Printed Electronics
Fall 2020

Instructor:
Prof. Siddhartha Das
Associate Professor
Department of Mechanical Engineering
Office: 3163 Martin Hall
Phone: 301-405-6633
Email: sidd@umd.edu

Study Materials:
Class notes and research papers provided by Prof. Das

Purpose of the Course:
Additive manufacturing has emerged as an exciting option for fabricating electronics enabling fabrications on difficult geometries otherwise inaccessible by traditional techniques. The eventual aim is to 3D print an entire electronic system. For that purpose, one needs to master the strategy to print the electrical connections (such as circuitization and interconnects) and electronic components (such as resistors, capacitors, transistors, inductors, etc.) on surfaces of varying geometries and complexities. Of course, equally important are issues for ensuring that (a) these printed components and circuitry have performance that are comparable to that of traditionally fabricated electronics, (b) they can survive different reliability tests, making them deployable actual systems, and (c) the processes can be scaled up for ensuring large volume fabrication. The development of such capabilities will require new concepts in (1) CAD design, (2) toolpath generation - CAM, (3) materials, (4) printing tools, (5) processing, and (6) reliability testing; all based on additive manufacturing rather than the more mature subtractive manufacturing methods.

This course will introduce some basic concepts of 3D printed electronics. The primary objectives of the course are:

1. Introduction of the different technologies and materials used for 3D printed electronics
2. Introduction to the relevant materials science and thermo-fluidics dictating the behavior of the nanoparticle-based inks used for the printing
3. Introduction to the current state of the art in terms of printing the electronic components (such as circuitization, interconnects, resistors, capacitors, transistors, inductors, etc.)
4. Introduction of the reliability analysis of printed electronics.

5. Providing students an opportunity for a simulation-driven research project on a cutting edge printing problem
6. Providing students live online demonstrations of actual printing and printing-related experiments.

Evaluation Procedure

Students will be evaluated on the basis of (a) regular course assignment and quizzes, (b) one numerical/simulation based group project, and (c) one 2-hour final exam

Grades:

Your final grade will be determined by the following components:

Assignments	20%
Quizzes (3 in all)	15%
Project #1	30%
Final Exam	40%
TOTAL	**100%**

SYLLABUS

Week 1 (Week of August 31)

Introduction – I

- What is printed electronics? Discussion of its need in terms of (a) replacing the standard electronic chip by printing circuits and printing circuit components (e.g., resistors, capacitors, inductors) and (b) enabling electronic circuit design on complicated surfaces inaccessible by conventional fabrication strategies.
- Physical evidence of the printed components from our research groups.
- Current and future applications of printed electronics. Examples of wearable electronics (as sweat sensors, would healing sensors, body temperature sensors, etc.), printed electronics for cellular phone, printed electronics for *in-situ* threat sensing, printed electronics for smart, temperature-adjusting car seats, etc.

Week 2 (Week of September 7)

Introduction – II

- Approaches for 3D printed electronics: Transfer printing, Aerosol Jet and Inkjet Printing (liquid-droplet based printing), Syringe Printing. Basic introduction of these processes and the examples of printed electronics achieved with these processes
- Materials for 3D printing: metallic NP-based inks. Can't use direct metals that enable such dimensions with such precisions. Brief idea of the challenges since we are entering the realm of NP colloidal hydrodynamics
- Materials on which 3D printing is achieved: FR4 to polymer. Issues of concern: wettability, adhesion of deposited traces
- Introduction of team-based research projects

Week 3 (Week of September 14)

Examples of Printed Components from Prof. Das' Lab

- Printing of conducting traces with silver nanoparticle NOVACENTRIX ink. The experiments will be conducted using the Hyrel 3D printer available with Prof. Das. The experiments will involve loading the syringe with the ink, printing traces on bare FR4 and coated (with PDMS) FR4 substrates, curing the traces, and obtaining the conductivity of the printed traces. This entire lecture will be devoted in ensuring that the students get a live online demonstration of actual syringe-based printing of the conductive traces. The students will watch the demonstration using the zoom session, while the experiments will be conducted by Prof. Das' graduate students.

Week 4 (Week of September 21)

Materials for 3D printed conducting traces - I

- Introduction to Fabrication, Processing, and Properties of nanoparticle-based conducting inks

Week 5 (Week of September 28)

Materials for 3D printed conducting traces - II

- Key thermo-fluidic and thermo-mechanic principles at pre-printing (e.g., factors driving the stability of the nanoparticles dispersed in the background solvent) and post-printing stages (e.g., formation of coffee-stain, aggregates, and cracks) dictating the use of nanoparticle NP-based inks for printing conductive traces

Week 6 (Week of October 5)

Materials for 3D printed conducting traces - III

- Examples of ink other than the metal NP-based inks for printed electronic applications (e.g., inks based on metal nanowires and inks based on graphene, graphene-oxide, and CNTs)

Week 7 (Week of October 12) (With the help of Prof. Das' PhD students)

Examples of Printed-Electronics related Experiments from Prof. Das' Lab

Live online demonstration (the students will watch the demonstration using the zoom session, while the experiments will be conducted by Prof. Das' graduate students) showing the conducting of experiments to demonstrate (a) arrest and non-arrest of coffee stain effect with certain types of inks through the corresponding drop experiments (emphasizing the need for such drop experiments for choosing the appropriate ink); (b) conducting adhesion test (scotch-test tape) to demonstrate the adhesion of the printed traces on different surfaces.

Week 8 (Week of October 19)

Detailed Understanding of the Thermofluidics of Coffee Stain Effect

- Importance of arresting the coffee stain in 3-D printing
- Introduction to Lubrication equation for modeling fluid flows in an evaporating drop
- Formation of coffee stain due to drop evaporation
- Effect of particle shapes on the coffee stain

Week 9 (Week of October 26)

Detailed Understanding of the Thermofluidics and Solid Mechanics of Aggregation and

Cracking

- Critical nucleation during aggregate formation
- Scaling of the aggregate sizes
- Role of Capillary stresses and hydrophilicity of the nanoparticles in Crack Formation
- Scaling estimates of the film thicknesses that lead to the crack formation

Week 10 (Week of November 2)

Effect of Bendability/Flexibility of the Substrates on Printed Electronics

- Mechanics of bendable/flexible substrates
- Effect of substrate bendability on Printed Electronics

Week 11 (Week of November 9) (With the help of Prof. Abhijit Dasgupta and his students)

Reliability analysis of Printed electronics

Week 12 (Week of November 16) (With the help of Prof. Abhijit Dasgupta and his students)

Reliability analysis of Printed electronics

Thanksgiving Recess (Week of November 23)

Week 13 (Week of November 30)

Summary of the course; expectations from the project presentations and the one-hour final exam

Week 14 (Week of December 7)

Project Presentation

- Presentation by each group

One-hour Final examination