Transactions on Additive Manufacturing Meets Medicine
Trans. AMMM, Vol 1, No 1, 2019, Article ID S02T02

Infinite Science | Publishing

Aerosol jet fabricated biodegradable antenna for bioelectronics application

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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, $\varepsilon_r = 1.00$ 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

DOI: 10.18416/AMMM.2019.1909S02T02

developed in the material by the applied field. The low dielectric constant of PLC indicates that it can act as insulator. The trend and values of dielectric measurements were taken in to consideration to design antenna circuit (fig 2B and C).

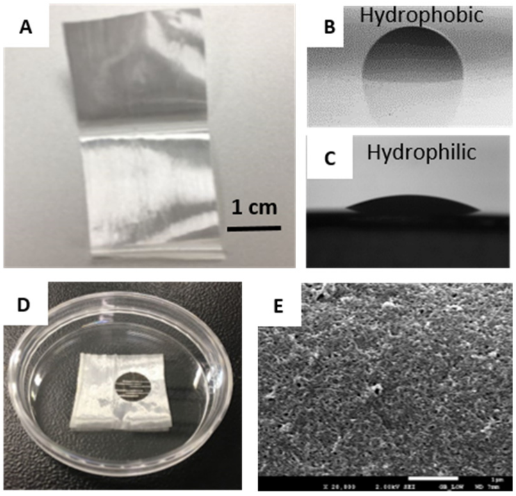

Figure 1: A) Image of melt-drawn PLC scaffold. Water contact angle measurements on B) as-fabricated and C) GelMA coated PLC scaffold. D) Antenna design printed on GelMA coated PLC using CNT ink. E) SEM micrograph showing printed antenna design.

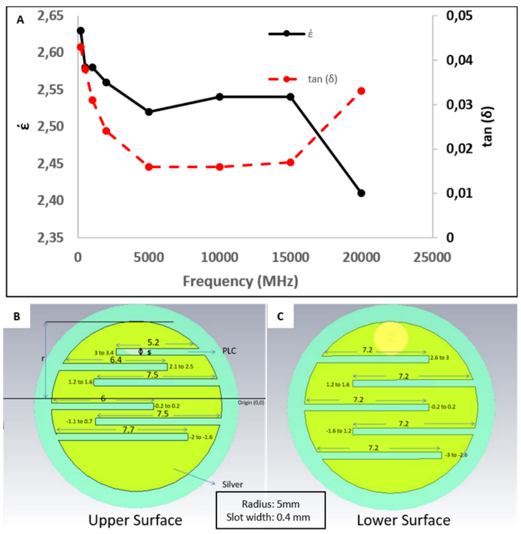

Figure 2: A) Graph plotting the trend of dielectric constant (έ) and dielectric loss (tan(δ)) for PLC material. Schematic showing physical dimensions of the antenna design on B) upper and C) lower surface of PLC to be printed using CNT ink.

The antenna design was optimized for good impedance match. The measured frequency response for 1 and 4 layers of CNT ink is shown in fig 3. Printing more than one layer is required to obtain continuous and void free films, which result in better electrical conduction. S parameter measurements are done to determine the return loss and isolation of the fabricated device. The operating bandwidth of the antenna is determined by the point where the return loss falls below -10 dB. As can be observed from the graph in fig 3, the antenna operates between 1.2-1.6 GHz and 2.4-2.7 GHz. The resulting antenna is fully printed, flexible and biodegradable. This work opens the door for employing 3D printing route of aerosol jet to design antenna on biodegradable substrate, thus bringing electronics and biomaterials on the same platform, which may have potential for implantable applications.

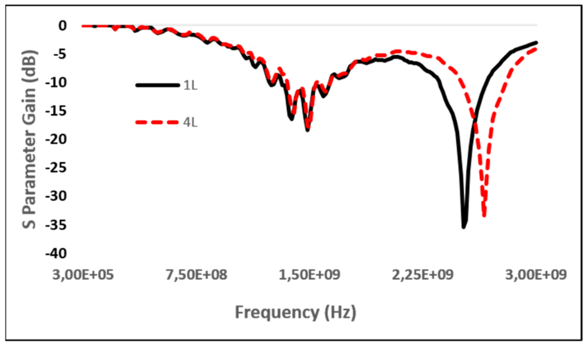

Figure 3: Plotted frequency response of the CNT printed antenna on PLC substrate. 1L and 4L refer to one and 4 layer of CNT inks printed on the polymer scaffold.

IV. Conclusions

Here we demonstrate the application of 3D printed electronics for designing biodegradable antenna for bioelectronics and medical applications. Aerosol jet is used to print CNT electrode material on a PLC polymer. PLC is well known for it's biocompatibility and biodegradability. An interfacial GelMA layer is required to prepare the PLC surface for printing CNT ink. The fabricated antenna performs well in the range of 1.2-1.6 GHz and 2.4-2.7 GHz. This work is a step ahead in fabricating conformal, flexible and biocompatible devices for future medical applications.

Acknowledgments

This research was supported by the National Research Foundation, Prime Minister's office, Singapore under its medium-sized center-funding scheme.

Author's statement

Authors state no conflict of interest.

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