Bio-Compatible Implantable Energy Harvesting Device: Material Selection, Design, and Simulation

Mechanical Engineering

Students: Daniel Ryan Apuan, Greg Beyersdorf, Andrew Lute, and Majerle Reeves

Advisors: Sankha Banerjee, Ph.D.

FRESNO STATE

Lyles College of Engineering

Abstract

The ability to collect energy generated by involuntary motions that occur within the body due to organs or muscles or voluntary motions outside of the body is of importance in the biomedical engineering field. Piezoelectric materials have been studied to generate energy for implanted and external electrically powered medical devices. In this study, Barium Titanate [$BaTiO_3$], Zinc Oxide [ZnO], and Aluminum Nitride [AlN] based devices were analyzed to determine which material is most effective for internal and external applications. $BaTiO_3$ was able to produce 26 µW when experiencing 10mm stretching displacement. With this power a 10 µW pacemaker can be powered or it can provide supplemental power for an external device. A Zinc Oxide based device will be able to provide 5.47 µW. This alone will not be enough to power a single device but can provide supplemental power for small wearable devices such as external sensors. Aluminum Nitride produce 0.00576 µW, which is not enough power to be used in medical applications currently. The current work proposes proof of concept device designs based on the above analysis.

Zinc Oxide

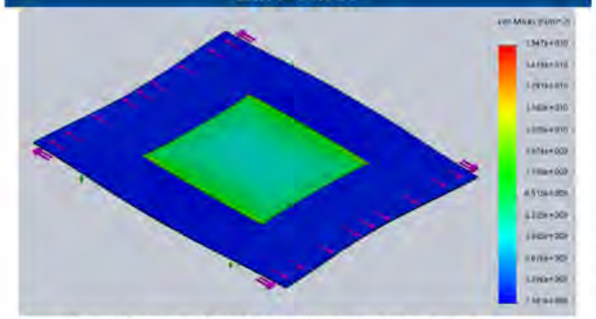


Figure 3: Stress of Zinc Oxide Device at t = 2s (maximum stress)

Aluminum Nitride

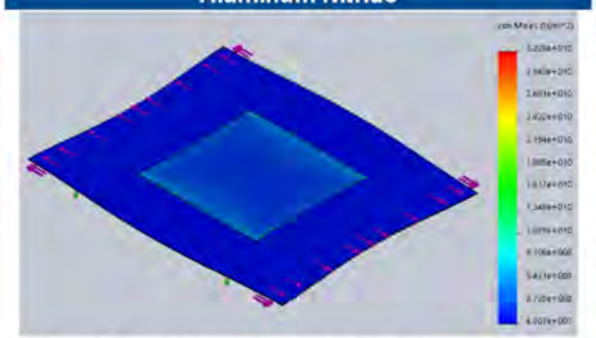
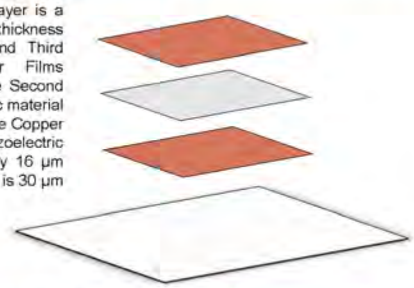


Figure 5: Stress of Aluminum Nitride Device at t = 2s (maximum stress)

Device Design

Figure 1: Assembly of the Device: The Bottom layer is a PET Substrate thickness (120µm). The Top and Third Layers are Copper Films (thickness 1 µm). The Second Layer is a Piezoelectric material (thickness 8.4 µm). The Copper Films and the Piezoelectric material are 16 µm by 16 µm and the PET substrate is 30 µm by 30 µm. [1]



Barium Titanate

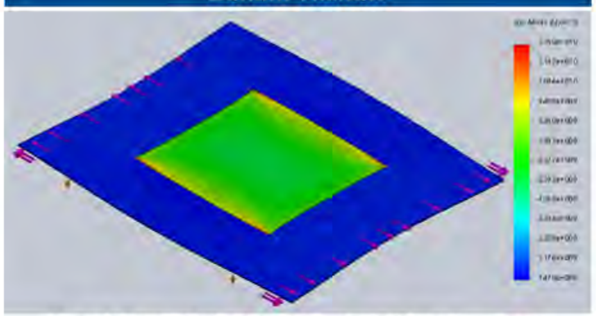


Figure 4: Stress of Barium Titanate Device at t = 2s (maximum stress)

Results

Piezoelectric Material	Simulated Power (µW)
Barium Titanate	26.0
Zinc Oxide	5.47
Aluminum Nitride	0.00576

Conclusions

Energy harvesting for biomedical devices both implanted and wearable is feasible when using barium titanate as the piezoelectric material in this device configuration. This configuration with Barium Titanate has the potential to power a cardiac pacing device (pacemaker) to extend the life the implanted batteries reducing the number of surgeries a patient undergoes. Zinc Oxide can be used for low power sensors. Under a different configuration Zinc Oxide may be feasible for use as implanted energy harvester as well with the small external sensors it is currently an option for. Due to the low value dielectric and piezoelectric properties, Aluminum Nitride is not a feasible option for energy harvesting.

Simulation Design

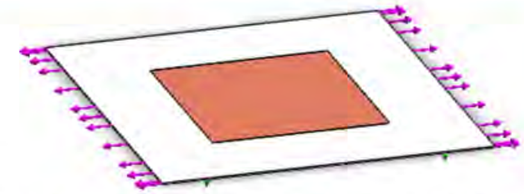


Figure 1: Forces Applied to Create a Maximum Displacement of 10mm

$$\Delta L = \begin{cases} \frac{\Delta L_{max}}{4}\left[1-\cos\left(\frac{\pi t}{T_1}\right)\right]^2 & 0<t<T_1 \\ \Delta L_{max} & T_1<t<T_1+T_2 \\ \frac{\Delta L_{max}}{4}\left[1-\cos\left(\frac{\pi(t-2T_1-T_2)}{T_1}\right)\right]^2 & T_1+T_2<t<2T_1+T_2 \\ 0 & 2T_1+T_2<t<2(T_1+T_2) \end{cases}$$

Equation 1: Function for Displacement of the Diaphragm

$$V = \frac{-\bar{e}Nt_{piezo}}{\bar{k}} e^{\frac{Nt_{piezo}}{A_{piezo}Rk}t} \int_0^t \frac{d\epsilon_m}{dt} e^{\left(\frac{Nt_{piezo}}{A_{piezo}Rk}t\right)} dt$$

Equation 2: Equation of Voltage as a result of mechanical Strain

References

[1] B. Jaffe, *Piezoelectric ceramics*. Elsevier, 2012, vol. 3.

[2] C. Dagdeviren, B. D. Yang, Y. Su, P. L. Tran, P. Joe, E. Anderson, J. Xia, V. Doraiswamy, B. Dehdashti, X. Feng *et al.*, "Conformal piezoelectric energy harvesting and storage from motions of the heart, lung, and diaphragm," *Proceedings of the National Academy of Sciences*, vol. 111, no. 5, pp. 1927–1932, 2014.

[3] H. G. Mond and A. Proclemer, "The 11th world survey of cardiac pacing and implantable cardioverter-defibrillators: Calendar year 2009-a world society of arrhythmia's project," *Pacing and clinical electrophysiology*, vol. 34, no. 8, pp. 1013–1027, 2011.

[4] "Electrical/physical properties of gan," http://www.ee.sc.edu/personal/faculty/simin/ELCT871/02%20GaN%20Properties.pdf, accessed: 2017-12-9.

[5] "Aluminum nitride," http://www.ioffe.ru/SVA/NSM/Semicond/AlN/basic.html, accessed: 2017-12-9.

[6] P. Gopal and N. A. Spaldin, "Polarization, piezoelectric constants, and elastic constants of zno, mgo, and cdo," *Journal of Electronic Materials*, vol. 35, no. 4, pp. 538–542, 2006.

[7] H. Xiao-Kang, Z. Li-Bo, W. Qiong-Shui, Z. Li-Yan, Z. Ke, and L. Yu-Long, "Determination of elastic, piezoelectric, and dielectric constants of an r: Batio3 single crystal by brillouin scattering," *Chinese Physics B*, vol. 21, no. 6, p. 067801, 2012.

Acknowledgements

Special thanks to the Southern California Edison Energy Grant for funding this project and Dr. Sankha Banerjee for advising the project.

2018