Direct Ink Writing of Inorganic- Organic Composites for High Performance Energy Materials

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Introduction

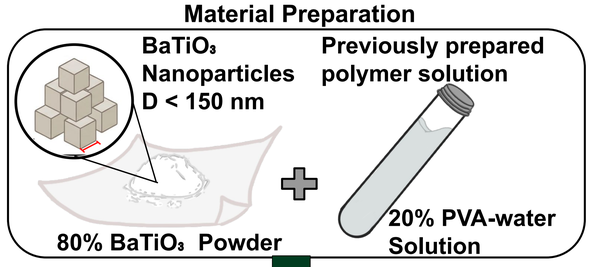
Barium titanate ($BaTiO_3$) is a functional ceramic widely used in dielectric and energy-related applications because of its favorable electrical properties. Direct ink writing (DIW) offers a flexible approach for fabricating components, such as capacitors, sensors, and energy storage devices, with controlled geometries. However, incorporating a high concentration of ceramic particles produces highly viscous inks that can be difficult to extrude and may result in inconsistent dimensions and poor layer accuracy[1]. The **objectives** of this study are to:

1) Find the **ideal mixture ratio** of $BaTiO_3$ and PVA-water solution for smooth printing.

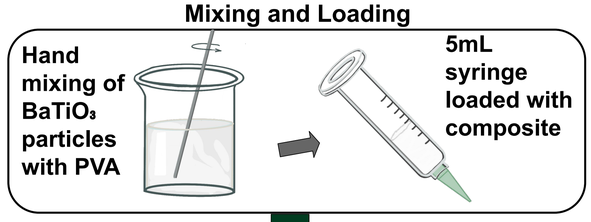
2) Evaluate the printed structures by comparing **layer height**s and mapping the **temperature distribution** to **improve dimensional accuracy** and **printing consistency.**

Methodology

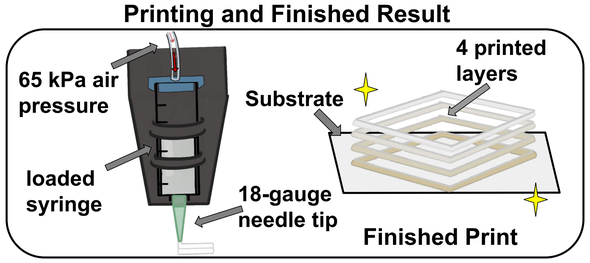
Material Preparation



Mixing and Loading



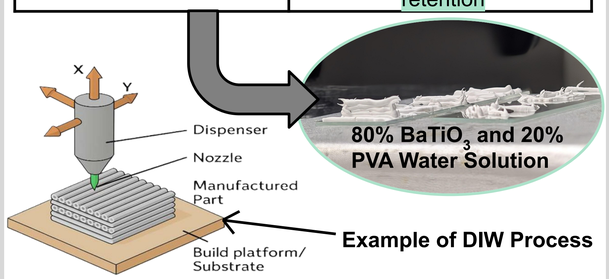
Printing and Finished Result



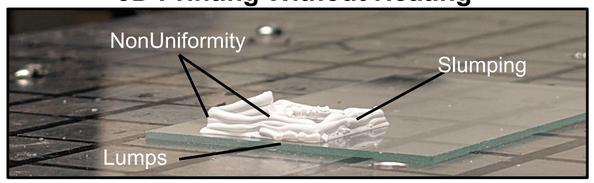
Ink Formulation and Printing Process Optimization

Optimization of $BaTiO_3$/ PVA-Water Ratio

$BaTiO_3$/PVA-water Ratio	Observation
50/50	Low viscosity; excessive spreading
70/30	High viscosity; poor shape retention
80/20	High viscosity; good shape retention



3D Printing Without Heating



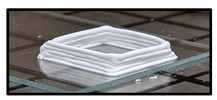
First 3D print: Analysis of print consistency and failure

Heated Drying Time Maximization

Temperature (°C)	Observation
25	Slow drying; significant slumping
40	Moderate drying; poor shape retention
55	Rapid drying; smooth surface and good shape retention
65	Rapid drying; increased risk of cracking

Effect of Ink Aging on Printability

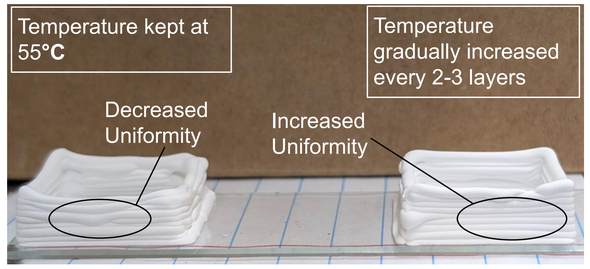
Aging Time (days)	Observation (Printed 65 kPA air Pressure)
0	Too viscous for reliable printing; prone to printing defects
1	Lower viscosity and improved printability
6	Consistent printability with fewer defects
7	Easy to print and handle



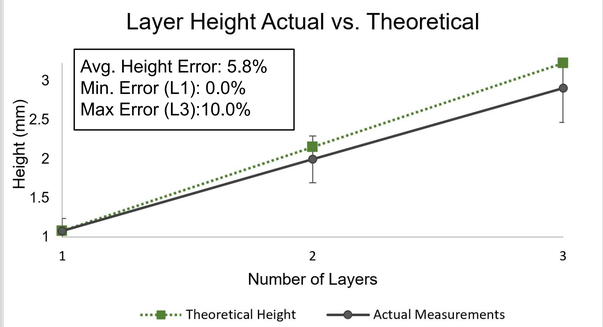
Ink rested overnight prior to printing

Characterization Results

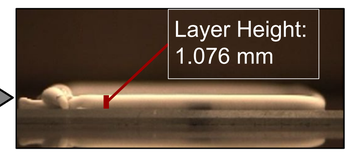
Improvement of Printing Consistency with Gradual Temperature Increase



Nine layer print comparison of composite kept at 55 °C during print vs. composite increased from 55 °C 75 °C gradually

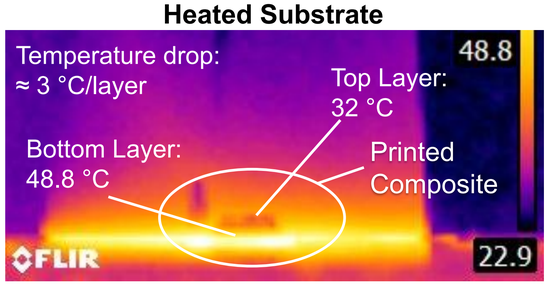


Graph Displaying Error Margin Between Actual and Theoretical measurements

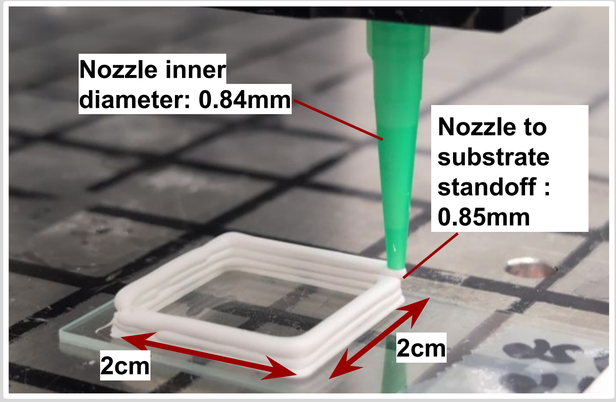


Printed Composite positioned for optical profiling and experimental height validation

Thermal Profile of printed Composite on a Heated Substrate



Thermal Image displaying temperature gradient on a layered composite structure on a heated substrate.



$BaTiO_3$-PVA composite being printed at a speed of 2mm/s, for a total of four layers.

Conclusions & Future Directions

Conclusions

- **Ink formulation:** An 80/20 $BaTiO_3$/PVA–water ratio provided the best printability and shape retention.
- **Aging:** Overnight aging improved ink processability and printing consistency.
- **Thermal control:** A substrate temperature of **55° C** reduced slumping and improved layer uniformity.
- **Dimensional accuracy:** The average layer-height error was **5.8%**.
- **Thermal profile:** Infrared imaging showed a clear temperature decrease from the substrate to the upper layers.

Future Work

- Characterizing rheological changes during ink aging.
- Optimizing substrate heating for taller structures.
- Evaluating the electrical and mechanical properties of the printed composites.

References

1) Khecho, Anasheh, et al. “Process Design and Direct Writing of Flexible Multilayered Ceramic-Magneto-Polymer Composites for Humidity-Sensitive Devices.” *Polymer*, vol. 346, 2026, article 129630. *ScienceDirect*
2) Soliman, T. S., et al. "The Structure and Optical Properties of PVA-$BaTiO_3$ Nanocomposite Films." *Optical Materials*, vol. 111, 2021, article 110648. *ScienceDirect*,