

# Quantum Phase Transitions and Superconductivity in Calcium



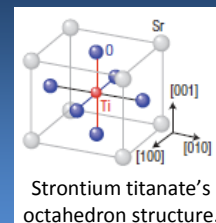
## Doped Strontium Titanate

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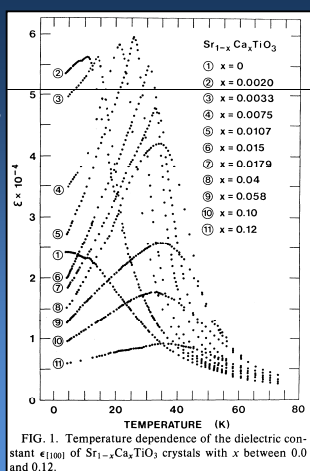
### Introduction:

Strontium Titanate ( $\text{SrTiO}_3$ ) is a quantum paraelectric, an insulating dielectric material that approaches a state of ferroelectricity, but never achieves it as its temperature approaches absolute zero. Recent research<sup>2</sup> suggests however, that in a field effect transistor (FET) geometry charge may be induced into  $\text{SrTiO}_3$ , and metallic properties and superconductivity can be achieved at temperatures slightly above absolute zero. We have procured single crystals of Calcium doped Strontium Titanate ( $\text{Sr}_{1-x}\text{Ca}_x\text{TiO}_3$ ) with a calcium concentration of  $x=0.06$ . This material actually undergoes a transition to ferroelectricity at temperatures substantially above absolute zero<sup>1</sup>. We plan to measure its dielectric constant as a function of temperature. If the result of this measurement indicates that a sharp enough ferroelectric transition occurs, then we will test the material in a FET geometry and attempt to induce metallic properties in  $\text{Sr}_{1-x}\text{Ca}_x\text{TiO}_3$ . If this is found to be possible, the next step would be to try to search for superconductivity.



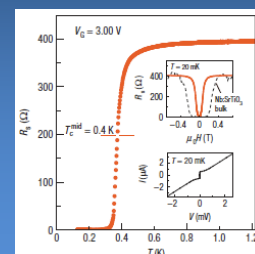
### Related Research:

Superconductivity-Insulator transitions have been observed in pure single crystals of strontium titanate, and are believed to exemplify a quantum phase transition<sup>3</sup>. The quantum phase transition (QPT) occurs as a result of the softening of the modes of the crystalline structure's vibrations. Along with the QPT comes electronic property changes such as the possibility of induced ferroelectricity and even superconductivity. QPT's occur at what is called the critical temperature ( $T_c$ ). One variable that can modify this is doping concentration. The figure to the right displays the  $T_c$  of several different calcium concentrations in  $\text{Sr}_{1-x}\text{Ca}_x\text{TiO}_3$ .



The concentration we are most concerned with is  $x=0.06$ , which is curve (9) in the figure. The purpose of this research is to search for metallic properties and superconductivity in the non-zero temperature regime. As can be seen the QPT of the  $x=0.06$  concentration is just below 40 K.

The curve to the right shows the resistance of  $\text{SrTiO}_3$  as a function of temperature; the occurrence of superconductivity. It also shows the QPT of pure  $\text{SrTiO}_3$  which is around 0.4 K.

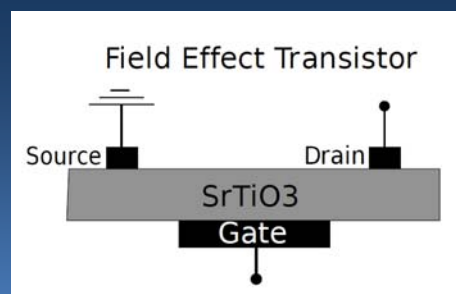


### Experimental Process:

Using a pure single crystal of  $\text{Sr}_{1-x}\text{Ca}_x\text{TiO}_3$  with a calcium concentration of  $x=0.06$  we will attach electrodes by thermal evaporation. Then we will measure the dielectric constant as a function of temperature using an alternating current process. The dielectric constant should diverge as the temperature approaches zero, and this point of divergence is the critical temperature, the temperature at which a quantum phase transition occurs. If the divergence of the dielectric constant is highly defined, then it implies the possibility of induced ferroelectricity and superconductivity.

### Goal:

To explore the possibilities of higher temperature ferroelectricity and superconductivity in strontium titanate that is both electrostatically and chemically doped. If discovered, this would be a very interesting phenomenon.



The field effect transistor geometry (pictured above) is the basic method for modifying charge carrier density<sup>3</sup>. This is used to explore the physical properties of the Strontium Titanate. We will employ this 2-dimensional system to study the electronic properties of calcium strontium titanate.

### Literature:

- 1) J. G. Bednorz; K. A. Müller.  $\text{Sr}_{1-x}\text{Ca}_x\text{TiO}_3$ : An XY Quantum Ferroelectric with Transition to Randomness. The American Physical Society. 1984, 52, 2289-2292.
- 2) K. Ueno; S. Nakamura; H. Shimotani. Electric-field-induced Superconductivity in an Insulator. Nature. 2008, 7, 855-858.
- 3) K. A. Parendo; K. H. Sarwa B. Tan; A. Bhattacharya. Electrostatic Tuning of the Superconductor-Insulator Transition in Two Dimensions. The American Physical Society. 2005, 94, 1-4.