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Research Field: Condensed Matter Physics
Expected Semester of Graduation: Spring 2018

Growth of Crystals with Electric Dipole Moments for Use as Dielectrics

Abstract:

The project concerns the growing of ferroelectric crystals for use as dielectrics. The crystals are grown in the lab and are analyzed though x-ray diffraction. These crystals are unlike normal crystals as they have electric dipole moments. Their dielectric properties can be measured. Eventually these crystals may have applications such as increasing the signal range of the devices such as phones and computers.

Prospectus:

Every year, technology advances, and more efficient technology is produced. My research focusses on growing crystals for use as dielectrics. Capacitors are widely used in most electronic devices and are essential to most basic circuits. In recent years there has also been an increasing interest in supercapacitors in an effort to make better capacitors. Supercapacitors can store more charge than regular capacitors and try to bridge the gap between capacitors and batteries. The crystals for this research project will have a molecular rotation because they have electric dipole moments. We hope to make better dielectrics. These dielectrics can be used to increase the signal range of electronic devices, such as phones or computers. They can also be used in adaptive circuits and communication systems [1].

The crystals grown in the lab are currently hydrated crystals. The crystals are grown using supersaturated solutions of the salt. Cupric Sulfate Pentahydrate ($CuSO4{\cdot}5H2O$), was first grown followed by Nickel Sulfate Hexahydrate ($NiSO4{\cdot}6H2O$). The Nickel Sulfate proved to be a suitable material for growing crystals since the volume of the water did not decrease after mixing the salt. A common method for growing crystals is using supersaturated solutions of the salt [2]. This was the method used in the lab, but had some shortfalls and so vapor diffusion was used. The crystals once grown can be examined under a microscope and using x-ray diffraction. Nickel Sulfate Hexahydrate can also be grown under a magnetic field to increase the quality of the crystals. Since the material is ferromagnetic, by applying a magnetic field opposing the force of gravity, sedimentation could be stopped. By increasing the magnetic field strength convection can be stopped, which causes the crystals to grow slower, and thus creates better quality crystals [3].

The crystals are examined under an x-ray diffractometer and the data is analyzed to determine properties of the material, such as crystal properties and phase transition. Ferroelectrics also undergo a phase transition that can be dependent on temperature. As a result, the crystals will also be examined under variable temperature to test the temperature dependence of the dielectric properties of the crystal. After these tests the crystals can then be used as a dielectric in a capacitor, and the dielectric constant of the material can be measured. A material with many electric dipole moments correlates to a higher dielectric constant which is preferred [4-7]. For Nickel Sulfate Hexahydrate, it is still not clear whether the crystals grown in the absence of a magnetic field are of a high enough quality to produce acceptable x-ray diffraction data. In the future, organic molecules might be used instead of the hydrated crystals used currently.

Bibliography:

[1] "Adaptive Electronics with Ferroelectric Capacitors," T.S. Kalkur, Y. Zhang, *Integrated Ferroelectrics*, **125** (2011).
[2] Holden, Alan and Phylis Morrison. *Crystals and Crystal Growing*. MIT Press, 1982.
[3] "Suppression of Convection Using Gradient Magnetic Fields during Crystal Growth of Ni SO 4· 6 H 2 O," Poodt, P. W. G. et al, *Applied Physics Letters*, **87** 214105 (2005).
[4] "Molecular ferroelectrics: where electronics meet biology," J. Li et al, *Physical Chemistry Chemical Physics*, **15** 20786 (2013).
[5] "Organic ferroelectrics," S. Horiuchi and Y. Tokura, *Nature Materials*, **7** (2008).
[6] "Dielectric Behavior of Hydrated Crystals. IV. Cupric Formate Tetrahydrate Cu (HCO2) 2· 4H2O" H. Ibamoto, *Bulletin of the Chemical Society of Japan*, **35** 1199 (1962).
[7] "Directionally tunable and mechanically deformable ferroelectric crystals from rotating polar globular ionic molecules," J. Harada et al, *Nature Chemistry*, **8** (2016).
[8] "Ferroelectric instability of two-dimensional crystals," A. Mikhailov, *Physical Review B*, **88** 195410 (2013).
[9] Jona, Franco and G. Shirane. *Ferroelectric crystals*. New York: Dover Publications, 1993.

Timeline:
October 2015
- Joined Research group

Until December 2016

- Crystal growing basics for the first year
- Growth and study of Nickel Sulfate and Cupric Sulfate

Until August 2017

- Growth and study of Rochelle salt

September 2017

- Began growth and study of Triglycine Sulfate

October 2017

- Dielectric spectroscopy
- Study of ferroelectric transition

October 15th

- Start writing Thesis

By December 15th:

- Complete main research activities
- Have a first draft of thesis
- provide initial draft to advisor for feedback

By January 15th :

- Have a second draft of thesis

By February 24th

- provide polished thesis to committee that incorporates research advisor's feedback (>1 week prior to defense)

By February 15th :

- Have a final draft of thesis

By March 31st :

- Defend thesis.