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Investigating the Dielectric Properties of BTO Nanocomposites Using Novel Fabrication Techniques

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Presenting Researcher: Josh Morgan HMC ‘20

Sandia National Laboratories

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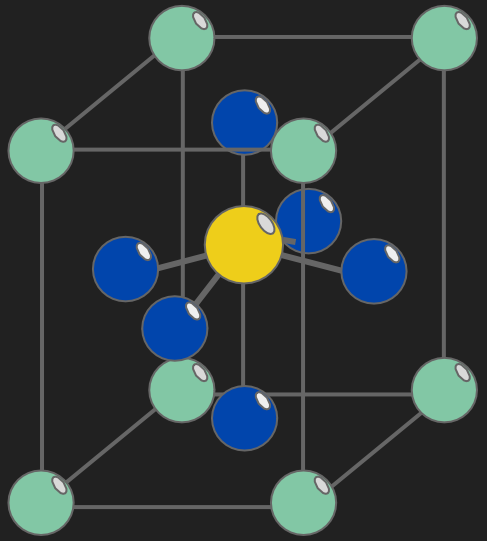
HARVEY MUDD COLLEGE

Previous Research on Barium Titanate (BTO)

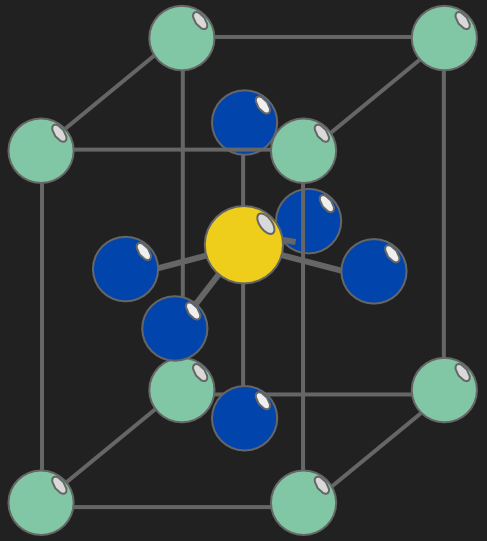


Barium

Titanium

Oxygen

Previous Research on Barium Titanate (BTO)

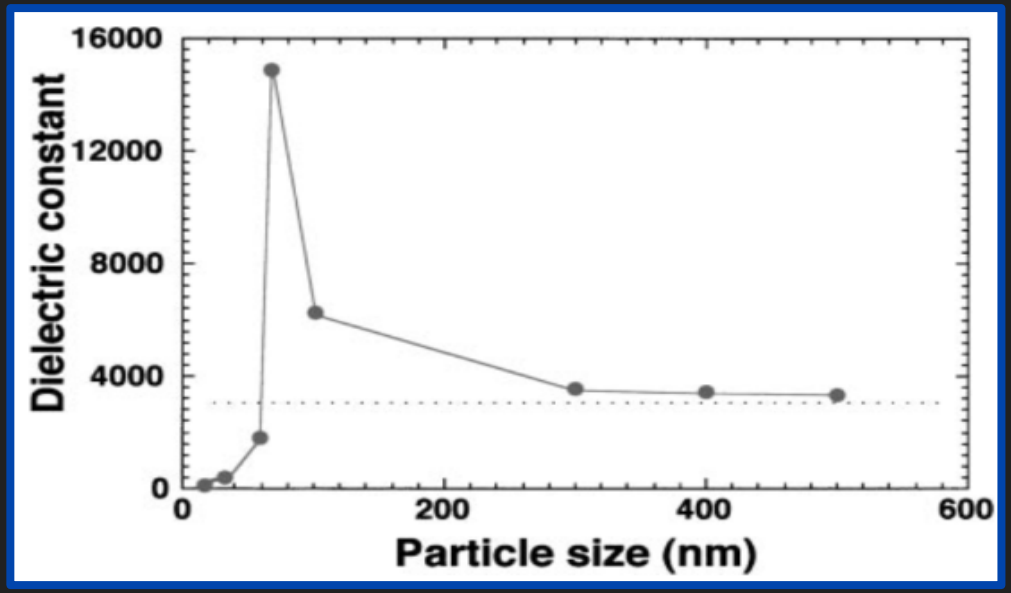


Barium

Titanium

Oxygen

- Investigation of previous results: Wada et. al., 2006.



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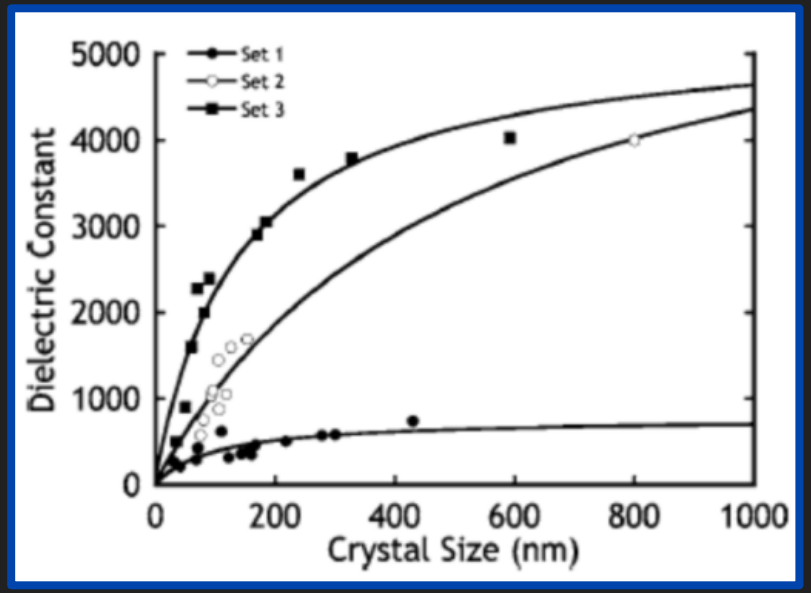
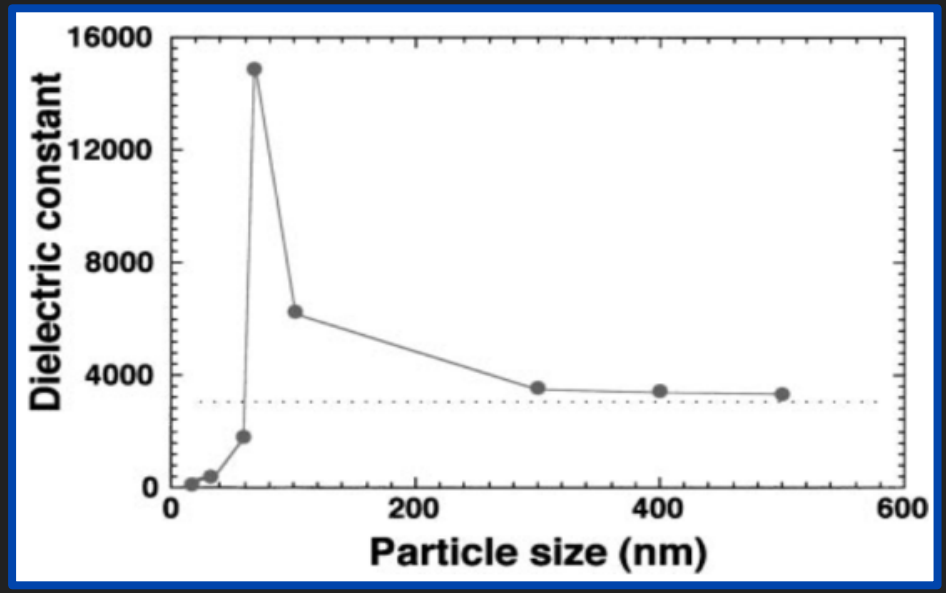
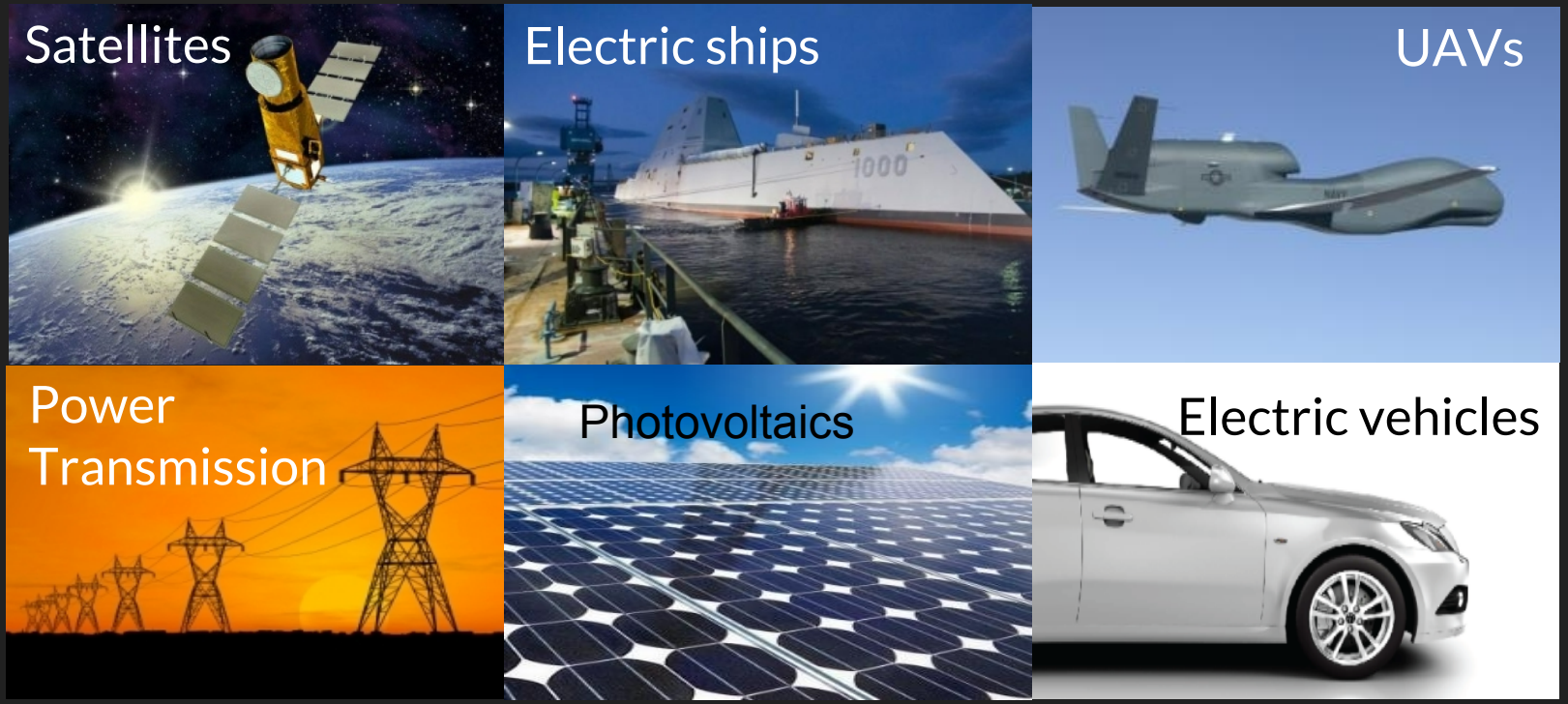


Aygun et. al., Jpn. J. Appl. Phys. Vol. 109 (2011) 034108



Wada et. al., Jpn. J. Appl. Phys. Vol. 42 (2003) 6188-6195

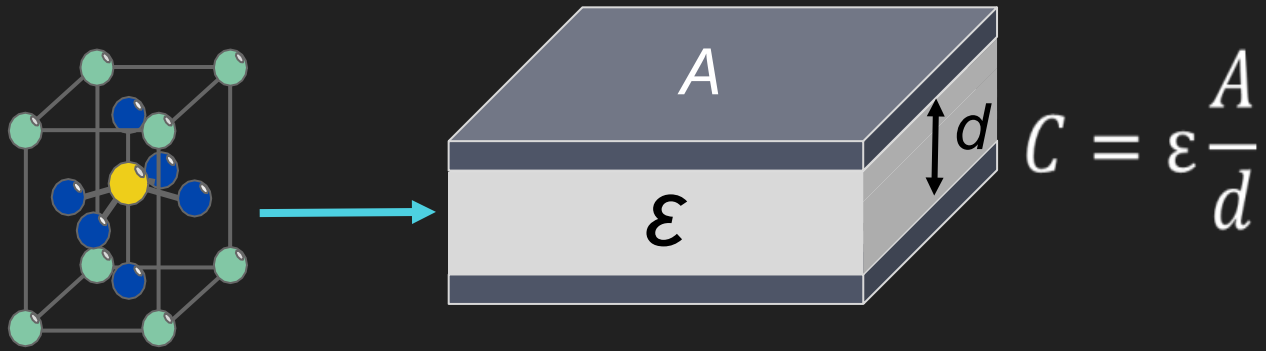
Motivation and Background: Applications of Capacitors



Slide courtesy of Bob Kaplar, Sandia National Labs

Project Goal

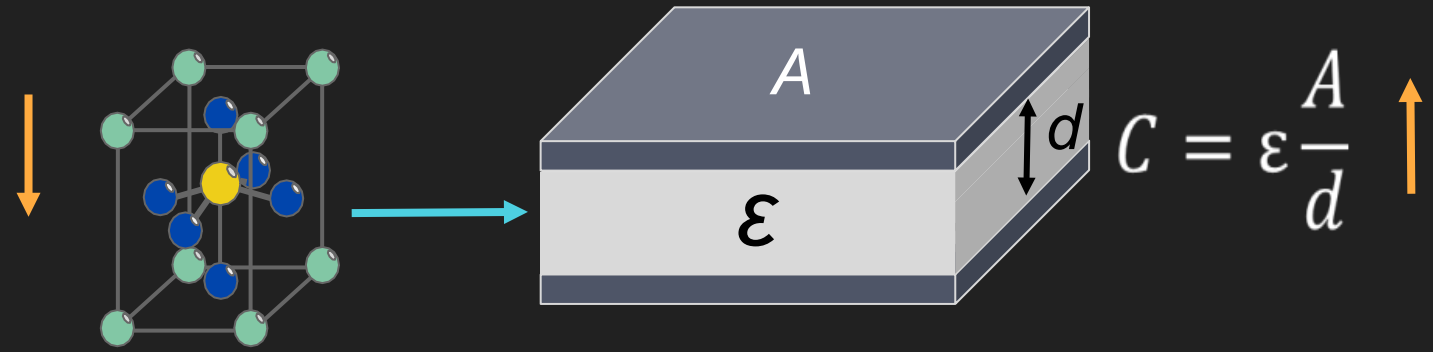
Determine the dielectric constant of barium titanate (BTO) nanoparticles as a function of particle size.



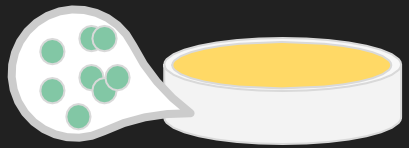
Project Goal

Determine the dielectric constant of barium titanate (BTO) nanoparticles as a function of particle size.

Hypothesis: BTO nanoparticle permittivity increases as particle size decreases.

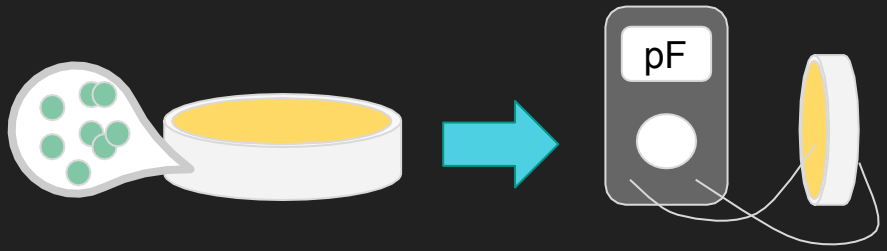


Fabrication Process & Techniques



Make a composite

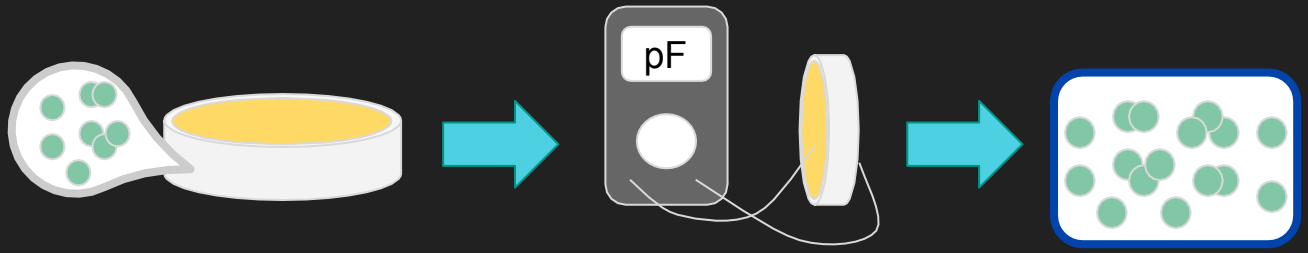
Fabrication Process & Techniques



Make a composite

Measure capacitance

Fabrication Process & Techniques

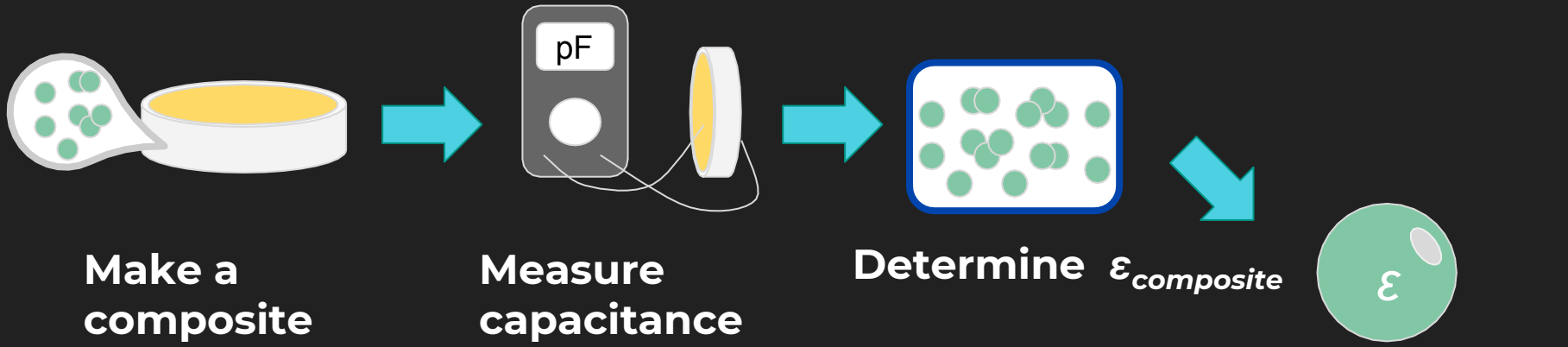


Make a composite

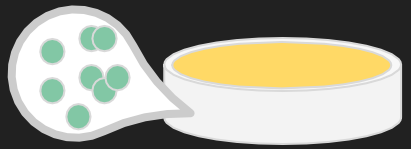
Measure capacitance

Determine $\varepsilon_{composite}$

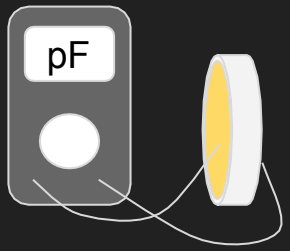
Fabrication Process & Techniques



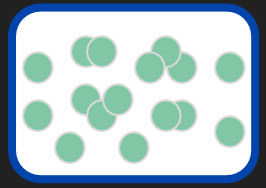
Fabrication Process & Techniques



Make a composite

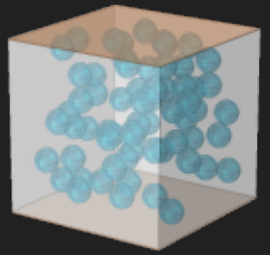


Measure capacitance

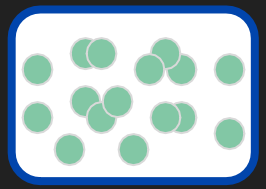


Determine $\varepsilon_{composite}$

Compare to find $\varepsilon_{particle}$



COMSOL Model of composite material



Determine $\varepsilon_{composite}$

Fabrication Process & Techniques

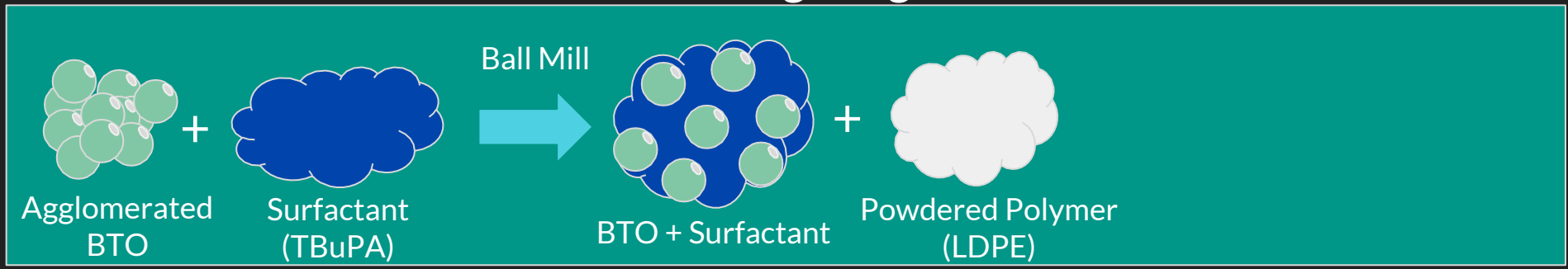
1. Mixing Stage

Agglomerated BTO

Surfactant (TBuPA)

Fabrication Process & Techniques

1. Mixing Stage



Fabrication Process & Techniques

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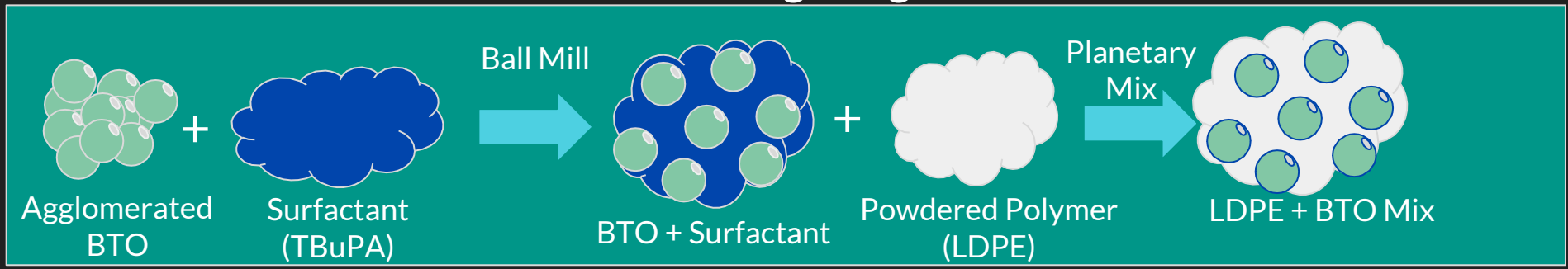
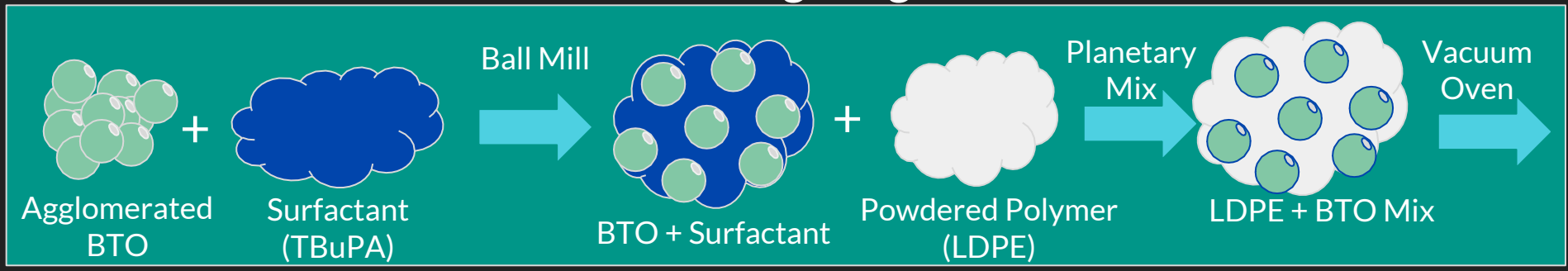


Fabrication Process & Techniques

1. *Mixing Stage*

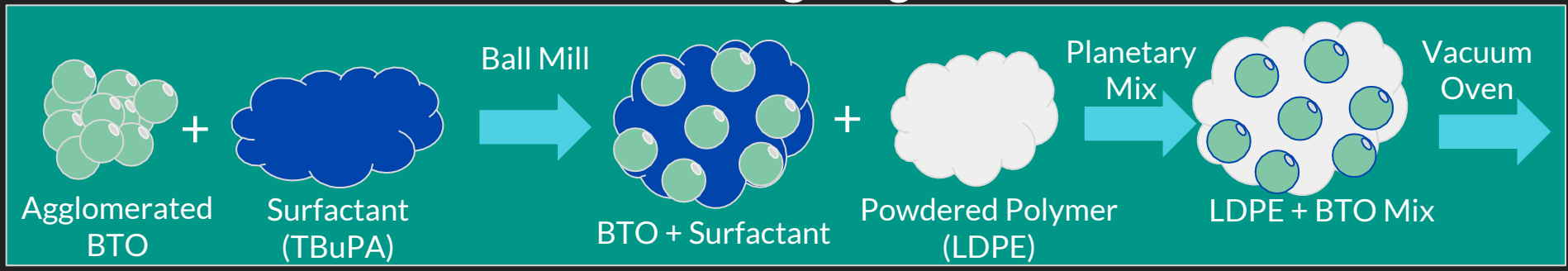


2. *Fabrication Stage*

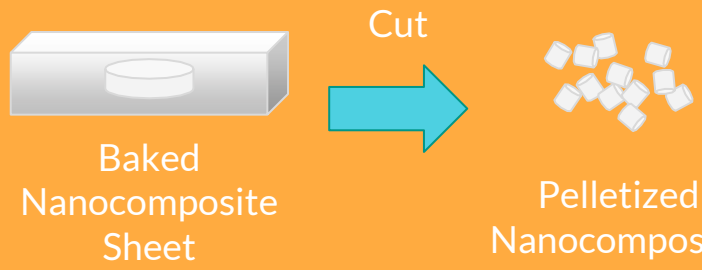
Baked Nanocomposite Sheet

Fabrication Process & Techniques

1. *Mixing Stage*



2. *Fabrication Stage*



Fabrication Process & Techniques

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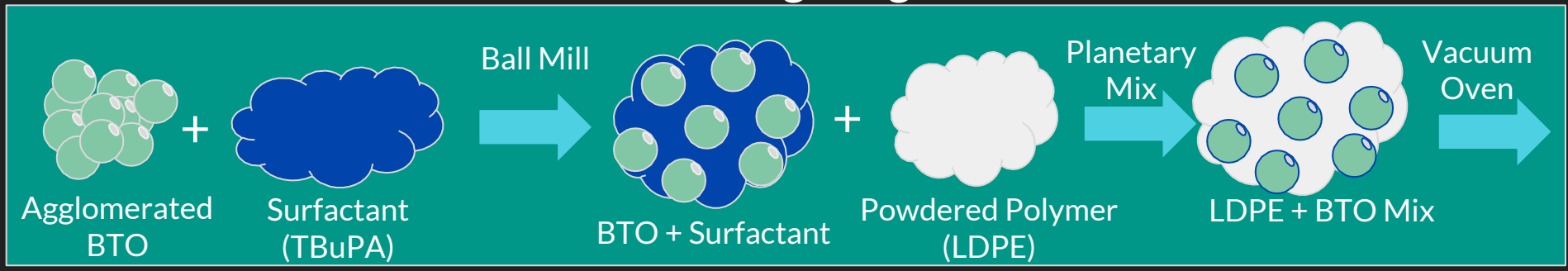

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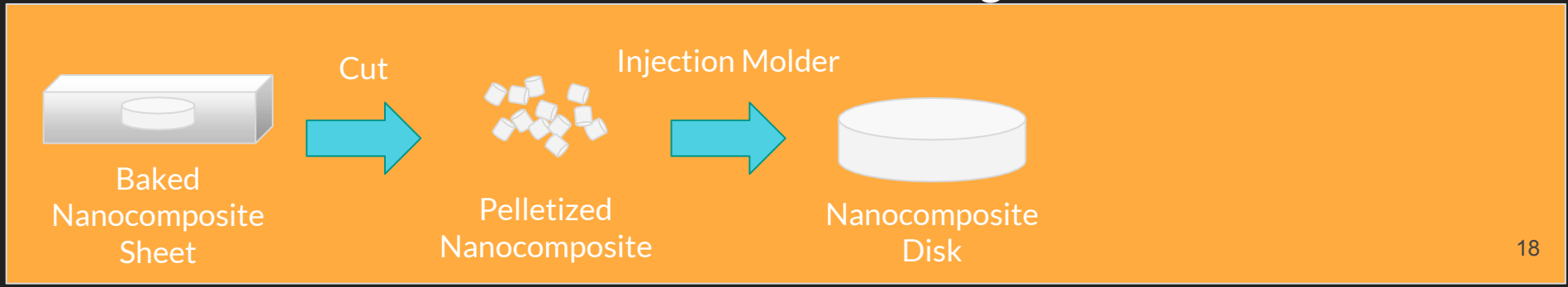

Fabrication Process & Techniques

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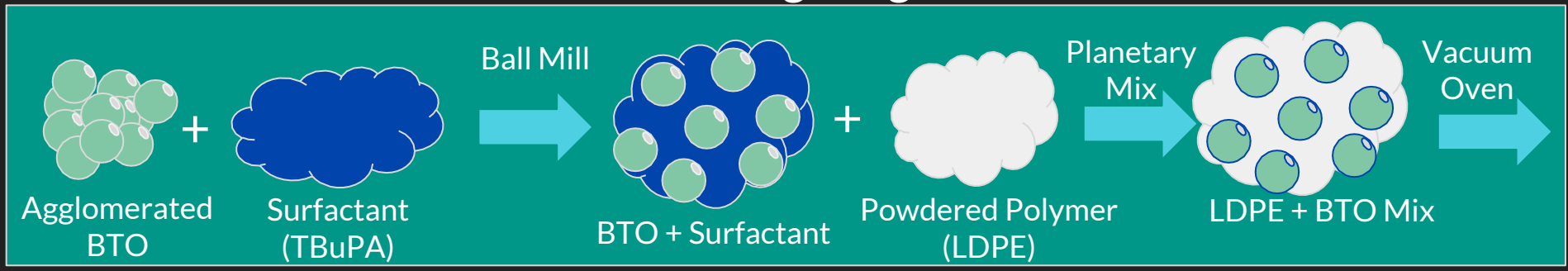

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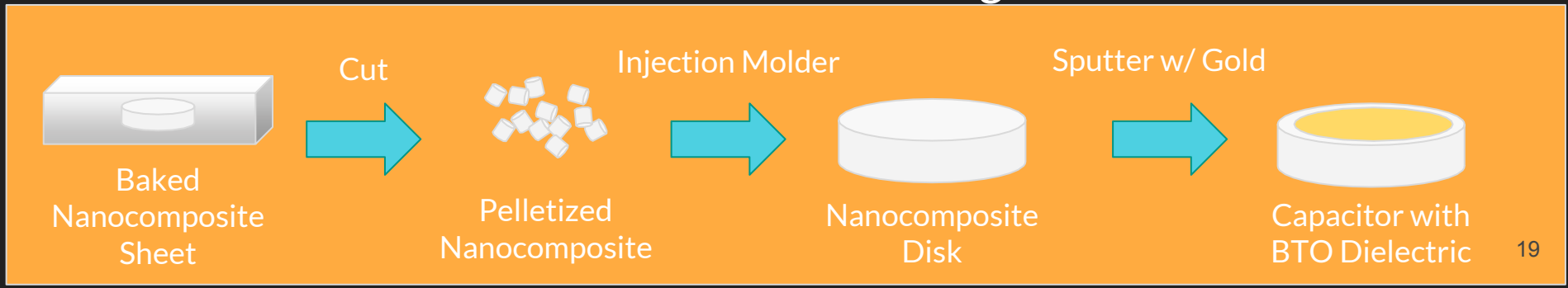
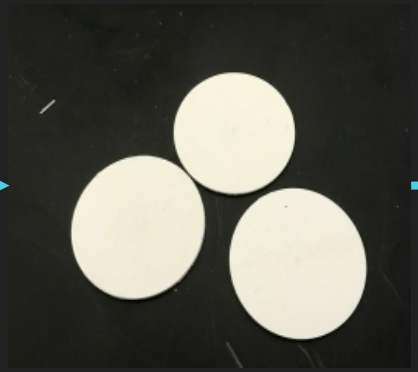


Fabrication Process & Techniques

- Manufactured 6 nanocomposite disks per particle size at 5% volume loading.

Injection Molder



Injection Molded nanocomposites

Sputtered nanocomposites

Testing Techniques

- Determine $\varepsilon_{composite}$ by:
  - Experimentally measuring volume & density.
  - Measuring capacitance within a Faraday cage.

$$C = \varepsilon \frac{A}{d} \longrightarrow \varepsilon_c = \frac{Cd}{A\varepsilon_0}$$

Testing Techniques

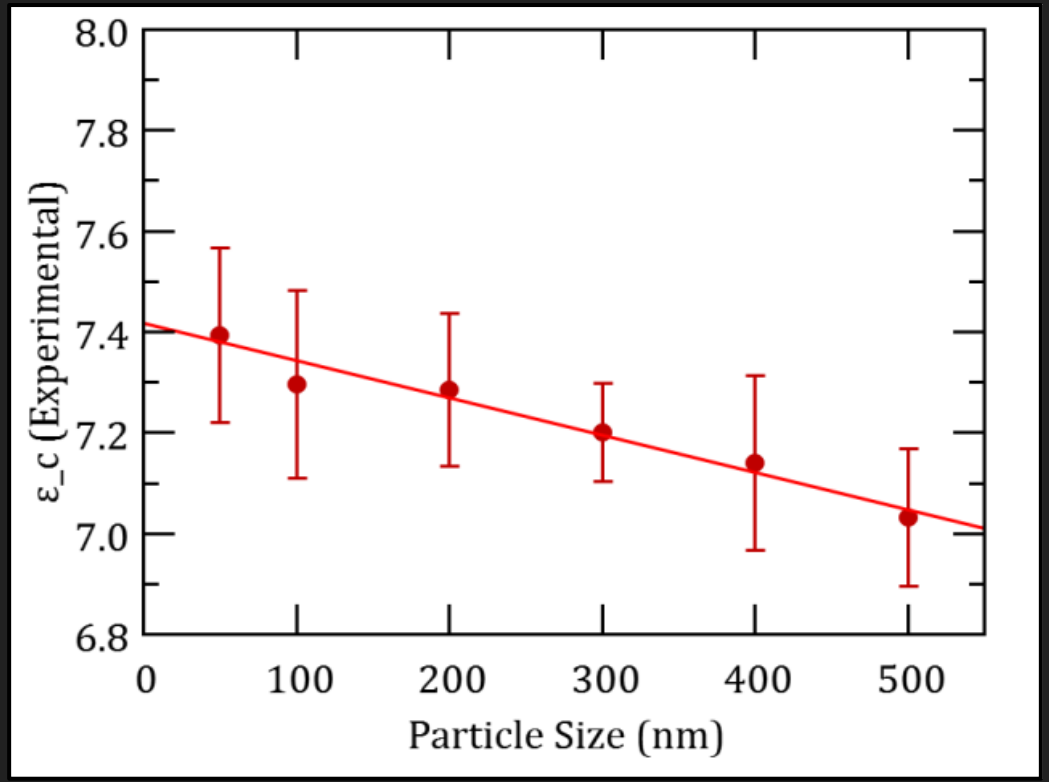
- Extract $\varepsilon_{particle}$ using the Jayasundere-Smith EMA:

$$\varepsilon_c = \frac{\varepsilon_m(1-\delta_p) + \varepsilon_p\delta_p\left(\frac{3\varepsilon_m}{\varepsilon_p+2\varepsilon_m}\left(1+\frac{3\delta_p(\varepsilon_p-\varepsilon_m)}{\varepsilon_p-2\varepsilon_m}\right)\right)}{(1-\delta_p) + \delta_p\left(\frac{3\varepsilon_m}{\varepsilon_p+2\varepsilon_m}\left(1+\frac{3\delta_p(\varepsilon_p-\varepsilon_m)}{\varepsilon_p-2\varepsilon_m}\right)\right)}$$

  - Where ε_m=ε_{medium}, ε_p=$\varepsilon_{particle}$, and δ_p= volume % of BTO.
    - δ_p= 0.05 for all specimens produced and examined.

Data Processing

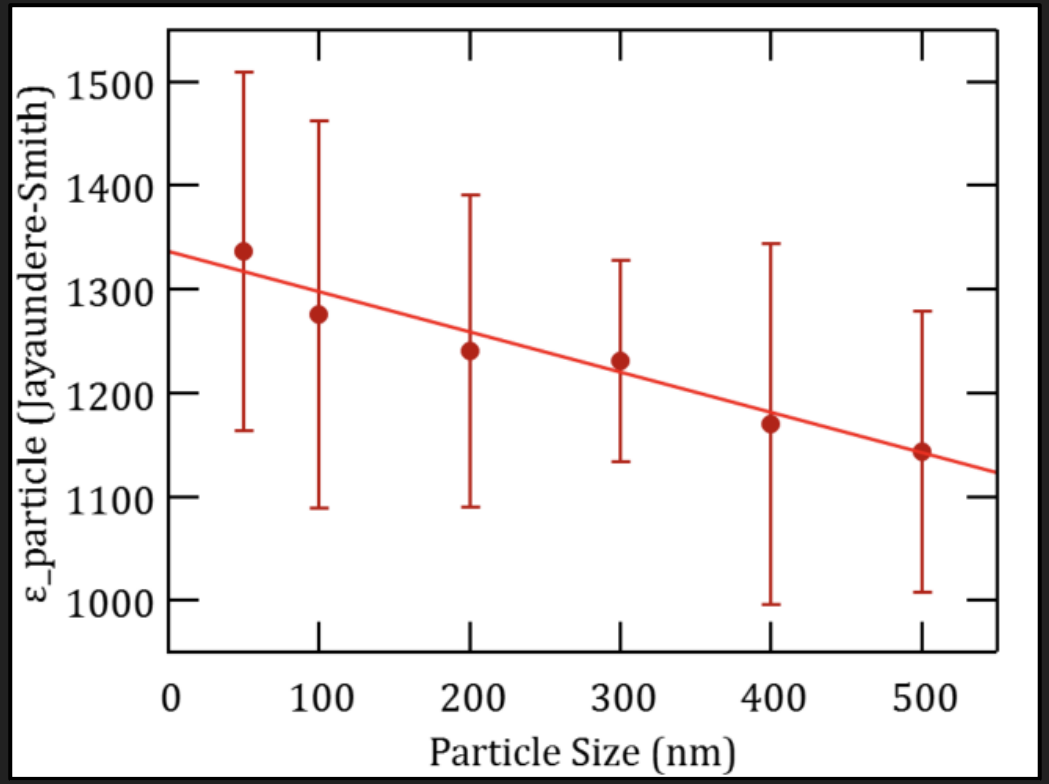
$\varepsilon_{composite}$ v. Particle Size



Brito et. al., MRS Communications 1-7, (2020), doi:10.1557/mrc.2020.69

Data Processing

$\varepsilon_{particle}$ v. Particle Size



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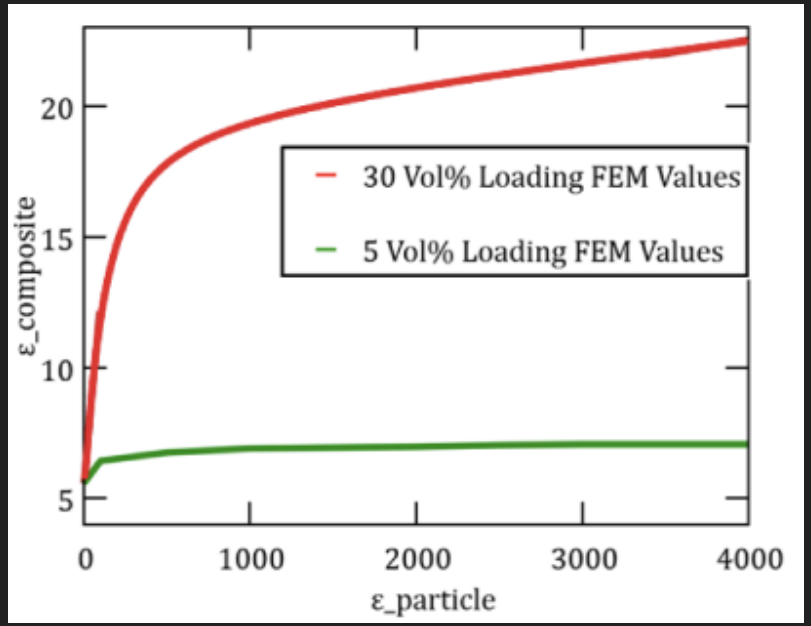
Results and Discussion

- Key Takeaways:
  - Created a method for producing BTO/polymer nanocomposites in a repeatable and consistent manner.
  - Investigation of LDPE-matrix nanocomposites with 5 vol% BTO showed no clear relationship between nanoparticle size and dielectric constant.
  - A BTO/polymer composite has a higher dielectric constant than the pure polymer.

Moving Forward: Impact of Results

- Relationship between dielectric constant and particle size is expected to be clearer at higher volume loading.



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Questions

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Email: jmorgan@g.hmc.edu
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