Intrinsic dead layer in MIM capacitor devices

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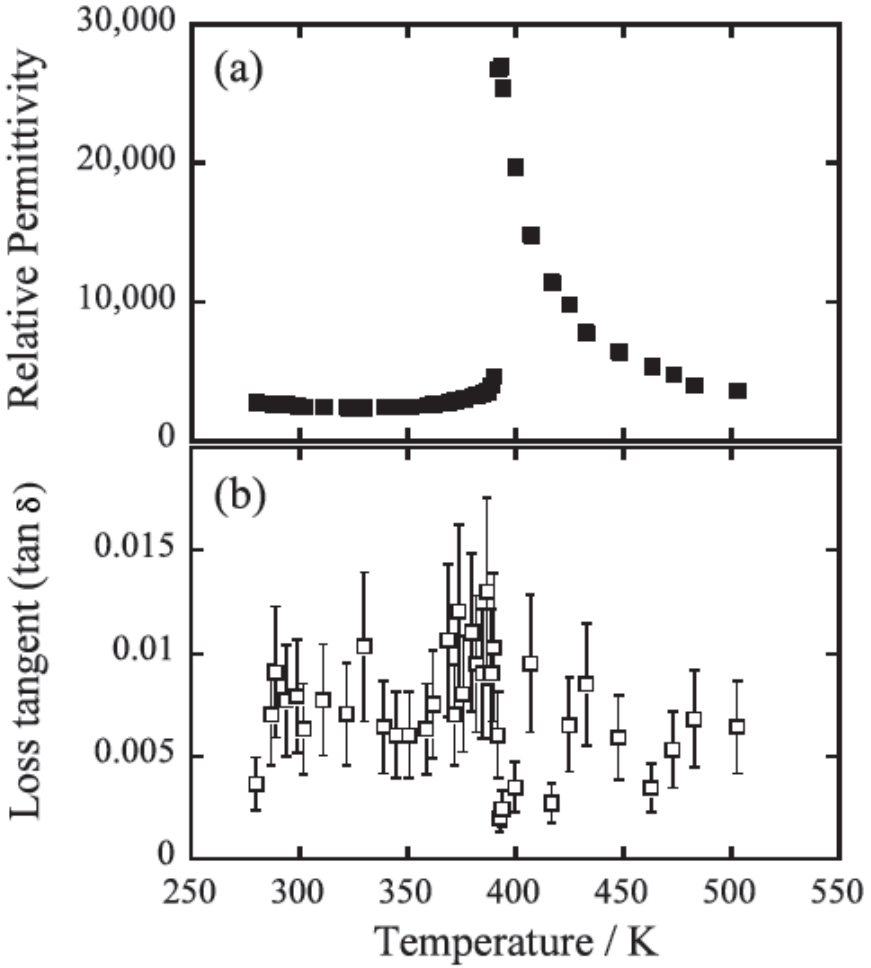
Prof. Xu's Group meeting

Reduced capacitance in nanocapacitors

1. Capacitor——largest components in circuits
2. High-permittivity insulator like $SrTiO_3$——reduced capacitance!?
3. For ferroelectrics in nanoscale, coercive fields increase, tunability decreases and permittivities are severely suppressed, often by several orders of magnitude.
4. Interfacial dead layer——1) a low permittivity interfacial capacitance is intrinsic and unavoidable: an inevitable consequence of the physics of joining a material which sustains an internal polarization (the ferroelectric), to one which does not (the metal); ——**OR**——2) entirely extrinsic in origin, and not fundamental at all, arising from imperfections in thin film processing or device design (defects and strains at interface)?

No “size effect”?



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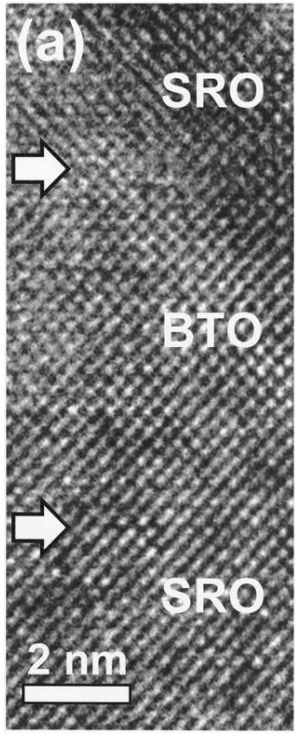
LETTER TO THE EDITOR

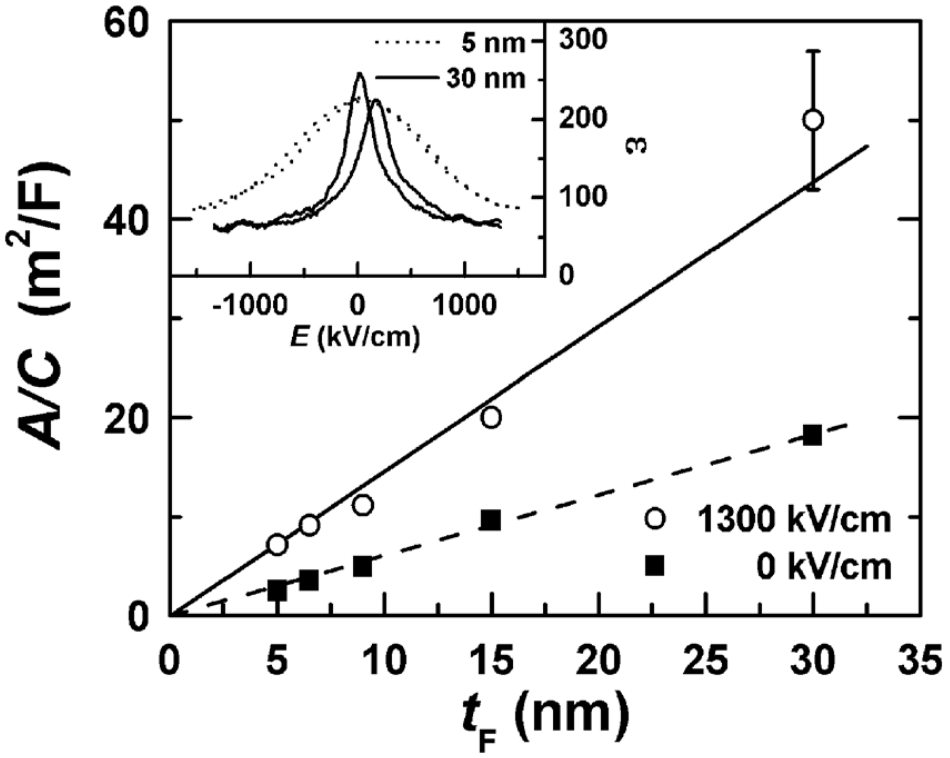
Intrinsic dielectric response in ferroelectric nano-capacitors

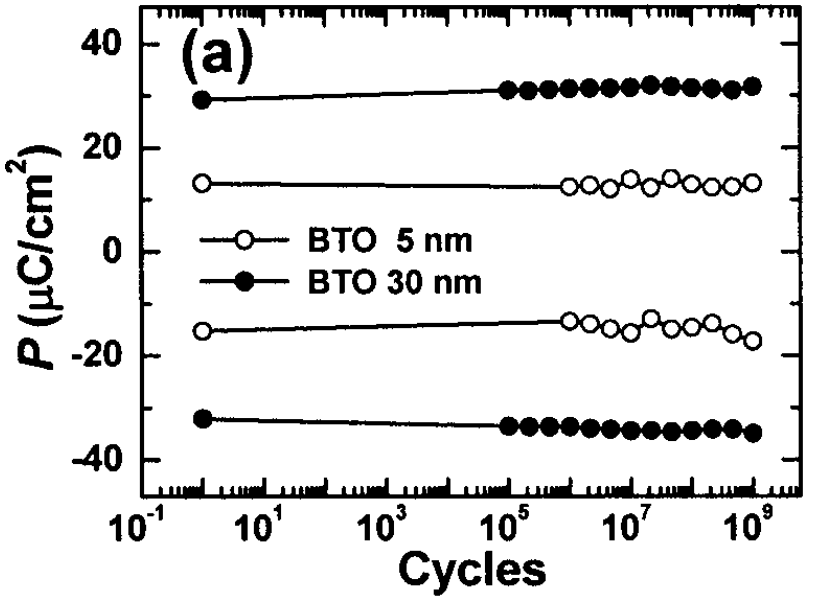
M M Saad[1], P Baxter[1], R M Bowman[1], J M Gregg[1], F D Morrison[2] and J F Scott[2]

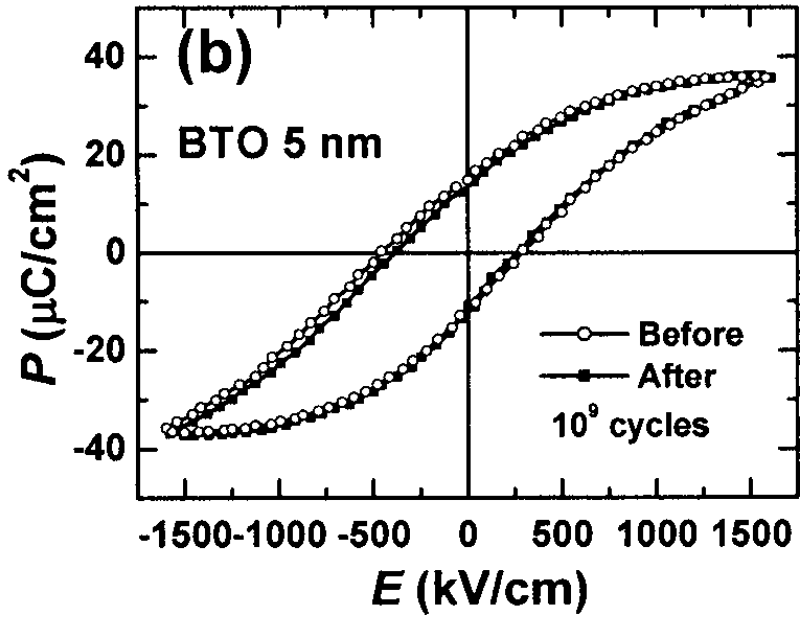
- The focused ion beam microscope has been used to fabricate thin lamellae of single crystal BaTiO3 (75nm), with gold evaporated on the lamellar walls to form parallel-plate capacitor structures.
- There is a notable absence of any broadening or temperature shift of the dielectric peak.
- The dielectric response is that expected from bulk single crystal, with none of the changes in behavior seen in conventionally grown systems, universally accepted as size effects.

Free from passive layers



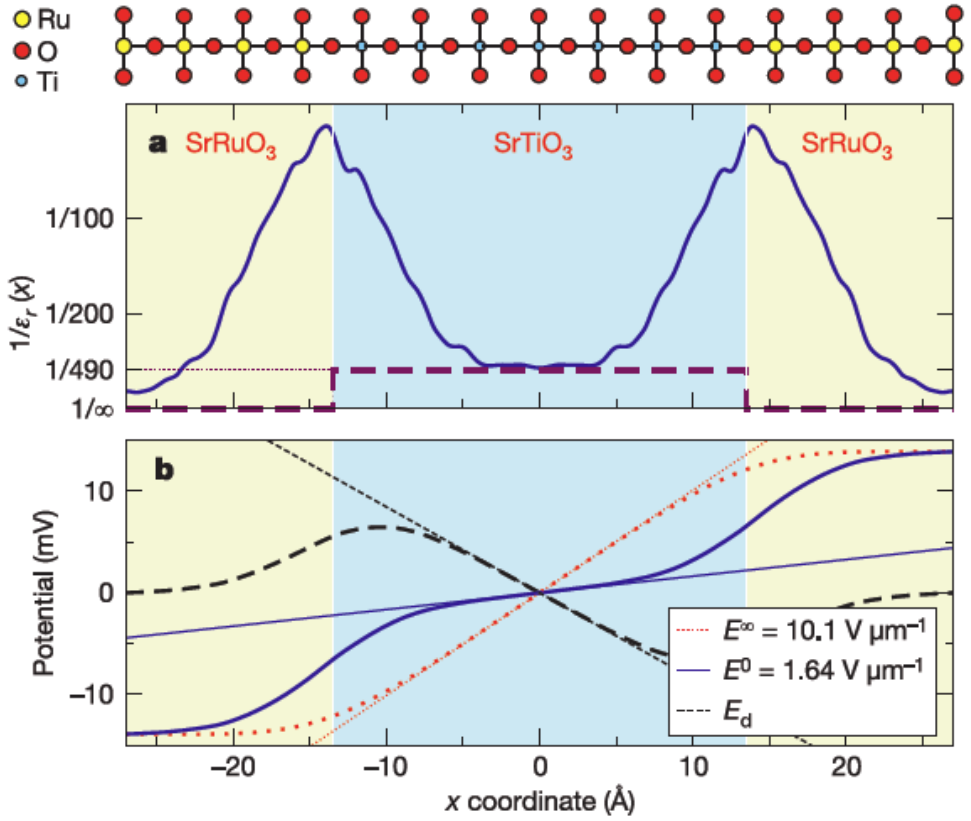


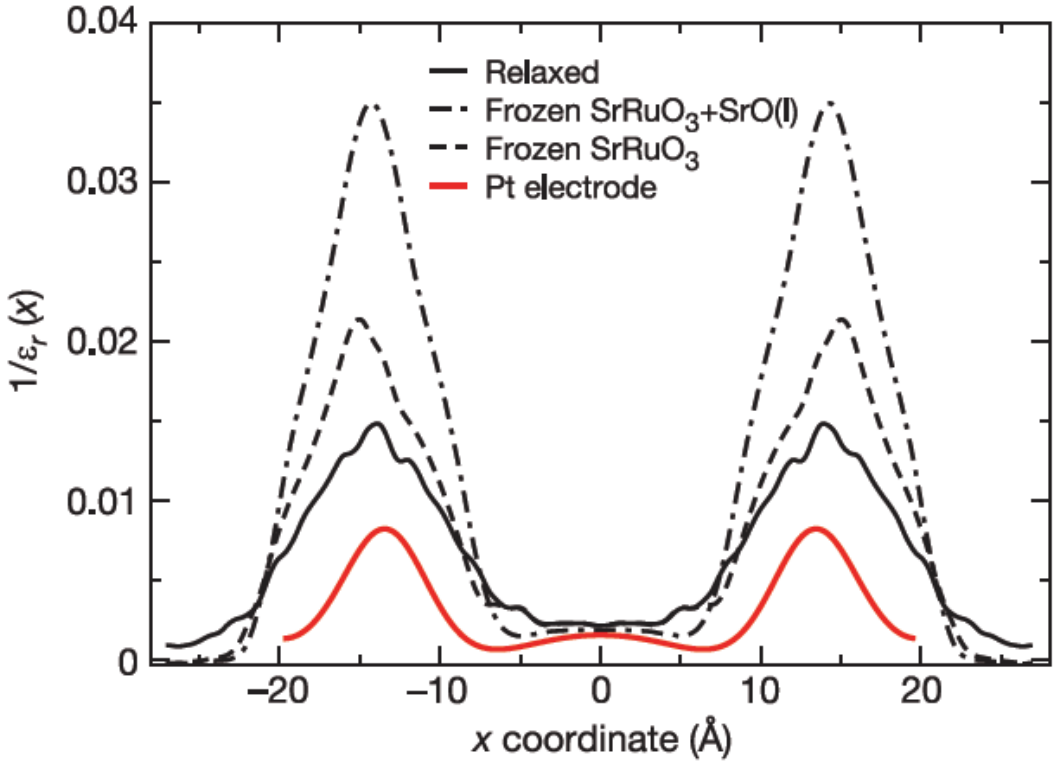




- No extrinsic electrical effects due to either the formation of an insulating interfacial passive layer or passive-layer-induced charge injection.

Intrinsic dead layer–incomplete screening





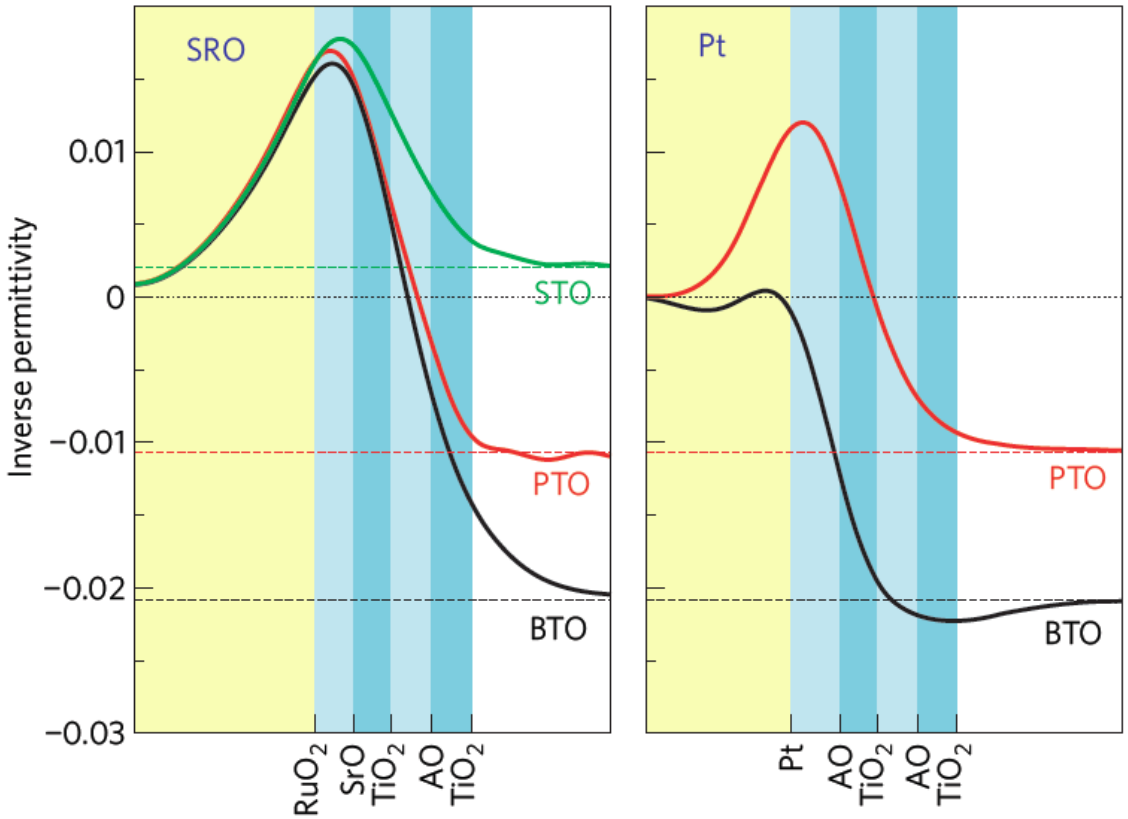
- Intrinsic dead layer with lower permitivity stems purely from **the fundamental quantum mechanical** and **electrostatic properties of the ideal metal–insulator interface**.

Nature 443, 679 (2006)

Local chemical environment-negative dead layer

- AO-terminated perovskite ferroelectrics can show a strong interfacial enhancement of the ferroelectric properties when weakly bonded to a simple metal.

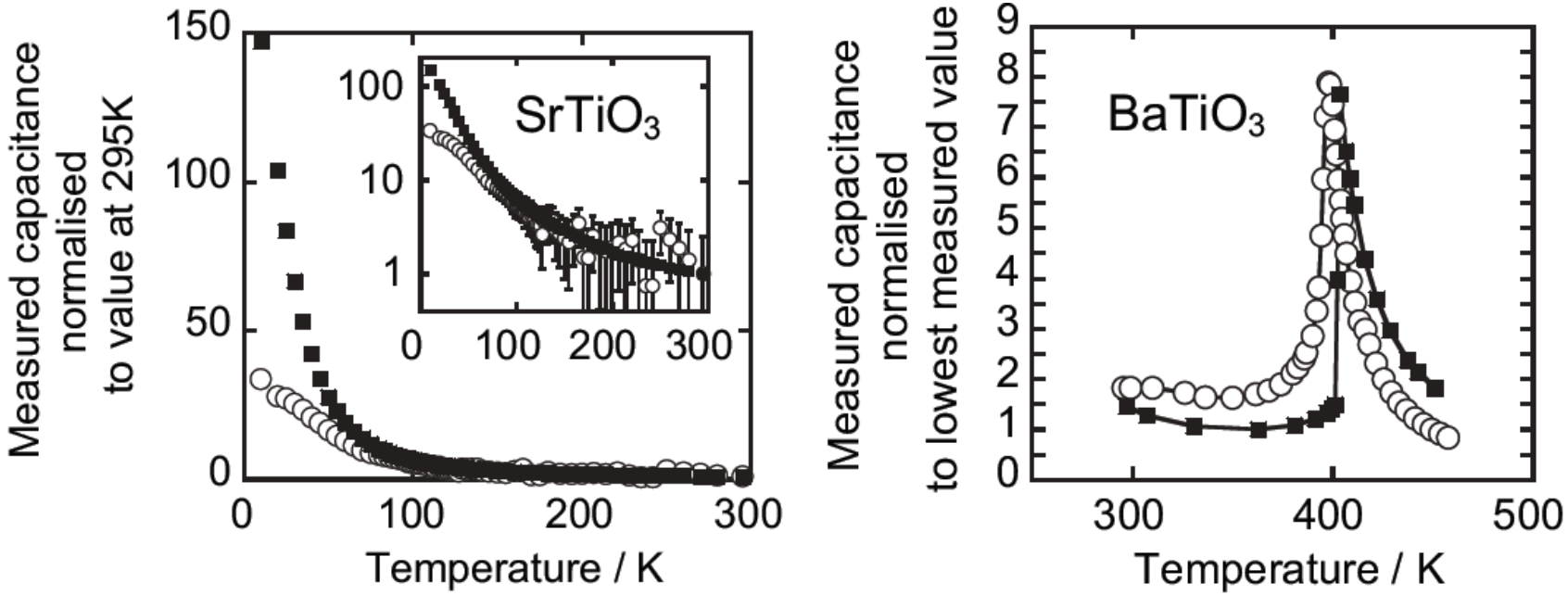
	N	$C^{-1}S$ ($m^2\,F^{-1}$)	$C_i^{-1}S$ ($m^2\,F^{-1}$)	N_{crit}	λ_{eff} (Å)
BTO-SRO	6.5	−1.553	2.280	4.85	0.202
PTO-SRO	6.5	0.439	1.727	7.45	0.153
STO-SRO*	6.5	3.876	1.647	—	0.146
PTO-Pt	8.5	−1.427	1.258	5.42	0.111
BTO-Pt	8.5	−7.920	0.037	0.08	0.003



Nature Materials, 8, 392 (2009)

Settling the "Dead Layer" Debate in Nanoscale Capacitors

By *Li-Wu Chang, Marin Alexe, James F. Scott,* and *J. Marty Gregg**



- Inherent dead layers occur in SrTiO3 single crystal thin film capacitor structures with platinum electrodes, which do not exist in analogous structures involving BaTiO3.

Advanced Materials 21, 4911 (2009)

Conclusion

- The **incomplete screening of the depolarizing field** is an intrinsic property of the metal/ferroelectric interface as a whole and is responsible for the experimentally observed detrimental effects on the ferroelectric properties of ultrathin films. The associated finite effective screening length, however, depends critically on the **stiffness of the electrode-oxide bonds**, and while for many combinations of metals and ferroelectrics it is unavoidable, a careful choice of electrode cannot only reduce this screening length but, in some cases, can even lead to **interface-induced enhancement of ferroelectric** properties