Using defects to create ceramics with giant permittivity as ultracapacitors

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Abstract

Dielectrics with a high and weakly-temperature-dependent permittivity are highly desirable for the development of high performance energy storage devices. It is well known that ferroelectrics (FEs) exhibit a high permittivity that is strongly dependent on the temperature due to phase transition.
In this project, the FE $BaTiO_3$ (BTO), based ceramics are developed as ultra-capacitors by introducing defects to eliminate the phase transition and enhance the permittivity. The ceramics are fabricated using a unique process: BTO nanoparticles are coated with a nano-layer of SiO_2 and, then, sintered in vacuum using SPS process.
The ceramics exhibit a giant permittivity and many other unique properties.

Motivation

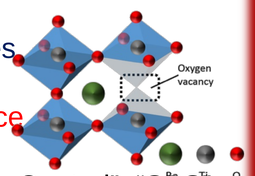
Today & Future Demands

Objective

BTO

Ferroelectric properties

Temperature dependence



"Vacuum Treated", "SiO_2 Coated", "SPS"

➔ Giant permittivity and high energy density with good stability
➔ Negative Permittivity with a low Plasma Freq

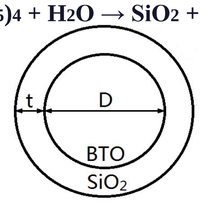
Fabrication

Vacuum Treatment: Inducing Defects (Oxygen Vacancy)

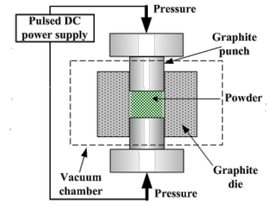
Sol-Gel

Chemical Coating of BTO powder

$Si(OC_2H_5)_4 + H_2O \rightarrow SiO_2 + C_2H_5OH$



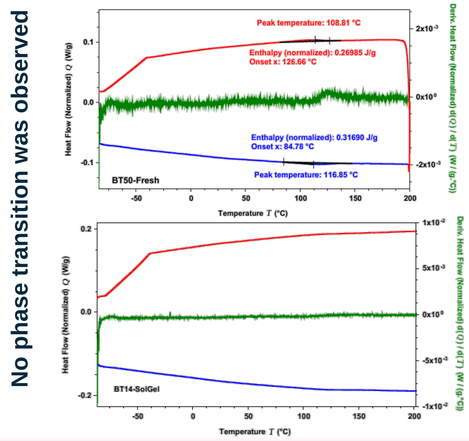
Spark Plasma Sintering (SPS)



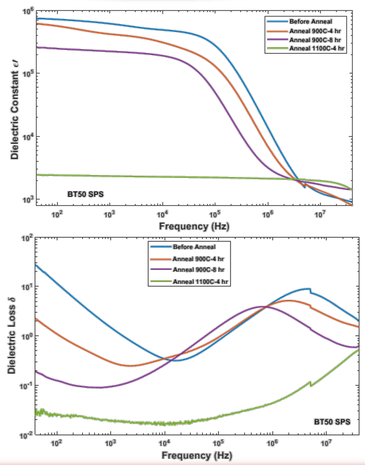
Heat to 1050 C-1100 C

DSC

Temperature independency



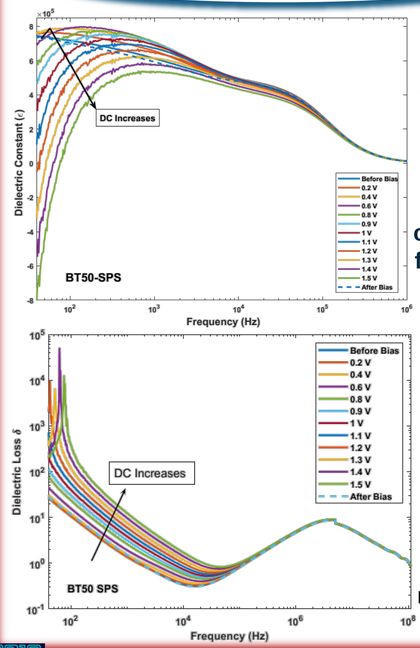
Dielectric behavior



Giant permittivity directly determined by fabrication condition

Acceptable Loss

DC Bias Effect



➔ **Tunable permittivity with a giant tunability**

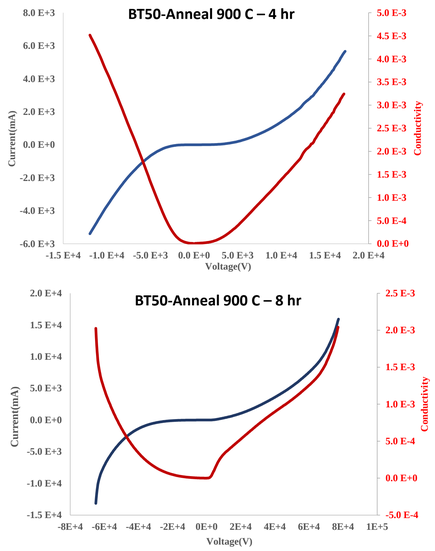
The permittivity can be tuned from ~ 10^5 to ~ -10^5 even -10^6

➔ **Negative permittivity with a low plasma frequency**

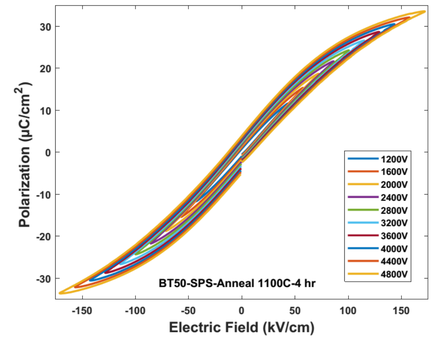
A new mechanism!

Thermal Annealing & I-V Curve

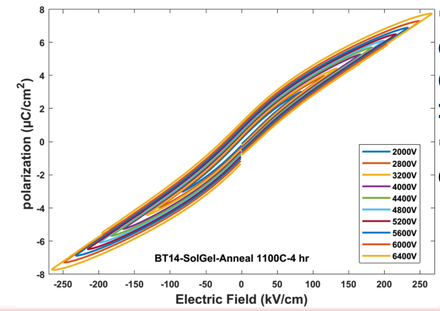
Nonhomogeneous structure p-n junction behavior



P-E Loop

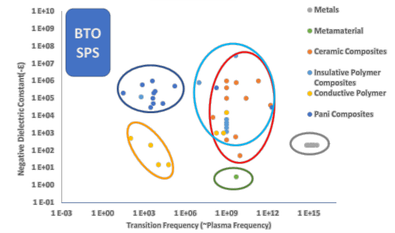


➔ **High polarization**
➔ **High electrical breakdown field up to 27 MV/m**



➔ **High energy density of > 3 J/cm³**
➔ **High efficiency**

Achievement



Unique Material Properties

Conclusion

The unique processes developed in this project can be used to fabricate the ultra-capacitors and dielectric materials, such as

1. Ultra-capacitor with **High energy density with a high efficiency**
2. Ultra-capacitors exhibit a **giant permittivity** (up to 10^6)
3. Permittivity exhibits a **giant tunability** > 100%
4. **Giant negative permittivity** with a low plasma frquency
5. **p-n junction** like behavior in a ceramic sample.

Future Work

- Optimize the process to maximize properties for different applications
- Fundamental understanding of the unique and abnormal properties observed in the ceramics.

Acknowledgement

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