Direct Writing of $BaTiO_3$ Nanocomposites with Tailored Microstructure for Energy Harvesting

M.H. Malakooti[1], A. Nafari[1], F. Jule[1], and H.A. Sodano[1,2 *]

[1]Department of Aerospace Engineering, University of Michigan
1320 Beal Avenue, Ann Arbor, Michigan, 48109
[2]Department of Materials Science and Engineering, University of Michigan
2300 Hayward Street, Ann Arbor, Michigan, 48109

*H.A. Sodano: hsodano@umich.edu

Conversion of kinetic energy into electrical energy, called mechanical energy harvesting, is a common approach used in the development of self-powered devices. Conventionally, monolithic lead-based piezoceramics with high electromechanical coupling such as lead zirconate titanate (PZT) and lead magnesium niobate lead titanate (PMNT) have been employed to convert dynamic mechanical loading to electrical energy in devices called piezoelectric energy harvesters. Despite of their high piezoelectric coefficient, the brittleness and poor flexibility of these ceramics have significantly limited their practical applications. Piezoelectric nanocomposites with decent electromechanical coupling, high flexibility, and low density appear to be suitable replacements for monolithic piezoceramics. In recent research efforts, many researchers have explored various combinations of different active fillers and polymer matrices to develop functional nanocomposites with high energy conversion efficiencies. It has been established that the performance of piezoelectric nanocomposites for sensing, energy harvesting, and actuation is highly dependent on the structural properties of devices as well as the electromechanically properties of active piezoelectric phase. More importantly, it is demonstrated that the electromechanical response of the active nanocomposites is governed by the morphology and arrangement of fillers in the polymer matrix. Therefore, these parameters can be tuned as a design variable in order to develop nanocomposite energy harvesters with improved energy density.

Here, a simple additive manufacturing method is proposed for tailoring the arrangement of piezoelectric nano-fillers in a polymer matrix to enhance the energy harvesting performance of these piezoelectric nanocomposites. High aspect ratio nanowires (NWs) were used as active phase rather than spherical nano-fillers due to their enhancing effect on the piezoelectric coupling of nanocomposites. Barium titanate ($BaTiO_3$) NWs with controlled morphology were synthesized in a two-step hydrothermal reaction. Next, a polymer solution was prepared by dispersing the $BaTiO_3$ nanowires into a dissolved polylactic acid (PLA) solution at a high concentration. After tailoring the viscosity of the solution, nanocomposites with different degree of alignment were printed through direct writing (DW) of the prepared ink on conductive substrate and optimizing the printing parameters. Using the DW technique, two sets of energy harvesters in beam configuration were fabricated; one with nanowires aligned in the axial direction of the beam and one with nanowires aligned in the beam's lateral direction. Fabricated devices were subjected to vibration testing in order to study the role of filler alignment on the energy harvesting performance of the nanocomposites. The results demonstrated that between the two sets of samples, the devices with nanowires aligned in the axial direction of beam generate up to two times higher peak to peak voltage under harmonic base excitation. This result is in agreement with anticipated response based on micromechanics models and confirms the crucial role of microstructure architecture on the overall performance of a nanocomposite. Furthermore, the proposed methodology can be considered as a novel additive manufacturing technique that enables fabrication of nanocomposites with tailored properties through controlled assembly of the fillers inside polymer matrices.