Additive Manufacturing of Energy Harvesting Material System for Active Wireless MEMS Sensors

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Objective

- Use binder jetting 3D printing to design, fabricate, and evaluate ceramic/graphene composites capable of working up to 1000 °C.

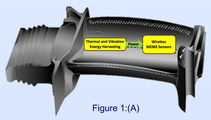


Figure 1:(A)

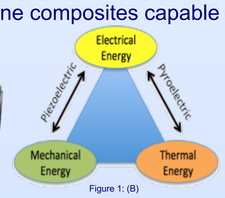


Figure 1: (B)

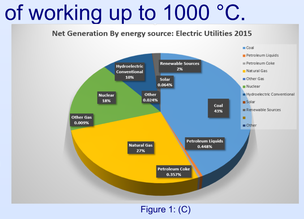


Figure 1: (C)

Figure 1: (A) Energy harvesting for wireless MEMS sensors, (B) piezoelectric and pyroelectric energy harvesting, (C) motivation behind research project.

Methodology & Materials

Order of Objectives:

Materials:

- Lithium Niobate ($LiNbO_3$)
- 2-Methoxyethanol
- Graphene Oxide/ Graphene

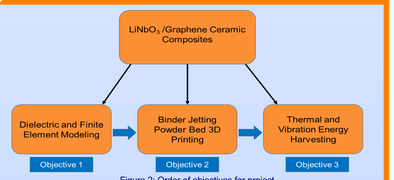
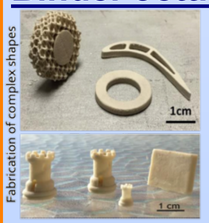


Figure 2: Order of objectives for project.

Binder Jetting Fabrication:



Density results

Layer Thickness (µm)	Sintered Profile (hrs)	% Rel ρ
106	2	91.10
45	2	92.72
106	16	94.04
45	16	96.51

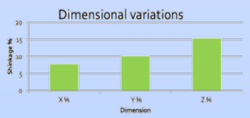


Figure 3: (A)

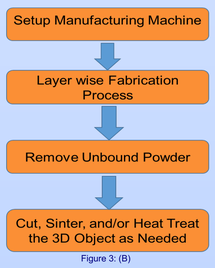


Figure 3: (B)

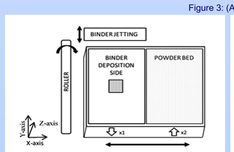


Figure 3: (C)

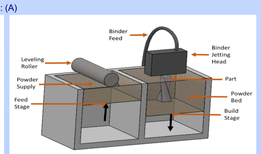


Figure 3: (D)

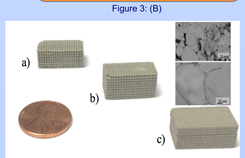


Figure 3: (E)

Figure 3: (A) Binder jetting ceramic components with density results and dimensional variations, (B) binder jetting fabrication process, (C) schematic of M-Lab binder jetting technology, (D) schematic representation of binder jetting additive manufacturing technology, (E) Al_2O_3 manufactured via binder jetting with tailored density of a.) 25%, 50%, 75%.

Graphene Oxide Synthesis:

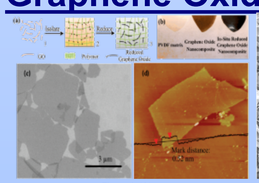


Figure 4: (A)

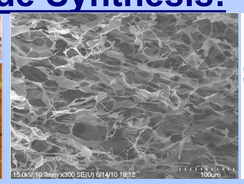


Figure 4: (B)

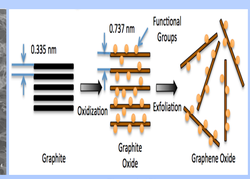
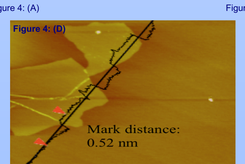


Figure 4: (C)



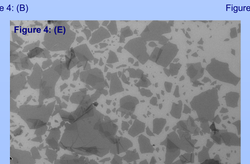


Figure 4: (A) In situ reduced process for a single layer reduced-graphene oxide nanocomposite, (B) zoomed inSEM image of graphene oxide, (C) illustration of fabrication process for graphene oxide sheets, (D) digital image of graphene oxide and in situ reduced-graphene oxide nanocomposite, (E) SEM image of graphene oxide.

Results

Dielectric Ceramic Testing:


Figure 5: (A)

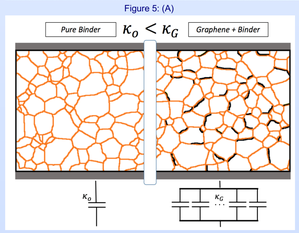


Figure 5: (B)

Figure 5: (A) Fabricated press-fit BTO samples containing various concentrations of graphene oxide solution, (B) schematic view of effect of adding graphene in ceramic, (C) schematic of BTO press-fit fabrication, (D) press fit tool used for BTO press-fit fabrication located at the University of Texas at El Paso, (E) dielectric constant for painted and unpainted sintered press-fit samples at various concentrations of graphene oxide.

- Press-fit $BaTiO_3$/Graphene oxide fabricated.
- Ceramic compressed at 3 metric tons
- Cured at 250°C for 30 minutes

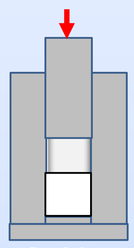


Figure 5: (C)


Figure 5:(D)

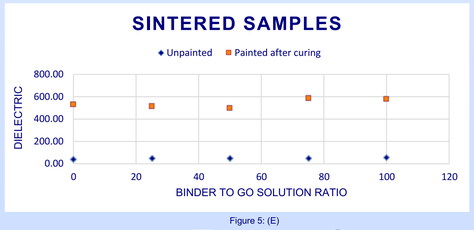


Figure 5: (E)

Ceramic Binder Jetting:

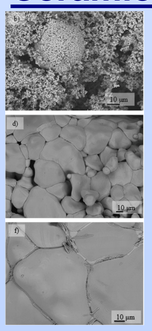


Figure 6: (A)

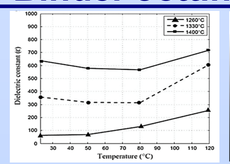


Figure 6: (B)


Figure 6: (C)

Figure 6: (D)

Figure 6: (A) High magnification BTO specimen after sintering between 1260 °C -1400 °C, (B) dielectric constant for $BaTiO_3$ at various temperatures, green body BTO binder jetting printed sample, (D) ExOne M-Lab binder jetting printer.

Testing Setup:

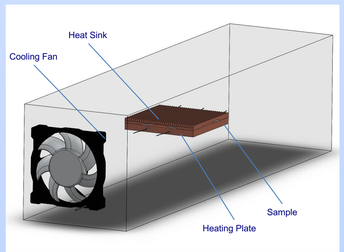


Figure 7: Test setup for pyroelecetric preliminary results.

Lithium Niobate Preliminary Results:

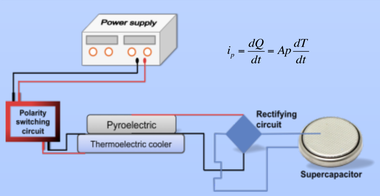


Figure 8: (A)

$$i_p = \frac{dQ}{dt} = Ap\frac{dT}{dt}$$

150 to 200		200 to 250	
Heating	Cooling	Heating	Cooling
1.623E-4	2.131E-4	2.304E-4	2.298E-4
dT/dt	dT/dt	dT/dt	dT/dt
0.202	0.1399	0.1683	0.1703

Figure 8: (B)

150 to 200 (1M)	200 to 250 (1M)
21.96 nW	31.47 nW
0.4816 nW/cm2	0.6901 nW/cm2

Figure 8: (C)

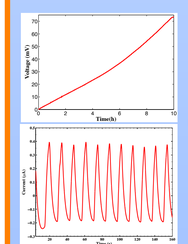


Figure 8: (D)

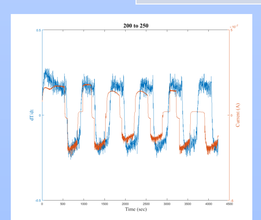


Figure 8: (E)

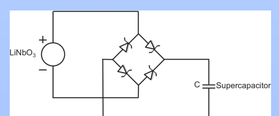


Figure 8: (F)

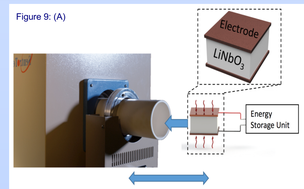
Figure 8: (A) Schematic of pyroelectric energy harvesting, (B) pyroelectric energy harvesting with all coefficients used, (C) power for pyroecetric energy harvesting, (D) results of pyroelectric energy harvesting with pyroelectric coefficient between 150 and 200 temperature range, (E) results of pyroelectric energy harvesting with pyroelectric coefficient between 200 and 250 temperature range, (F) Current generated and storage from $LiNbO_3$ with heating and cooling.

Conclusion

- Pyroelectric ceramic can be 3D printed using binder jetting printing.
- Thermal energy harvesting has been achieved using pyroelectric ceramics.
- Dielectric material property can be tuned by adding carbon nanomaterials into ceramic.
- Higher energy harvesting output can be achieved at higher temperature ranges.

Future Work

	Year 1				Year 2				Year 3			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Objective 1												
Task 1: Dielectric Modeling												
Task 2: Finite element Modeling												
Objective 2												
Task 3: Graphene Synthesis												
Task 4: *Binder Jetting 3D Printing*												
Task 5: *Material Characterization*												
Objective 3												
Task 6: *Thermal Energy Harvesting*												
Task 7: *Hybrid Energy Harvesting*												
Progress Report												
Final Report												



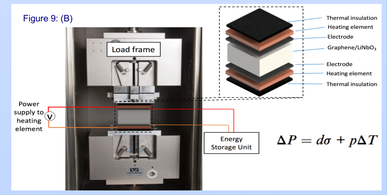
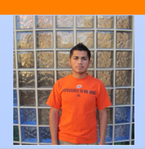
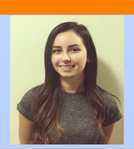
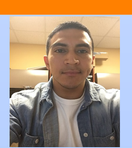


Figure 9: (A) Schematic view of thermal energy harvesting, (B) schematic view of hybrid energy harvesting.

Student Involvement


Acknowledgements

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References

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- M. R. H. Sarker, J. L. Silva, M. Castañeda, B. Wilburn, Y. Lin and N. Love, "Characterization of the Pyroelectric Coefficient of a High Temperature Sensor," El Paso.