Additive Manufacturing of Nanomaterial Based Sensors for Extreme Environments

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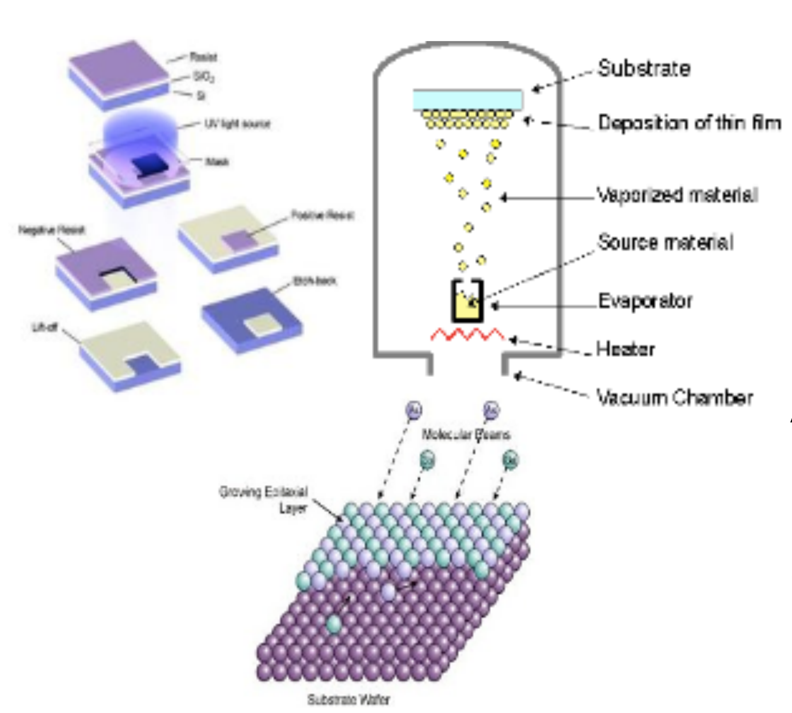
Introduction

Additive manufacturing, specifically inkjet printing (IJP) and aerosol jet printing (AJP), have shown great potential for rapid prototyping and direct writing of electronic sensors. These additive techniques provide the developer much flexibility in controlling the sensor response through materials selection and system design. Recently, the research community has started exploring applications of additive manufacturing for extreme environments, such as space and nuclear applications. In this work, we explore both IJP and AJP of sensors for applications in human performance monitoring onboard the International Space Station and field property measurements inside nuclear test reactors. We use IJP of custom graphene inks on flexible substrates to sense pH and electrolyte concentrations, with potential applications in flexible and wearable electronic sensors for real time analysis of various biological functions. We also explore the utility of AJP in conjunction with commercial nanoparticle inks for temperature melt arrays for in-pile nuclear sensors capable of measuring peak temperatures achieved during long-term irradiation experiments. Our results highlight the importance of structure-property-processing correlations in additively manufactured sensors to their performance in relative extreme environments.

Background and Motivation

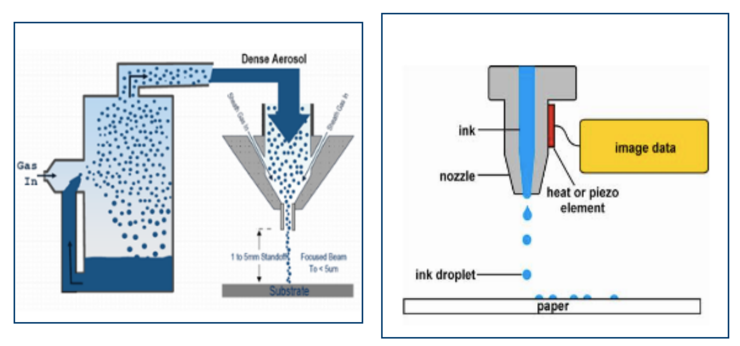
Conventional Methods



Conventional Methods- Vacuum Deposition/Photolithography

- Multi-step, high processing temperatures, toxic waste[1,2]
- High cost, restriction of device design
- Increasing size of electronics poses great difficulty in adapting standard microfabrication processes[1,2]

Additive Manufacturing



Additive Manufacturing- Inkjet Printing (IJP) and Aerosol Jet Printing (AJP)

- Non-contact, additive patterning, maskless approach
- Deposition of versatile thin films, with ease of design alteration[1]
- Reduced material waste, low cost, scalability to large area manufacturing[2]
- Allows flexibility in controlling sensor response through materials selection and system design[3-5]
- Key feature is the fine feature sizes able to be achieved as well as the functional material that can be printed

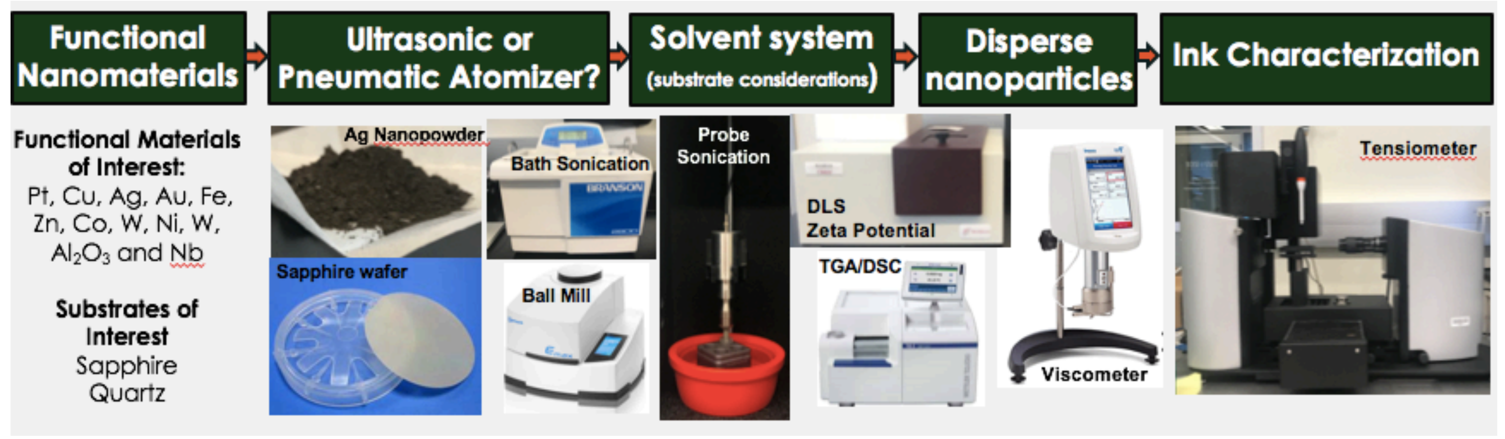
Objectives

- Explore utility of IJP and AJP as additive techniques for electronic sensors
- Characterize IJP graphene electrodes response in unique environments
  - Different pH solutions and ion selectivity
- Identify material loss in AJP temperature melt arrays after subjective annealing temperatures

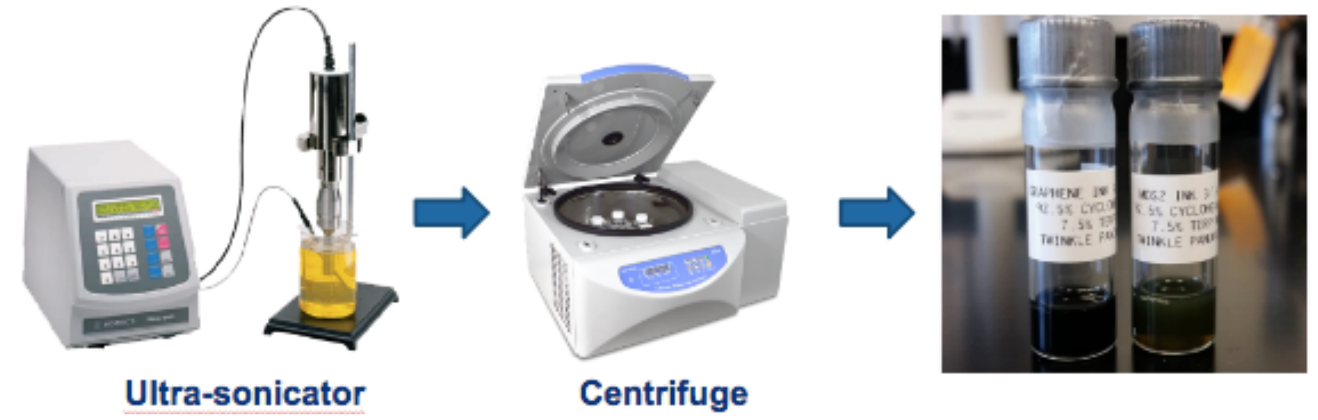
Materials and Methods

Ink Synthesis

Aerosol Jet Printer Ink Synthesis



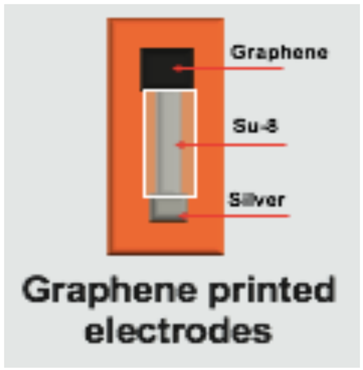
Inkjet Printer Ink Synthesis



- Graphite/Ethyl Cellulose (EC)/Ethanol (EtOH) sonicated
- Suspension is centrifuged, graphite sediments–Graphene in solution
- Graphite removed, EtOH allowed to evaporate
- Graphene/EC dispersed in cyclohexanone/terpineol

Device Fabrication

Graphene Printed Electrode (IJP)



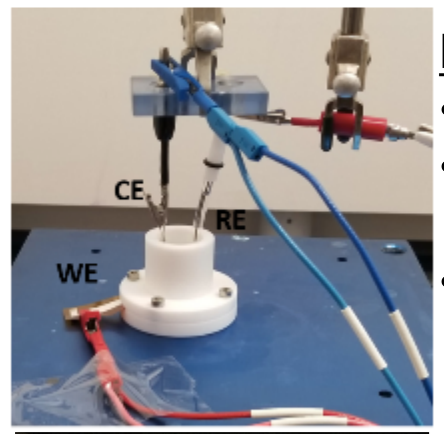
Graphene printed electrodes

- Square graphene ink working electrode w/ silver contact pad
- Optimized printing parameters (# of layers, print rate, nozzle size, etc.)
- Each electrode annealed at 350˚ C
- Conductivity, porosity and defects present characterized

Temperature Melt Array (AJP)

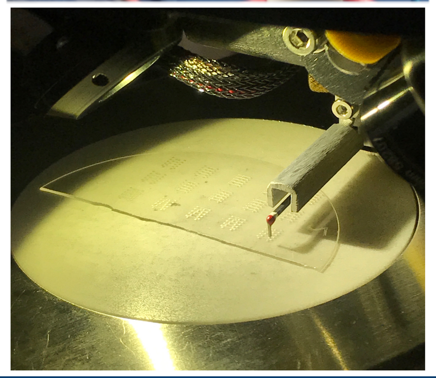
- Printed with silver nanomaterial based inks
- Variable dimensions to verify different sensing patterns
- Devices sintered at 300-100˚ C at 100˚ C intervals

Device Testing



<u>Measurement Set-up:</u>

- WE: Graphene CE: Platinum mesh RE: Ag/AgCl
- Chronopotentiometric tests to measure change in potential over time
- Tested different solutions of different pH to determine electrode response to change in H^+ concentration



<u>Measurement Set-up:</u>

- Bruker Stylus Profilimeter map scans
- X and Y measurements pre and post annealing
- Change in dimensional measurements (step height, total volume, X/Y distance, etc.) would indicate material loss[6]

Results and Discussion

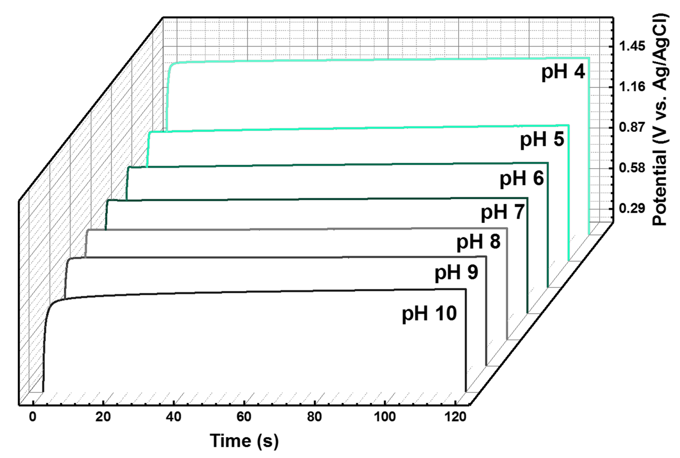


Figure 1: Potential vs. Time plot of response to solutions of different pH

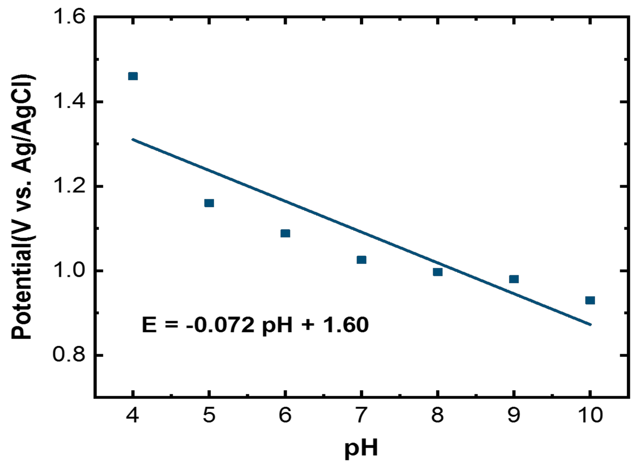


Figure 2: Potential vs pH plot along with linear equation.

Summary

- IJP graphene electrode electrochemical response dependent on pH
- Repeatable performance indicates viability of graphene as electrode

Future Work

- Response due to ion selectivity
- Data on real-time pH alterations

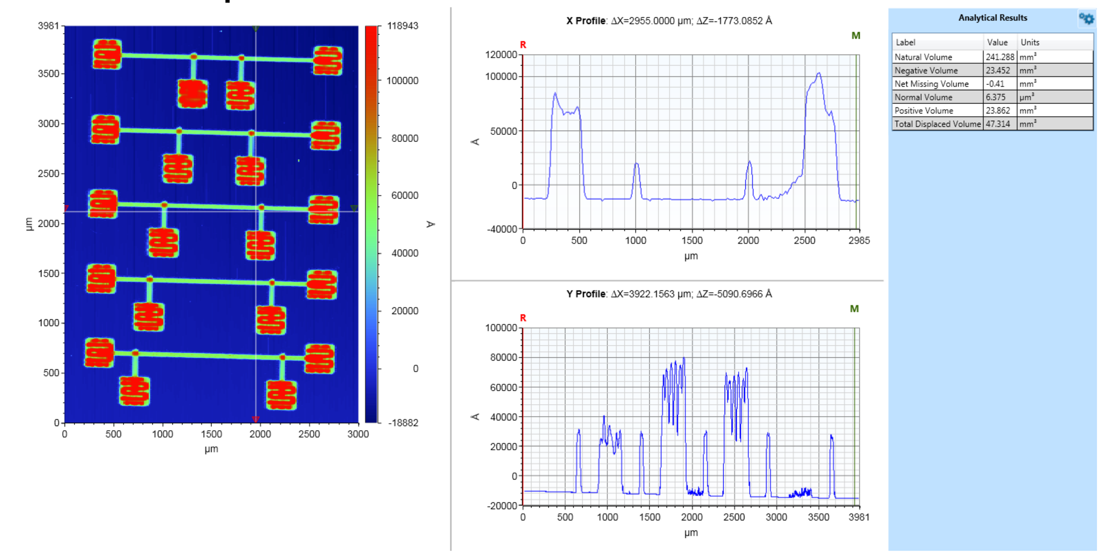


Figure 3: Map scan of melt array with dimensional analysis data

Summary

- Dimensional analysis of pre and post anneal map scan will confirm whether or not there was material loss
- Characterized melt array will be used in tests to determine if specific peak temperature has been reached or exceeded

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