FMRI RET 2017-Synthesis and Characterization of Nanocomposities for 3D Printed RF Devices

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Abstract

Current RF antenna design is limited to two dimensions due to the limitations of manufacturing. 3D printing provides the opportunity to create entirely new RF antenna designs based in three dimensions provided a composite can be created using a favorable thermoplastic with a high-k dielectric, low-loss tangent ceramic filler. In this study, high-k, low-loss, barium strontium titanate (BST) ceramic nanoparticles were created by high energy ball milling with and without surfactant to prevent clumping. The nanoparticles were then integrated into a cyclic-olefin polymer (COP) thermoplastic matrix in various ratios, with and without a surfactant, and extruded into 3D printing filament using a Filabot EX2 extrusion system. Once the filament was extruded thin-sheet samples were printed on a Lulzbot TAZ 6 fused deposition modeling (FDM) 3D printer and the materials permittivity and loss-tangent were characterized at wide frequencies in the microwave (GHz) band by a cavity resonator. By changing the ratio of COP to BST the optimal mixture was determined. This research laid the groundwork necessary to test many other combinations of ceramics and thermoplastic polymers in the future.

Background

Additive manufacturing, specifically FDM 3D printing, is an exciting new technology that has the potential to radically change how devices are designed and manufactured. No longer will engineers be limited to two dimensional designs and can instead create 3D structures for devices. As such a 3D printable filament with favorable dielectric properties must be produced. The chosen thermoplastic must be high strength, chemically inert, have a high enough relative permittivity (ε_r) with a relatively low loss tangent (tan *δ)*.

Research done at the Center for Wireless and Microwave Information System (WAMI) at the University of South Florida (USF) has shown that COP, as opposed to the popular 3D printing thermoplastic acrylonitrile butadiene styrene (ABS), has the most favorable properties. While COP has a slightly lower permittivity as compared to the ABS (2.12 vs 2.37), it has a considerably lower loss-tangent (0.0009 vs 0.0055)[1], a more important property for a thermoplastic matrix. COP is also more chemically inert and has a higher glass transition temperature (T_g) and melting temperature compared to ABS making it more durable when used in the field[1].

WAMI has gone on to integrate high-k ceramics into COP to create composites with high dielectric constants but also a relatively high loss[2]. Another group has found promise with the specific ceramic, barium strontium titanate (BST). They found that when integrated into the similar thermoplastic cyclic-olefin copolymer (COC) that it yields an even higher permittivity and lower loss[3]. Their approach, however, was limited to printing a nanoink with an Aerosol Jet printer and not true 3D printing via FDM. This work focuses on integrating previous findings to synthesis and characterize the dielectric properties for several variations of a 3D printable COP-BST composite.

Objectives

- Develop the process to synthesize 2.85 mm COP-BST filament with the Filabot EX2 extruder system to be printed on a Lulzbot TAZ 6 FDM printer
- Create several variations of 2.85 mm COP-BST filament while varying the concentration of BST and use of a surfactant
- 3D print thin film samples (~60mm X ~60mm X ~1.4mm) on the Lulzbot TAZ 6
- Characterize the dielectric properties of the thin films using a cavity resonator

Approach

Create raw composite for filament extrusion

- High energy ball mill BST with and without surfactant for 5 hours
- Dissolve and mix COP, solvent, and BST powder using magnetic stirrer and ultrasonic cell disruptor
- Pour out composite and allow all of the solvent to evaporate
- Pulverize composite for use in Filabot EX2 extrusion system

Fig 1. BST powder in container for ball milling

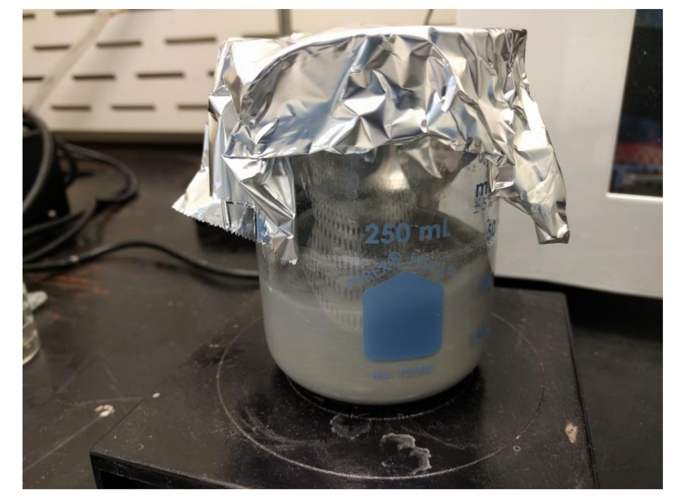

Fig 2. BST powder, COP, and solvent stirring together

Extrude filament for 3D printing using Filabot EX2 extrusion system

- Set Filabot EX2 to 250 °C and add raw COP pellets into hopper
- Run raw COP through Filabot EX2 to clean out impurities until COP comes out clear
- Add pulverized composite into hopper and allow to extrude
- Adjust speed of extruder and spooler until filament diameter is consistent at ~2.85 mm

Fig 3. Filabot spooler

Fig 4. Filabot EX2 filament extruder

Print thin films with Lulzbot TAZ 6 3D printer

- Load model into slicer and set print temperature to 280 °C with diameter to the actual filament diameter
- Add glue stick to PEI print bed surface to assist with adhesion and allow the printer to print

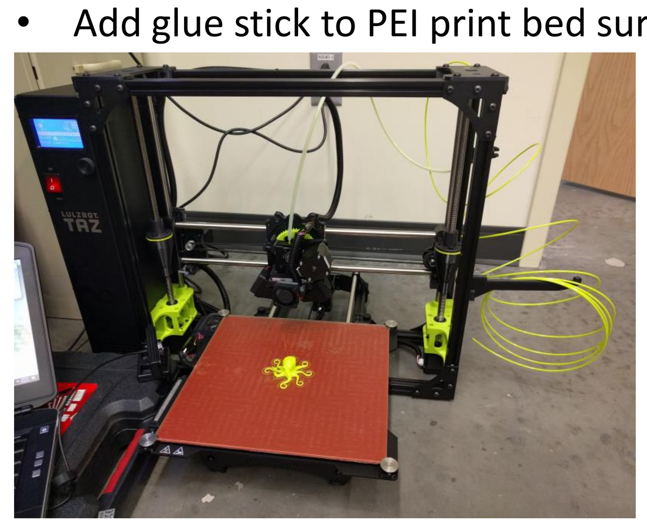

Fig 5. Lulzbot TAZ 6 3D Printer

Fig 6. Failed Thin Sheet Print

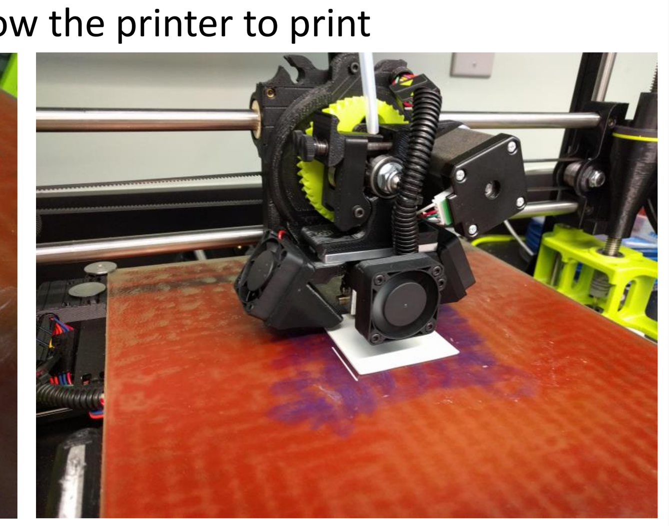

Fig 7. Successful Thin Sheet Print

Test dielectric properties of 3D printed thin films in cavity resonator

- Measure actual thickness of thin sheets and test dielectric properties at 1-7 GHz frequencies

Conclusions

Below are the results for samples of pure COP, 15% v/v COP-BST without surfactant, 15% v/v COP-BST with surfactant, and 30% v/v COP-BST without surfactant.

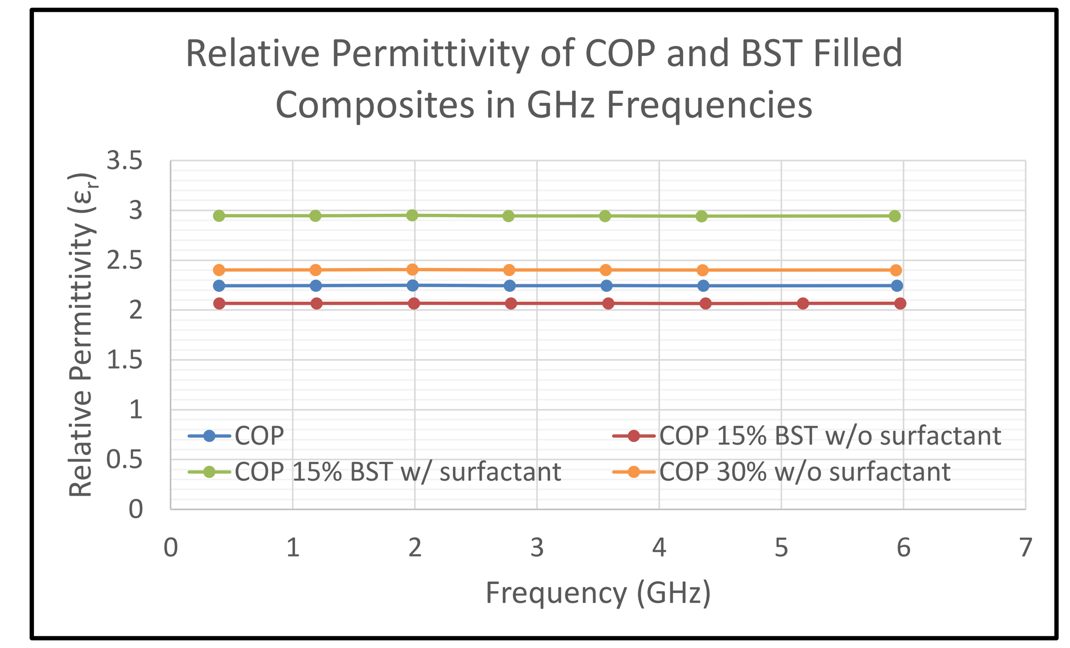

Fig 8. Relative permittivity of thin sheet samples

The 15% v/v sample with surfactant yielded the highest permittivity, even over the 30% v/v sample without the use of a surfactant. This gives evidence to the benefits of a surfactant in increasing particle dispersion and ensuring smaller BST particle size.

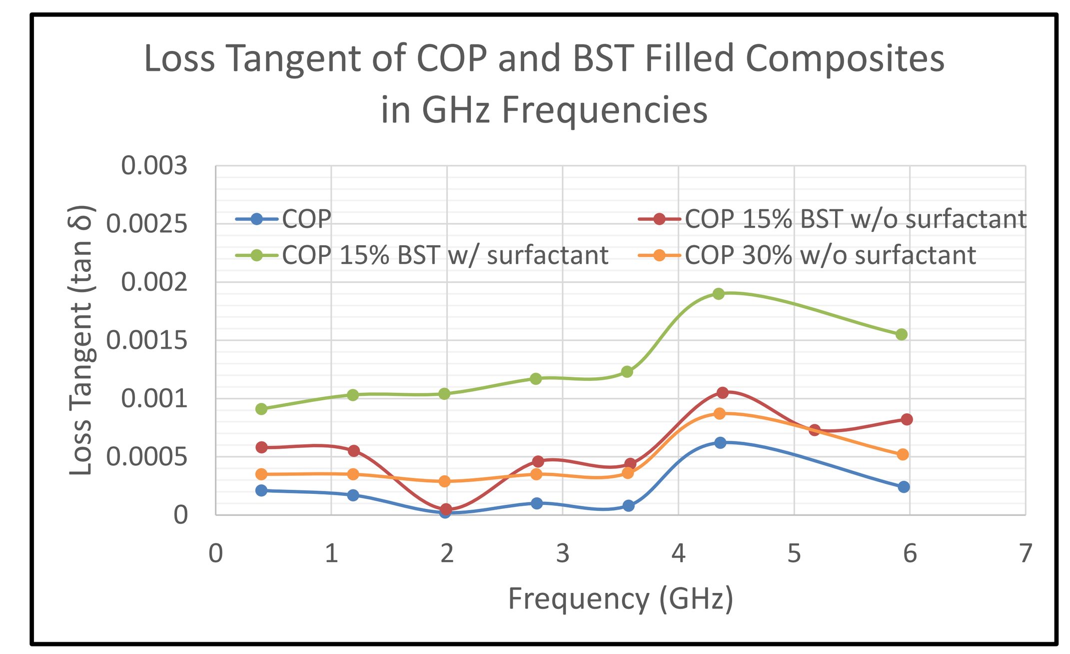

Fig 9. Loss tangent of thin sheet samples

The 15% v/v sample with surfactant also yielded the highest tangent-loss among all of the samples. This loss, however, is still much lower than that found with a COP BST composite from previous research[2].

These results are excellent and give a solid footing for further research. From here more samples will be created using even more variance in the concentration of COP-BST and with/without the use of surfactants. Additional research and characterization of the effects of using a surfactant need to be looked at to see what it actually is doing to the nanostructures of the composite. Other surfactants should also be looked at to allow a higher permittivity but with a lower loss than found here.

Referenced Resources

1. Castro, J., Rojas-Nastrucci, E. A., Ross, A., Weller, T. M., & Wang, J. (2017). Fabrication, Modeling, and Application of Ceramic-Thermoplastic Composites for Fused Deposition Modeling of Microwave Components. *IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES,65*(6), 2073-2084.
2. Castro, J., Rojas, E., Ross, A., Weller, T., & Wang, J. (n.d.). High-k and Low-Loss Thermoplastic Composites for Fused Deposition Modeling and their Application to 3D-Printed Ku-Band Antennas. doi:10.1109/MWSYM.2016.7540068
3. Haghzadeh, M., Armiento, C., & Akyurlu, A. (2017). All-Printed Flexible Microwave Varactors and Phase Shifters Based on a Tunable BST/Polymer. *IEEE TRANSACTIONS ON MICROWAVE THEORY AND TECHNIQUES,65*(6), 2030-2042.

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