

Aerosol jet fabricated biodegradable antenna for bioelectronics application

S. Agarwala^{1*}, W. Y. Yeong²

¹ Department of Engineering, Aarhus University, Aarhus, Denmark

² School of Mechanical and Aerospace Engineering, Nanyang Technological University, Singapore

* Corresponding author, email: shweta@eng.au.dk

Abstract: Aerosol jet printing is a process under the umbrella of additive manufacturing for conformably putting electronics on unconventional substrates. The project highlights potential of aerosol jet to print conformal and flexible antenna device. Polycaprolactone (PLC) polymer is chosen for its biodegradable nature. A flexible scaffold is fabricated using melt-drawn process and pre-treated with gelatin-based hydrogel to reduce surface roughness. Carbon nanotube (CNT) nanomaterial ink is printed directly on the treated PLC, and antenna characteristics are measured.

I. Introduction

Hard and rigid implants pose the risk of severe immune response, scarring of tissues, and infections [1]. This has led research community to look in to biodegradable, resorbable and transient electronics [2-3], especially antennas [4-5]. Aerosol jet, an additive manufacturing technique, is attracting attention as it can print material inks on any surface [6-7]. This has open doors to design circuits and devices using electronic inks on unconventional substrates like paper, textiles and polymers. Here, a scaffold is fabricated using a biodegradable polymer and electrical device is printed on it using aerosol jet technique. Polycaprolactone (PLC) scaffold is melt-drawn in to a sheet and coated with gelatin-methacryloyl (GelMA) material to reduce surface roughness and smooth out the surface. Carbon nanotube ink is used to print the antenna electrode design and tested for performance. The fabricated antenna is biodegradable, flexible and functional.

II. Material and methods

GelMA was synthesized by reacting Gelatin type A with Methacrylate Anhydride. Scaffolds of polymer polycaprolactone (PLC) were made by heating the materials at 150 °C in a custom made microfiber melt-drawn device. Synthesized GelMA was coated on the polymer scaffold to obtain a smooth surface, followed by printing carbon nanotube (CNT) ink by aerosol jet printer. Optomec® Aerosol jet printer was used to print the CNT ink. The average length of CNT in the ink were 1300 μm with a standard deviation of 615 μm. All materials were purchased from Sigma-Aldrich. JEOL scanning electron microscope was used for imaging the samples. The water contact angle of the ink on PLC was measured by a custom made setup with diffused light and high speed camera. The drop volume for the study was 0.2 μL. surface roughness was measured using Keyence 3D laser confocal microscope KV-X1000. Dielectric measurements of PLC samples were conducted using calibrated SPEAG DAK-TL-P measurement system fitted with a vector analyzer. Antenna was designed using ANSYS high-frequency structural simulator (HFSS). The simulation

was carried out in air with relative permittivity, $\epsilon_r = 1.00$ and conductivity, $\sigma = 5.5 \times 10^{-15}$ S/m. Antenna characterization was carried out in an anechoic chamber and the parameters were analyzed by a vector network analyzer. All measurements were performed at least five times to achieve statistically significant results.

III. Results and discussion

Polycaprolactone (PLC) is a biodegradable polymer, which exhibits excellent tissue compatibility and is widely used in tissue engineering. PLC is also well suited for implantable applications as it has higher degradation rate. Melt-drawn process is used to fabricate flat scaffolds of PLC (fig 1A). As can be observed the scaffold is made up of PLC fibers aligned side-by-side. The fabricated scaffold has high surface roughness (~ 3 μm) and water contact angle (110°) depicting the hydrophobic nature of the surface (inset fig 1B). A layer of GelMA is coated on PLC to reduce the surface roughness to 0.6 μm. Fig 1C shows the lower contact angle of 60° achieved for a more hydrophilic surface to print electronics on top. The antenna design is printed on GelMA coated PLC using CNT ink. To obtain a good electrical conductivity, it is important to print CNT along the direction of the fibers. The interfacial GelMA layer not only reduces surface roughness but also provide a continuous substrate surface to print by filling any voids in between the fibers. Printing continuous and homogeneous tracks is important to obtain a functional pattern, which enables electrons to flow. Fig 1E displays continuous and crack-free aerosol jet printed CNT network.

In order to design an antenna, it is important to know the dielectric properties of the underlying substrate. The electronic properties of PLC are unknown as its main application has been in bioengineering. This is the first attempt to measure dielectric properties of PLC material. The dielectric permittivity and dielectric loss are plotted in fig 2A. The graph has a standard deviation of 0.04. As expected, being a polymer PLC has low dielectric constant and low energy density. The permittivity is expressed as the ability of the material to polarize in response to an applied electric field. Physically it means the higher the dielectric constant, the greater will be the polarization

