ABSTRACT

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| Title of Dissertation: | EXPLORATIONS OF CARBON-NANOTUBE-GRAPHENE-OXIDE INKS: PRINTABILITY, RADIO-FREQUENCY AND SENSOR APPLICATIONS, AND RELIABILITY |
| | Beihan Zhao, Doctor of Philosophy, 2022 |
| Dissertation directed by: | Professor Siddhartha Das, Department of Mechanical Engineering;<br>Professor Abhijit Dasgupta, Department of Mechanical Engineering; |

Carbon-Nanotube (CNT) is a novel functional material with outstanding electrical and mechanical properties, with excellent potential for various kinds of industrial applications. Additive manufacturing or 3D printing of CNT-based materials or inks has been studied extensively, and it is vital to have a thorough understanding of the fluid mechanics and colloidal science of CNT-based inks for ensuring optimum printability and the desired functionality of such CNT-based materials.

In this dissertation, a custom-developed syringe-printable CNT-GO ink (GO: Graphene Oxide) is introduced and the fluid mechanics and colloidal science of this ink as well as the different devices (e.g., temperature sensor, humidity sensor, and RF antenna) fabricated with this ink are studied. The following topics are discussed in this dissertation: (1) the application and printability (in terms of the appropriate fluid mechanics and colloidal science) of CNT-based inks; (2) development of temperature sensors with CNT-GO inks; (3) development of humidity sensors

with CNT-GO inks; (4) development of RF patch antenna with CNT-GO inks; and (5) evaporation-driven size-dependent nano-microparticulate three-dimensional deposits (CNTs serve as one type of nanoparticle examined in this part of the study).

In Chapter 1 of this dissertation, a literature review is conducted on the application of CNT-based inks and the fluid mechanics and colloidal science issues dictating the printability and performance of such CNT-based inks. The problem statement and overall research plan are also introduced in this chapter.

In Chapter 2, the development of our custom CNT-GO ink is introduced. Detailed material selection and the mechanism of shape-dependent arrest of coffee-stain effect, which ensured that the printable ink led to uniform deposition, are discussed in this chapter. Temperature sensor prototypes printed with the CNT-GO inks are also presented in Chapter 2.

From Chapter 3 to Chapter 5, the performances of our CNT-GO based flexible temperature sensor, humidity sensor, and patch antenna prototypes are discussed. The ink printability on flexible thin PET films is studied, and a straightforward 'peel-and-stick' approach to use the CNT-trace (or patch)-bearing PET films on surfaces of widely varying wettabilities and curvatures as different prototypes is introduced. Excellent temperature and humidity sensitivity of our CNT-GO based sensors are presented in Chapter 3 and Chapter 4, and the potential of this CNT-GO material for fabrication of ultra-wideband (UWB) patch antennas is discussed in Chapter 5. Furthermore, the stability and reliability of these printed CNT-GO-based prototypes are also explored.

In previous Chapters, the printed CNT-GO patterns were cured by evaporation-mediated deposition on flat substrates (i.e., 2D deposition spanning in x and y directions). This motivated the extension of the physics to the 3rd dimension and probing of particle deposition on a 3D substrate and particle deposition in all x, y, and z directions. Therefore, in Chapter 6, we perform an experiment to demonstrate this kind of possibility using three kinds of micro-nanoparticle-laden water-based droplets (i.e. coffee particles, silver nanoparticles, and CNTs). These droplets were first deposited at the bottom of an un-cured PDMS film; these droplets were lighter than the PDMS and hence, they rose to the top of the PDMS where they could have either attained a Neuman like state or simply remained as an undeformed spherical drop with the top of the drop breaching the air-liquid-PDMS interface. The calculations based on air-water, water-PDMS, and air-PDMS surface tension values confirmed that the Neuman like state was not possible, and the droplets were likely to retain their undeformed shapes as they breached the air-PDMS interface. The timescale differences between the fast PDMS curing and the slower droplet evaporation, led to the formation of spherical shape cavities inside the PDMS after completion of the curing, and allowed evaporation-driven deposition to occur in all x, y, and z directions inside the cavity, with the exact nature of the deposition being dictated by the sizes of the particles (as confirmed by the experiments conducted with coffee particles, silver nanoparticles, and CNTs).

Finally, in Chapter 7, the major contributions of this dissertation and proposed future studies related to this dissertation work are listed.