would be 1.276 A and 2.787 V, respectively, which corresponds to an output power of 3.56W. [16] Compared to the standard 5W charger which comes in the iPhone box, the power output is too low to fast charge the device. However, it is still enough power to charge the device fast enough to power it on and provide enough electricity for a few phone calls in an emergency.

D. Financial Feasibility Study

While it is difficult to estimate the cost of producing such an array, NREL has released a techno-economic analysis of the cost of III-V cells. In the triple junction, lattice matched case of InGaP/GaAs/Ge they use, the estimated cost of such a cell at a 200kW/yr production level is \$70/W_{DC} with all manufacturing costs included. [17] For this array, this means a cost of \$1031 for the iPad size and \$250 for the iPhone size. While the price for the iPhone case may be in reach for some upper-middle-class people, the cost for the iPad version is likely to restrict the sale of such arrays to the wealthy upper class.

Because much of the manufacturing cost is related to the upstart cost of purchasing and optimizing an MOCVD system, the more arrays produced, the cheaper the technology will be. Thus, to fully take advantage of this proposed device, an established mobile device case company such as Otterbox or Spec will need to invest in an MOCVD system. While the technology has been simulated here, there are still several outstanding hurdles to be crossed before the widespread implementation of such a device.

IV. Conclusions and Summary

As the world becomes increasingly dependent on mobile devices such as iPhone and iPads for everything from entertainment to contacting emergency services, the integration of renewable energy is increasingly important from an environmental and an economic standpoint. While the amount of power consumed for mobile devices is near negligible compared to automobiles and factories, the integration of an instantaneous power source to a mobile device has many applications, especially during emergencies. Thus, the efficiency of a triple-junction III-V solar cell was optimized in this report based on base thicknesses and doping concentrations. Because the dual and single junction cells are connected in series, material parameters for the dual junction cell were varied to yield the highest output current possible while the single junction cell was optimized to yield the highest output voltage. Upon connecting these two cells mechanically with four terminals, the overall cell yielded a current density at the maximum power point (MPP) of 121.67 A/m^2 and a voltage at the MPP of 2.787V. This is enough power to fast charge an iPad when the entire back of the iPad is covered in solar cells and enough to standard charge an iPhone.

Although the technological feasibility has been proven in this report, fabricating high quality materials and interfaces may further hamper the efficiency of this cell, decreasing the potential power output. Additionally, the high cost especially for the iPad precludes most Americans from purchasing such an array. Widespread investment in MOCVD technology would certainly bring the cost down, but the mobile device market is not yet ready for such a large upfront investment.

Avenues of future simulation work include investigating more material variables such as carrier lifetime, emitter doping and thickness, and the addition of an anti-reflective coating on the top of the cell. The further optimization of this device would yield higher efficiency and a smaller amount of material required to produce the same output power. The natural next step towards realizing this technology is the fabrication with MOCVD. There are additional optimization avenues required to obtain the high crystal and interface quality required for the fabricated device to perform as well as the simulated device. Once proven in the lab setting, the widespread implementation of such a device is required to drive the price down. The simulations done in this report provide the technological groundwork required for the realization of such a device.

References

[1] Solar Technologies Office, "Crystalline Silicon Photovoltaics Research," Office of Energy Efficiency and Renewable Energy, [Online]. Available: https://www.energy.gov/eere/solar/crystalline-silicon-photovoltaics-research#:~:text=Crystalline%20silicon%20PV%20cells%20have,22%25%20under%20standard%20test%20conditions.. [Accessed 18 April 2022].

[2] Solar Energy Technologies Office, "Multijunction III-V Photovoltaics Research," Office of Energy Efficiency and Renewable Energy, [Online]. Available: https://www.energy.gov/eere/solar/multijunction-iii-v-photovoltaics-research#:~:text=Three%2Djunction%20devices%20using%20III,other%20materials%20are%20being%20investigated.. [Accessed 18 April 2022].

[3] N. W. Stauffer, "Transparent Solar Cells," MITEI, 20 June 2013. [Online]. Available: https://energy.mit.edu/news/transparent-solar-cells/. [Accessed 18 April 2022].

[4] A. H. Munshi, J. M. Kephart, A. Abbas, T. M. Shimpi, K. L. Barth, J. M. Walls and W. S. Sampath, "Polycrystalline CdTe photovoltaics with efficiency over 18% through improved absorber passivation and current collection," *Sol. Energy Mater. and Sol. Cells*, vol. 176, pp. 9-18, 2018.

[5] D. Aiken, "InGaP/GaAs/Ge multi-junction solar cell efficiency improvements using epitaxial germanium," *Conference Record of the Twenty-Eighth IEEE Photovoltaic Specialists Conference - 2000*, vol. Cat. No. 00CH37036, pp. 994-997, 2000.

[6] T. Takamoto, T. Agui, A. Yoshida, K. Nakaido, H. Juso, K. Sasaki, K. Nakamora, H. Yamaguchi, T. Kodama, H. Washio, M. Imaizumi and M. Takahashi, "World's Highest Efficiency Triple-Junction Solar Cells Fabricated by Inverted Layers Transfer Process," *2010 35th IEEE Photovoltaic Specialists Conference*, pp. 000412-000417, 2010.

[7] O. Saif, "On the optimization of InGaP/GaAs/InGaAs triplejunction solar cell," *8 IOP Conf. Ser.: Mater. Sci. Eng. 4*, 2018.

[8] T. Takamoto, E. Ikeda, T. Agui, H. Kurita, T. Tanabe, S. Tanaka and H. Matsubara, "InGaP/GaAs and InGaAs mechanically-stacked triple-junction solar cells," *Conference Record of the Twenty Sixth IEEE Photovoltaic Specialists Conference*, pp. 1031-1034, 1997.

[9] Stack Exchange, October 2016. [Online]. Available: https://physics.stackexchange.com/questions/287272/the-band-diagram-of-a-p-n-and-metal-semiconductor-junctions/287282#287282. [Accessed 18 April 2022].

[10] Y. Tao, "Screen-Printed Front Junction n-Type Silicon Solar Cells," *Printed Electronics - Current Trends and Applications*, pp. 47-73, 2016.

[11] C. Honsberg and S. Bowden, "Quantum Efficiency," PV Education, [Online]. Available: https://www.pveducation.org/pvcdrom/solar-cell-operation/quantum-efficiency. [Accessed 18 April 2022].

[12] Photovoltaics Lab IOFFE, "Solar Cells," PV Lab, [Online]. Available: http://pvlab.ioffe.ru/about/solar_cells.html. [Accessed 18 April 2022].

[13] J. Geisz, S. Kurtz and M. Wanlass, "High-efficiency GaInP/GaAs/InGaAs triple-junction solar cells grown inverted with a metamorphic bottom junction," *Appl. Phys. Lett.*, vol. 91, no. 023502, 2007.

[14] Apple, "About Apple USB Power Adapters," Apple, [Online]. Available: https://support.apple.com/en-us/HT210133. [Accessed 19 April 2022].

[15] Apple, "iPad Tech Specs," Apple, [Online]. Available: https://www.apple.com/ipad-10.2/specs/. [Accessed 19 April 2022].

[16] Apple, "iPhone 13 Tech Specs," Apple, [Online]. Available: https://www.apple.com/iphone-13/specs/. [Accessed 19 April 2022].

[17] K. A. Horowitz, T. W. Remo, Brittany Smith, and A. J. Ptak, "A Techno-Economic Analysis and Cost Reduction Roadmap for III-V Solar Cells", NREL, Golden, Colorado, rep., 2018.