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Measurements on a Thermally-Crosslinked Biopolymer for Future Implantable Antennas

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***Abstract*—The use of 3D printing in the body has a range of biomedical applications, including development of implantable antennas and other electronics. Using a biocompatible thermally crosslinked polymer material and a coaxial heating applicator, wire-like configurations could be "printed" directly into the body. This paper evaluates the heating time required to solidify the biopolymer in two concentrations of phosphate buffer solution.**

Keywords—3D printing antenna; biopolymer; wireless telemetry; implantable antenna

I. Introduction

Implantable medical devices, or IMDs, are becoming increasingly important in the medical industry. As these devices shrink in size, it is no longer practical to house the antenna solely in or on the package that holds the battery and electronics. [1] offers an innovative solution involving a focusing lens antenna that can direct energy to a small antenna in/on the IMD. This is done by constructive coupling between the two embedded biopolymer conductors (acting like wires) that focus energy at the tips. While this approach is promising, a biocompatible material with high conductivity (> 10^4 S/m [2]) is needed. We have proposed a 3D printing concept for making this antenna from a thermally activated biocompatible polymer that solidifies when heated [3], [4]. The material may be injected into the body through the hollow center conductor of a coaxial applicator, and heated by applying power to the coax. As the coaxial applicator is backed out of the body, a soft, pliable conductive wire can be produced or "printed" in the body, as shown in Fig. 1.

Conductive polymers are being designed, and this paper is a step in that direction. In this paper, we will evaluate the time required to solidify polymer materials. This is important in order to ensure that we can heat the polymer, which is initially fluid, fast enough that it does not disperse into the body tissues before solidifying. We will evaluate polymer of two different concentrations, and also egg white, which is sometimes used as a proxy for polymer heating measurements.

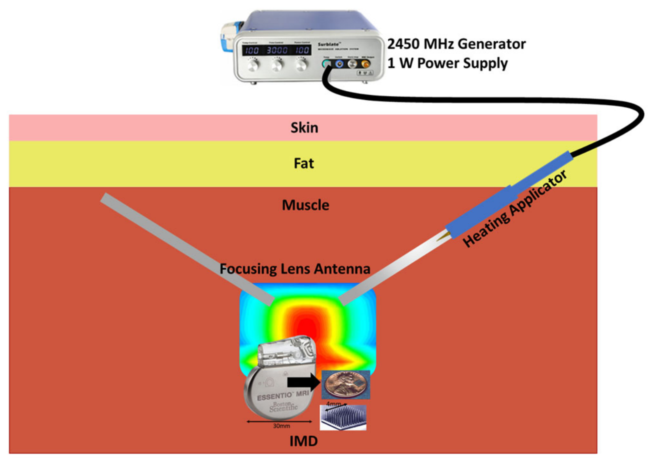

Fig. 1. The 3D-printing system which consists of a microwave generator, biocompatible biopolymer material, and a heating applicator which generates a focused lens of energy directly onto the IMD. From [4].

II. Methods and Results

A. Egg-White Simulation and Measurement

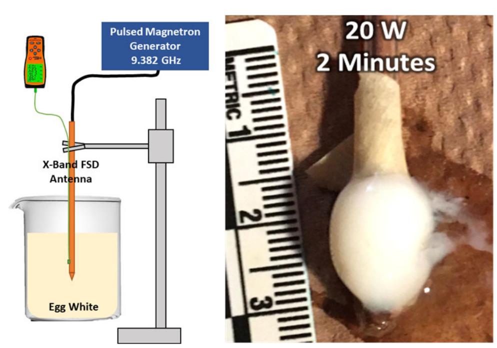

Fig. 2. A coaxial antenna used to heat in egg-white, causing it to solidify.

In previous work [5], we used an X band floating sleeve dipole (FSD) antenna connected to a pulsated magnetron generator to heat egg white, as shown in the Fig. 2. Egg white can be used as a proxy for the heating response of biopolymer. When heated for approximately 2 minutes at an average power of 20W, the liquid egg white turns to a solid as shown in Fig. 2. The temperature change as a function of time is shown by the highlighted black line in Fig.3. We also simulated the heating time at a few different monitor points of the antenna using CST Microwave Studio, and these results are shown in Fig. 3, as well.

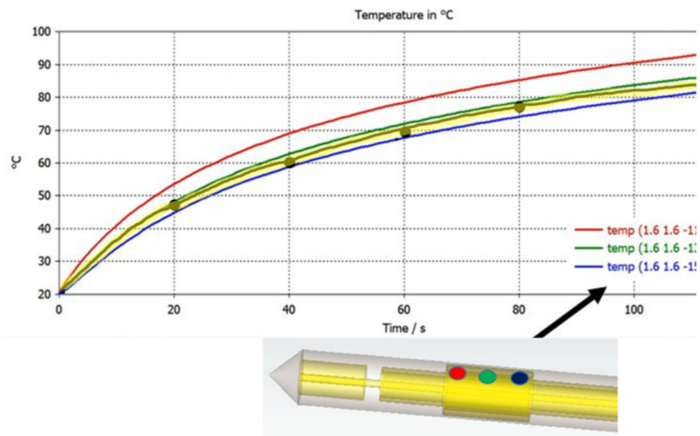

Fig. 3. Experimental and Simulation results for the change in temperature overtime for the heating of egg white. Measured results are shown in the highlighted black line and dots and are from [4].

B. *Biopolymer Simulation and Measurement*

A coaxial applicator [6] with a hollow center conductor with an extended tip was used to heat polymer in solution. Because the polymer is difficult to make, only a small quantity was available. We therefore submerged a small vial containing the polymer in a larger beaker of room temperature deionized water, to reduce reflections at the edges of the polymer, as shown in Fig. 4. The measurement setup is shown in Fig. 5. All materials are at room temperature (20°C). The system was also simulated with CST Microwave Studio.

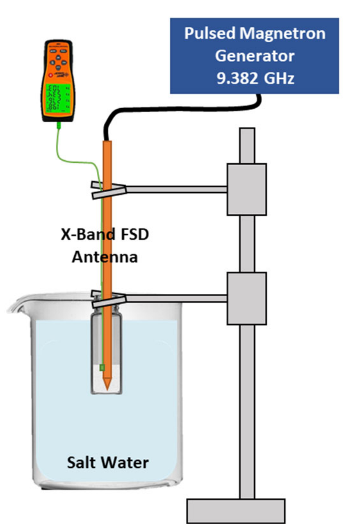

Fig. 4. Simulation setup of the biopolymer material in a vial submerged in a glass beaker of water.

The biopolymer solidifies at approximately 40 °C. At about 45 °C body tissues are damaged, so we want to stay in the range of 40-45°C. The average human body temperature is 37 °C. The simulated temperatures at the locations near the probe shown in Fig. 3 are given in Fig. 5.

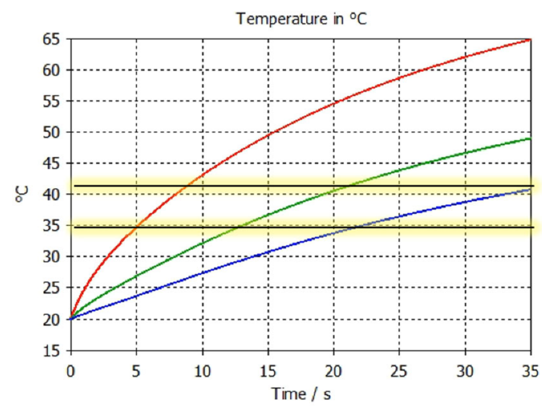

Fig. 5. Simulation results for the change in temperature overtime for the heating of the biopolymer.

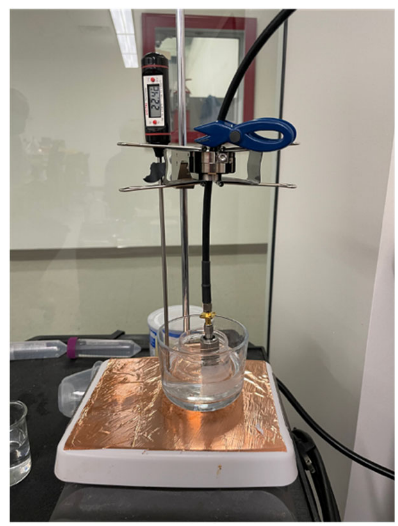

Fig.6. Experimental setup of heating of the phosphate buffer used to make the biopolymer. A dielectric measurement probe and temperature probe were immersed in a vial of polymer which was immersed in a glass beaker of 20 °C deionized water. A heating plate below slowly heats the buffer, so we can measure its electrical properties as a function of time and temperature. The hot plate is covered with a copper sheet, to help ensure repeatability of the electrical measurements.

Measurements were made on 1x and 10x phosphate buffer solutions. This buffer is used to produce the polymer, so will have approximately equal electrical properties. We placed 30mL of the phosphate solution in a vial immersed in a water bath with a hot plate underneath, as shown in Fig. 6. A temperature probe and dielectric measurement probe were placed in the polymer solution. The results are seen in Fig. 7. By varying the temperature of the buffer solutions, we observed an averaged change in the biopolymer permittivity. A nearly linear trend was observed in both buffers, with an r^2 value of 0.96 and 0.99 for the 1x and 10x buffers, respectively.

The higher level of correlation for the 10x buffer is likely due to the smaller frequency range used in our analysis.

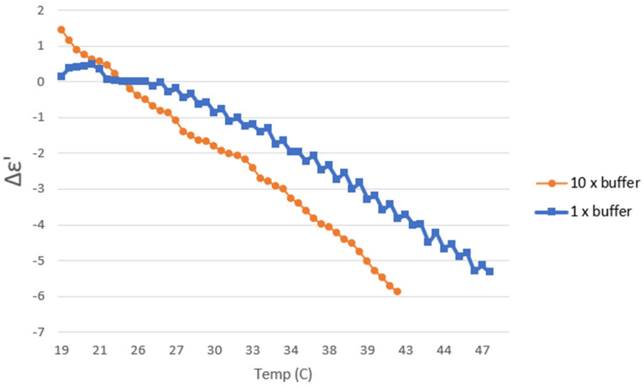

Fig.7. The results of the phosphate buffer experiment. Frequency ranges were 0-8GHz for the 1x buffer, and 2-3GHz for the 10x buffer.

III. Conclusion

In this paper, we show that the electrical permittivity of 1x and 10x phosphate buffer solutions changes as a function of temperature. These buffer solutions are electrically similar to the biopolymer. This provides values to be used future simulations, as they will affect the final design of our coaxial heating applicators.

Acknowledgment

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References

[1] H. M. Bernety, H. Zhang, D. Schurig, and C. M. Furse, "A Novel Method of Field Focusing for Implantable Devices," *IEEE Journal of Electromagnetics, RF and Microwaves in Medicine and Biology, Special Issue on the 2019 APS Symposium.*, 2020.

[2] A. Chrysler, K. Hall, F. Curry Jr., and H. Zhang, "Effect of Conductivity on Subdermal Antennas," *Microwave and Optical Technology Letters*, vol. 60, no. 5, pp. 1154–1160, 2018.

[3] F. Curry, Jr., A. M. Chrysler, T. Tasmin, C. Furse, and H. Zhang, "Biostable Cpnductive Nanocomposite for Subdermal Antenna," *APL Materials*, 2020, doi: DOI: 10.1063/5.0019720.

[4] K. L. Hall, H. Zhang, and C. Furse, "Design of an Interstitial Microwave Applicator for 3D Printing in the Body," *IEEE Journal of Electromagnetics, RF and Microwaves in Medicine and Biology*, 2020.

[5] K. L. Hall, T. Tasmin, C. Furse, H. Zhang, A. Evans, and S. C. Hagness, "Adaptation of a Microwave Ablation System for Wireless Medical Applications," presented at the IEEE International Symposium on Antennas and Propagation and USNC-URSI Radio Science Meeting, Montreal, Canada, Jul. 2020.

[6] A. Kiourti, K. A. Psathas, and K. S. Nikita, "Implantable and ingestible medical devices with wireless telemetry functionalities: A review of current status and challenges: Implantable/Ingestible Medical Devices," *Bioelectromagnetics*, vol. 35, no. 1, pp. 1–15, Jan. 2014, doi: 10.1002/bem.21813.