University of South Florida

Beyond Photovoltaics - Nanoscale Rectenna for Conversion of Solar and Thermal Energy to Electricity
(Final Report)

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Description: The main objective of the proposal is to commercialize and scale up a new technology, the rectenna, to convert waste heat energy to electricity. Although the prediction of highly efficient (~85%) solar rectennas was published almost 30 years ago, serious technological challenges have prevented such devices from becoming a reality. Since the ultimate goal of a direct optical frequency rectenna photovoltaic power converter is still likely a decade away, our plan is to convert optical solar radiation to thermal radiation (~30 THz regime) using an innovative blackbody source. Leveraging the research efforts of the world-class team members, we plan to further develop the rectenna technology that is within reach of efficient radiation conversion at 30 THz. A fully integrated, blackbody converter and a ~30 THz rectenna system will be capable of converting at least 50% of the solar and thermal energy into usable electrical power, clearly demonstrating a truly transformational new technology in the renewable energy technology sector. For the reporting period, emphasis has been placed on the development of the plasmonic emitter that converts solar radiation to infrared radiation, and the diode that acts as the rectifier in the rectenna concept.

EXECUTIVE SUMMARY

The main objective of the proposal is to commercialize and scale up a new technology, the rectenna, to convert waste heat energy to electricity. Although the prediction of highly efficient (~85%) solar rectennas was published almost 30 years ago, serious technological challenges have prevented such devices from becoming a reality. Since the ultimate goal of a direct optical frequency rectenna photovoltaic power converter is still likely a decade away, we can convert optical solar radiation to thermal radiation (~30 THz regime) using an innovative blackbody source. Leveraging the research efforts of the world-class team members, we have pursued the development of the rectenna technology that is within reach of efficient radiation conversion at 30 THz. A fully integrated, blackbody converter and a ~30 THz rectenna system are capable of converting at least 50% of the solar and thermal energy into usable electrical power, clearly demonstrating a truly transformational new technology in the renewable energy technology sector. In this project, emphasis has been placed on the development of the plasmonic emitter that converts solar radiation to infrared radiation, and the diode that acts as the rectifier in the rectenna concept. Metal-insulator-metal diodes were fabricated the self assembly (SAM) and various metal and oxide deposition layers. The results suggest that the large gradual turn on voltage of these diodes or the presence of pinholes in the insulator layer limit the application of these devices to rectennas. On the other hand the development of the infrared plasmon emitter suggests that, with additional research, the development of a suitable emitter that converts the solar spectrum to a narrow infrared range of frequencies is possible.

Detectors and sensors are an integral part of modern electronics and are crucial to highly sensitive applications. Metal-Insulator-Metal (MIM) tunnel junctions have been explored for the past five decades and are still being investigated due to its wide use of applications such as mixers, capacitors, detectors, rectifiers and energy conversion devices. In this research, various designs of thin film based tunnel junctions have been investigated and the optimum one picked for the purpose of a wide band detector up

to 10GHz based on their sensitivities. A modified design with an isolation layer incorporating a self-aligning method to increase fabrication throughput was developed. A mask for the reliability testing of multiple devices with different areas was also developed. Nickel Oxide based insulators with different stoichiometries have been incorporated in the fabrication of the device to identify which stoichiometry gives the best performance for high frequency applications. Nickel Oxide (NiO), Zinc Oxide (ZnO) and the combination of the two have been deposited using reactive sputtering and investigated as insulator materials. The bilayer devices showed increased sensitivities at lower turn on voltages and very good efficiencies at 100MHz and 1GHz. Although, the MIM device provides a simple structure, some of the critical parameters required to quantify the device functionality are still being explored. Based on the parameters, a criterion was developed to help engineer a tunnel device for a desired detectivity.

Control of spectral thermal emission from surfaces may be desirable in some energy related applications, such as nano-scale antenna energy conversion and thermophotovoltaic conversion. There are a number of methods, from commercially available paints to advanced surface gratings that can be used to modify the thermal emission from a surface. To find out the proper emission controlling technique for a given energy conversion method all the surface emission controlling methods are comprehensively reviewed regarding the emission control capabilities and the range of possible applications. Radiation with high degree of coherence can be emitted using advanced surface emission controlling techniques. The entropy of the thermal radiation, and therefore the exergy, is a function of the degree of coherence. A methodology is presented to calculate the exergy of partially coherent wave fields so that the radiation fields can be evaluated based on exergy. This exergy method is extended to develop a rigorous evaluation criterion for thermal emission controlling methods used in frequency dependent energy conversion applications. To demonstrate these developed criteria using actual data, a surface plasmon emitter is designed and fabricated. Also, possible ways of improving the emitter performance and the research needed to be carryout to fabricate cost effective emitters are described.

Patents

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