FMRI RET 2015-Synthesis and Characterization of Nanocomposite Materials for 3D Printed Devices

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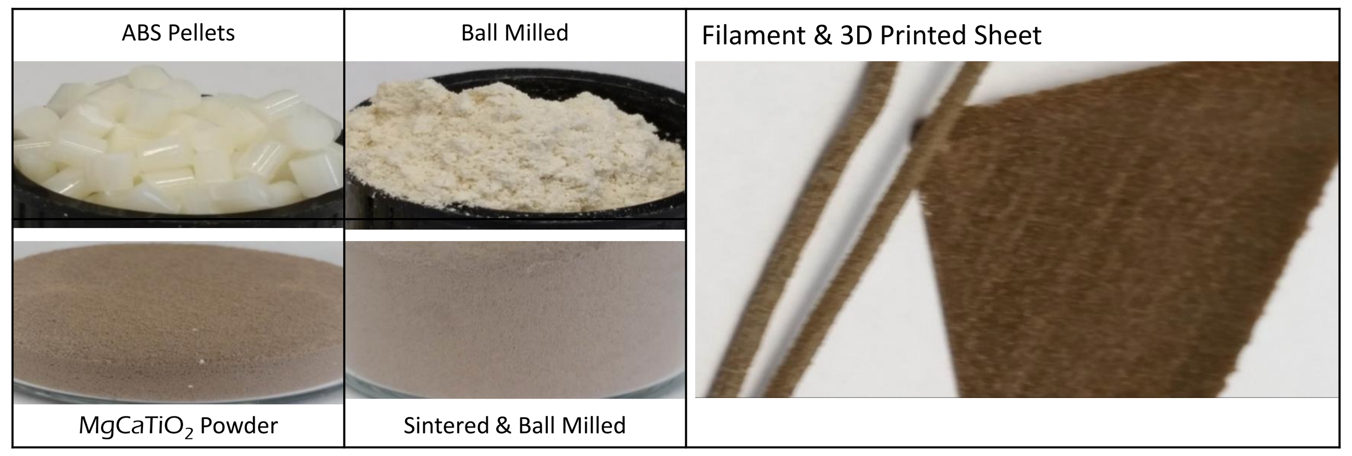
Abstract

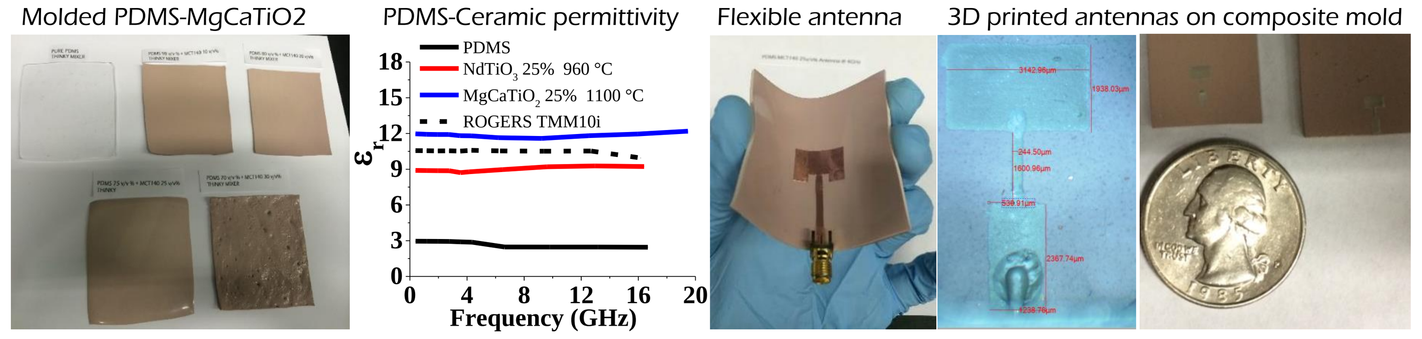
Ceramic materials have a high permittivity due to their excellent dielectric properties and polymer plastics have low-loss tangent and low melting point. The two materials combined into a composite offer two properties desired in applications of radio frequency (RF) and microwave devices such as antennas. In this study, $MgCaTiO_2$ ceramic powder (sintered and ball milled) was used as fillers with acrylonitrile butadiene styrene (ABS) powder (ball milled from pellets) to obtain a homogeneous mixture with dispersant agent. The mixture was then extruded with a Filabot extruder to produce filament for 3D printing. The ~1.4mm filament was printed into a thin-sheet specimen to characterize the permittivity and loss-tangent of the composite at wide frequencies up to 20GHz. Polymer-ceramic composites will improve the process of making RF and microwave antennas into a single step through 3D printing.



Background

In 2006, J. Volakis, et al. conducted a performance assessment of polymer composite of PDMS and different ceramic powders to reach a permittivity (ε_r) ~20 and loss-tangent ($\tan\delta_d$) ~0.009. In 2012, D.Cure, et al. reported similar composites implemented in antennas and in 2014 Shi, et al. reported composites with measured ε_r ~8.40 and $\tan\delta_d$ ~0.017 up to 10GHz.

Currently J. Wang, et al. have adopted a fabrication method to employed PDMS-ceramic composites to produce flexible and smaller antennas, through 3D printing. The results (below) show great promise and a new method is being formulated to produce 100% 3D printed antennas.

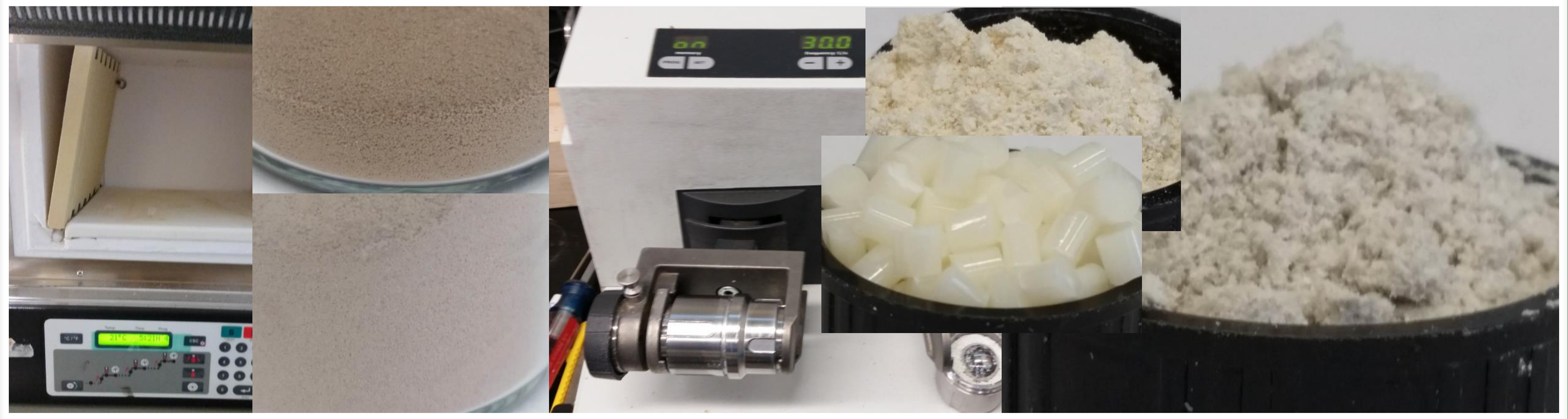


Objectives

- Formulate an ABS- $MgCaTiO_2$ composite mixture suitable for extruding 3D-printer filament
- Use filament to 3D print a sample sheet ~0.5mm thick through fused deposition modeling (FDM)
- Determine the permittivity and loss-tangent of sheet using cavity resonator

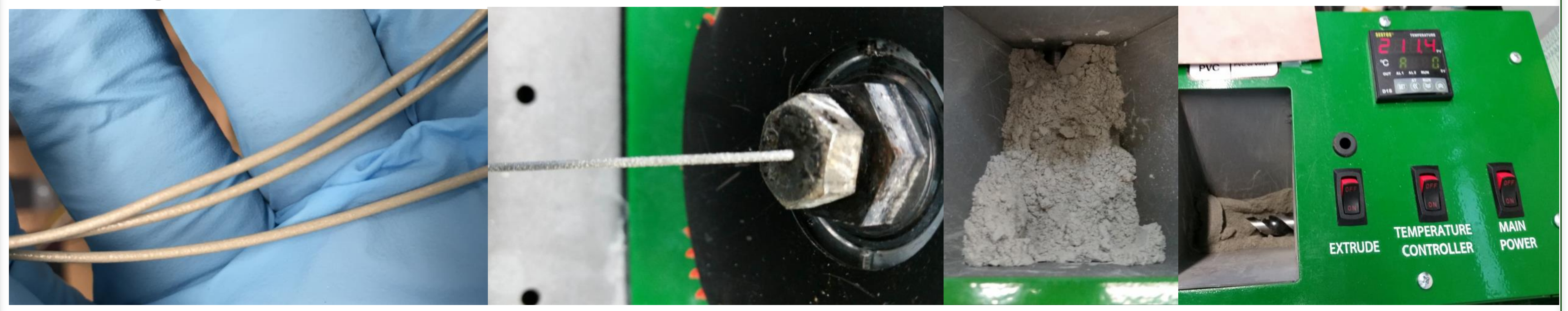
Approach

Mixture Preparation: Reducing the particle size improves their properties and ensures homogeneous mixture.



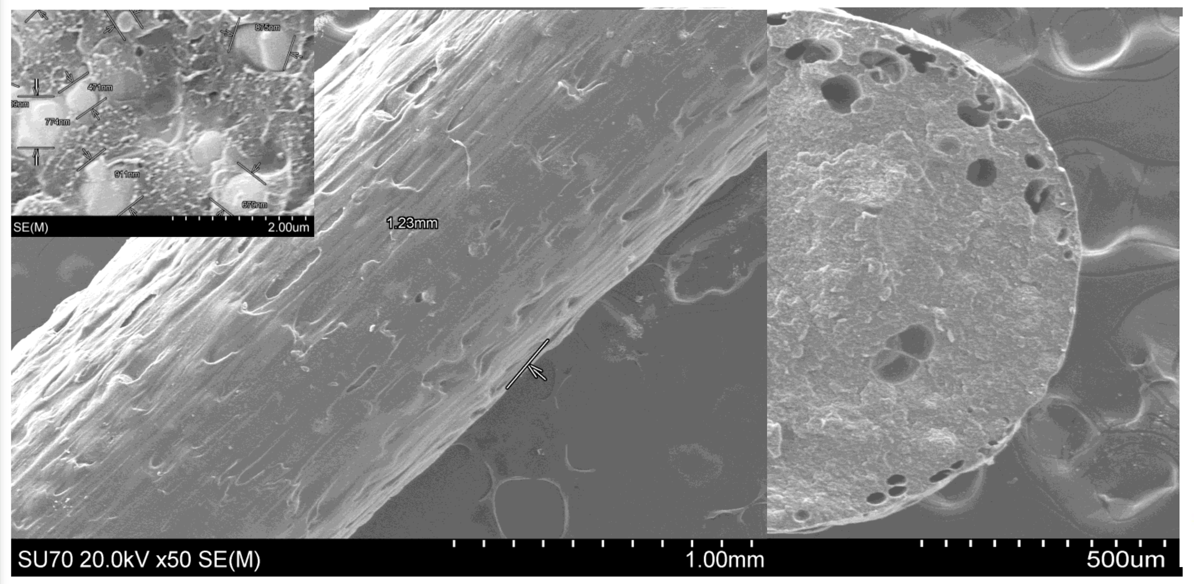
$MgCaTiO_3$ sintered at 1100°C & ball milled for 2min. ABS pellets ball milled to <5µm particles. 47% v/v ceramic-polymer mixture

Extruding of Filament: Extruding the mixture presents additional challenges compared to molding process

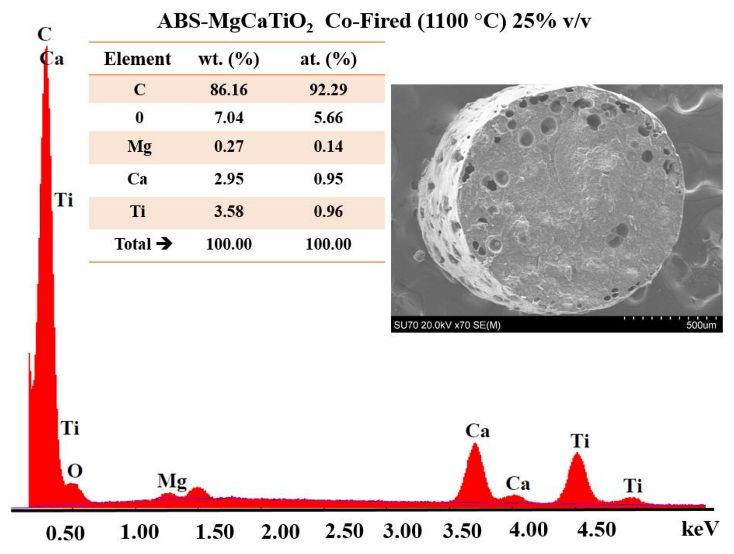


~1.4mm diameter filament. Extruding nozzle. Mixture in Filabot extruder

Filament Characterization: The filament sample showed even distribution of polymer and ceramic particles



SEM imaging at various powers of magnification

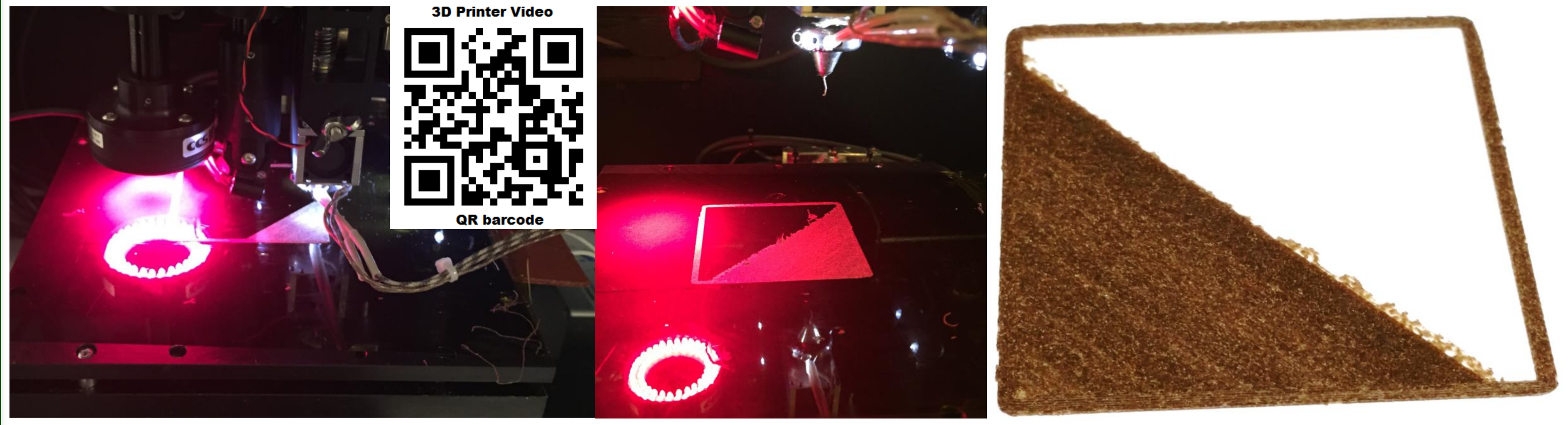


ABS-$MgCaTiO_2$ Co-Fired (1100 °C) 25% v/v

Element	wt. (%)	at. (%)
C	86.16	92.29
0	7.04	5.66
Mg	0.27	0.14
Ca	2.95	0.95
Ti	3.58	0.96
Total ➔	100.00	100.00

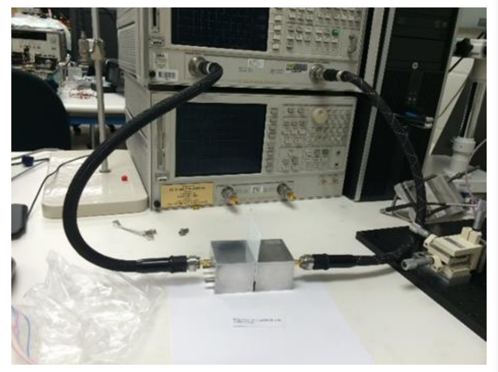
XRD element characterization

3D Printing: Process of 3D printing required wider nozzle and higher temperatures to prevent clogging



FDM 3D printing sheet for cavity resonator testing. ~0.4mm ceramic-polymer composite sheet

Conclusions



A cavity resonator (right) method was used to test the performance of a 3D printed composite sheet. The results show an increase in permittivity compare to pure ABS while keeping the loss tangent low (below). This proves for the first time that mixtures of polymer-ceramic composites can be made into filaments for 3D printing.

The promising results will continue to be improved by using different ceramics and polymers with binding agents to achieve higher permittivity. The improved composite will then be used to create 3D printed antennas.

It is worthwhile mentioning that a permittivity >12 have been achieved with PDMS-ceramic composites in prior work. However, this has been achieved through mold processing of the composite as oppose to extruding. Extruding the filament and 3D printing the composite material has introduced additional challenges. Nevertheless, different ceramics like $BaSrTiO_3$ and $NdTiO_3$ mixed with different polymers (e.g., Zeonex and ULTEM) with dispersant agents will improve the performance in later studies.

Accomplishments/Remarks

1. A. Perez will be co-author of a future publication "Enhancement of Microwave Dielectric Properties of Polymer-Ceramic Composites…"
2. A. Perez contributed in fixing the concentrations of mixtures by finding the proper bulk densities of each substance
3. A. Perez thanks Dr. Jing Wang, Juan Castro, and group for the opportunity of working in the summer of 2015. The experience in research will help him grow professionally as a science educator.

Referenced Resources

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4) J. Castro, T. Weller, J. Wang, "An Improved Fabrication Method of High-*k* and Low-Loss Polymer Composites with Sintered Ceramic Fillers for Microwave Applications," IMS 2015, May. 2015.
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