectric hysteresis loops at 80 K, we found that in-plane samples show a clear ferroelectric transition around 170K at about 1000 (see Figure 2) for *n* = 3 and around 180 K at about 1100 for *n* = 5 (note: *n* as in $(SrTiO_3)_n(BaTiO_3)_1SrO$). In-plane samples for *n* = 3, 5 are clearly ferroelectric at 80 K (see Figure 3). Additionally, out-of-plane measurements have high leakage (see Figure 4) and did not clearly indicate ferroelectric properties for any value of *n* (see Figure 5 a and b for further explanations and graphs). To lower dielectric leakage for the out of plane devices, recommendations





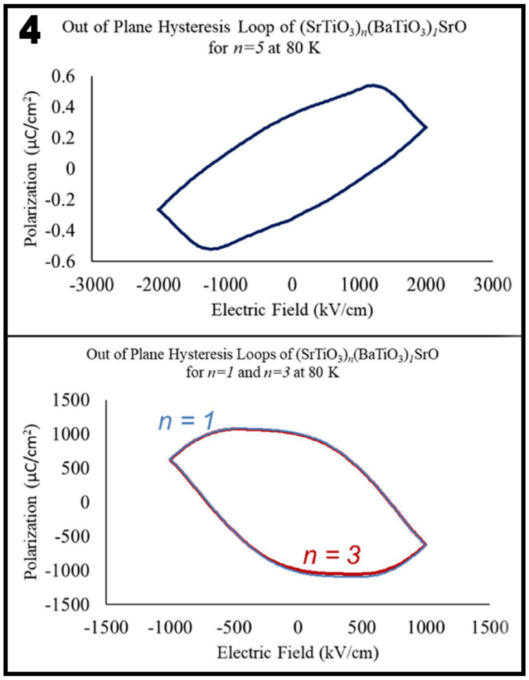


Figure 2, top left: For n *= 1, there is no peak that would be indicative of a ferroelectric transition. In contrast, for* n *= 3 and for* n *= 5, there are peaks indicating ferroelectric properties. Figure 3, bottom left: The shapes of the hysteresis loops indicate presence of ferroelectric properties (though probably not that strong). Figure 4, right: The top graph for the sample* n *= 5, while indicating reasonable looking polarization values, indicates leakage from the shape. This leakage is made much more clear in the* n *= 1 and* n *= 3 samples in the bottom graph, which shows unreasonable polarization measurements.*

are to use more oxide compatible materials for both electrodes and to use smaller pad sizes if possible (the size used was 150 μm in diameter).

Acknowledgements:

The author would like to thank Caltech SURF, PARADIM REU Program, and National Science Foundation for their support. The author would also like to thank Professor Schlom and Natalie Dawley for the opportunity to conduct this SURF project. And finally, she would like to thank to Dr. Julia Mundy for her advice and Dr. Vladimir Vladimirovich Protasenko for training on the cryoprobe equipment.

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[1] C.H. Lee, N.D. Orloff, T. Birol, Y. Zhu, V. Goian, E. Rocas, R. Haislmaier, E. Vlahos, J.A. Mundy, L.F. Kourkoutis, Y. Nie, M.D. Biegalski, J. Zhang, M. Bernhagen, N.A. Benedek, Y. Kim, J.D. Brock, R. Uecker, X.X. Xi, V. Gopalan, D. Nuzhnyy, S. Kamba, D.A. Muller, I. Takeuchi, J.C. Booth, C.J. Fennie, and D.G. Schlom, "Exploiting Dimensionality and Defect Mitigation to Create Tunable Microwave Dielectrics," Nature 502, (2013) 532-536.

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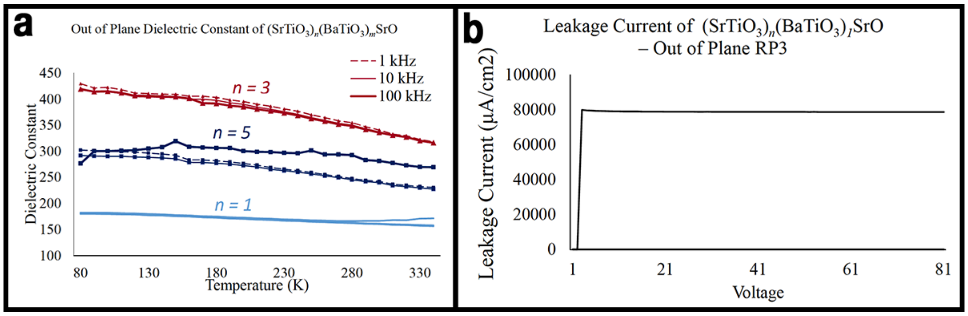

Figure 5: (a) For all of the samples measured, there is no clear peak, and therefore, ferroelectric transition indicated. Compared to in-plane, out-of-plane dielectric constants are much lower. (b) This measurement shows that for even voltages as low as perhaps 5V, the leakage current measured is extremely high.