

Integration of Knowledge for a Multidisciplinary Research Project in Engineering and Science Undergraduate Majors

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Abstract

This is a multidisciplinary research project model that combine elements from electrical engineering, computer engineering, mechanical engineering, and science. The project topic was chosen in the solid state area targeting solar energy application. The solving approach inquires mathematical model, CAD simulation, and experimental verification. The paper details the educational aspects of the project and the integration of knowledge in various fields. The project investigates a unique design for a high efficiency photovoltaic device using composite semiconductor materials interfaced to a diamond metallic substrate. The research also deals with optimizing the thermal response of the semiconductor metallic interface. The proper widths of the various semiconductor and metallic layers of the device will lead to maximum transmission for the thermal carriers throughout the device.

Key Words

Other: undergraduate research

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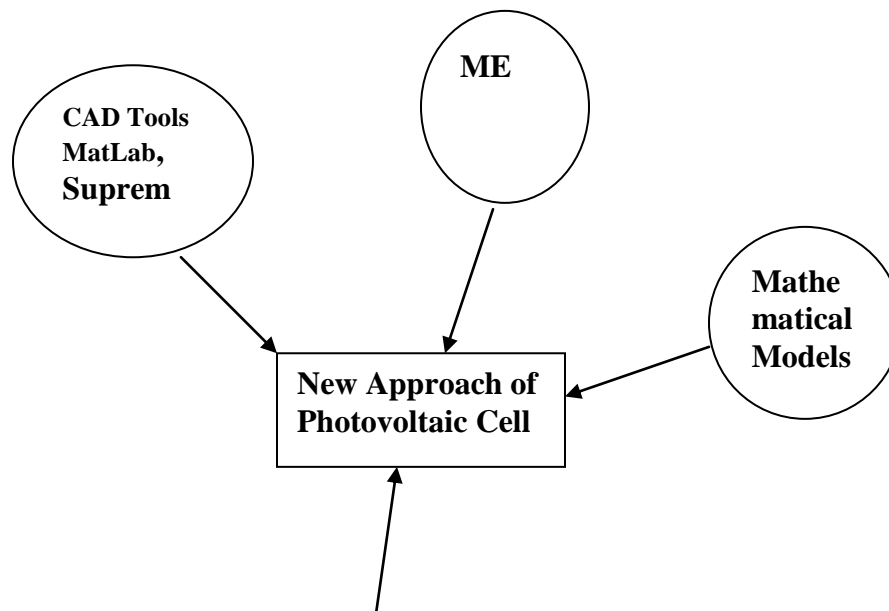
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I. Introduction

The importance of multidisciplinary undergraduate research activities have been emphasized recently by many campuses across the United States. The multidisciplinary undergraduate research initiative (MURI) [1] at the Indiana University Purdue University Indianapolis (IUPUI) was established in 2004, to enhance undergraduate students across the campus to pursue research projects to serve the community. Research projects are proposed every semester including summer sessions, and the selected projects are those that pass the screening and reviewing process. Within the MURI program at IUPUI, the integration of knowledge from various fields can be put together in a research project to accomplish enhanced performance devices and systems resulting in smart functions, better reliability, and high efficiency.

II. The Research Model

The proposed project objectives the design and manufacture of a new photovoltaic solar cell that can achieve higher efficiency as compared with the current technology. The idea is to use compound semiconductors interfaced to metallic material that maximizes the heat transfer from the metal to the semiconductor materials. The proper matching of the composite substrate may lead to maximum power efficiency. The new model approach the maximum efficiency in two fronts: the conduction heat transfer and the electron hole pair carriers generated from the solar energy penetrating into the compound semiconductors. In order to achieve such multidisciplinary project,



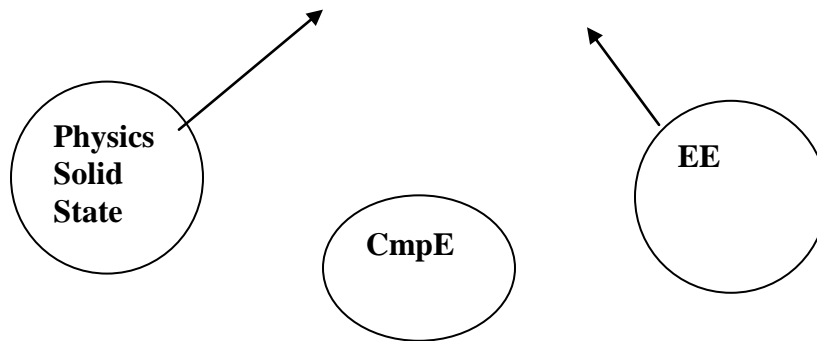


Figure 1: Integration of Knowledge from Various Fields Leading to the New Approach of the Photovoltaic Cell

As indicated in figure 1, the proposed project requires students with background from various fields that can be integrated into one multidisciplinary project. The pre-requisite materials required for this project are:

1. Solid state Physics (science)
2. Solid State Devices (EE) with tunneling properties
3. CAD tools (CmpE)
4. Thermal sciences (ME)
5. Software development (CmpE)
6. Integrated Circuit manufacturing (EE)

The multidisciplinary team assembled for this project consisted of

1. One student pursuing dual degrees:
 - a. B.S. in Physics
 - b. B.S. in electrical engineering
2. One student in computer engineering major
3. A faculty member in electrical and computer engineering
4. A faculty member in mechanical engineering
5. A research scientist in electrochemistry

The project duration is one semester period and a final report is required at the end of the semester. The research will follow two steps:

1. Electronic device model using MatLab simulation. This will lead to the best composite material that can generate sufficient electrical carriers and collect them via strong electric field strength.
2. Thermal simulation. This can be accomplished by either phonon modeling or solving heat equation over various boundaries. The following gives details for the two methods:

Throughout the project, it was the students' primary responsibility to generate mathematical models for the device's operation, under the guidance of the faculty and mentors. In most cases, the students were directed by the faculty toward reference materials, general concepts, and theories that would be useful to model the device, but the students were ultimately responsible for researching and implementing the theories into cohesive models. The faculty had done early work predicting what the expected materials, structure, and operation of the device would be, and it was the student's responsibility to provide more mathematically concrete models and optimization from the initial assumptions and expectations. Throughout this stage of the research, the faculty and students met one to two times per week to discuss the student's progress, get feedback from the faculty, and allow the faculty to direct the student's work on a regular basis.

A combination of layers must be optimized to motivate the thermally generated excitons from the compound semiconductor materials to the metal contacts. It is known that semiconductors produce a small thermally generated exciton population at room temperature as a result of phonon interaction through phonon/exciton equilibrium. While these thermal carriers have been used for other applications, such as improved MOS refresh rate via gold doped generation centers, thermal carriers are often ignored or avoided as dark current [1,3]. Here the phonon generated excitons will provide the primary source of electrical carriers for energy extraction. The number of thermally generated carrier and their generation rate are proportionate to the bandgap of the semiconductor, the crystal quality, and the temperature of the environment, using, at least partially, the Fermi-Dirac probability function. Under normal conditions these carriers will maintain thermal equilibrium throughout the device, however, tunnel barrier's are able to generate a nonequilibrium asymmetry of phonon generated electrical carrier populations as a result of drift-diffusion asymmetry [3,4]. Further carrier collection is supported through asymmetric metal contacts that generate large intrinsic electric fields inside the semiconductor inducing drift and exciton separation, as seen in many organic photovoltaic and silicon PIN junction devices [3]. Maximum power for a given operating temperature occurs when the maximum electrical current generated and extracted from the compound semiconductor equals the maximum direct tunneling current for a given thickness of semiconductor oxide. The following assumptions may be considered:

1. The only source of the phonon conversion to electrical excitons is the compound semiconductor (Germanium Tin) due to its relatively low bandgap compared to the surrounding materials.
2. The quality of the Germanium Tin, and therefore, the thermal generation rate of the semiconductor excitons are consistent with other CVD manufactured semiconductor devices (between 1×10^{-5} and 1×10^{-8} seconds).

With preliminary MatLab simulations we have obtained promising results. Figure 2 shows the current density obtained for various oxide thicknesses for the proposed materials. With a built in potential of 1eV at each interface (2eV overall which can be obtained from standard asymmetric metal contacts), we have shown direct tunneling can provide $>1 \text{A/cm}^2$ with an oxide thickness of over 1.7nm, which is sufficient to collect the majority of the generation current from the cell. Based on a band gap of 0.37eV for the

GeSn and reasonable generation rates assumptions, this device could produce power densities greater than 0.5 W/cm^2 , more than double standard silicon photovoltaic devices.

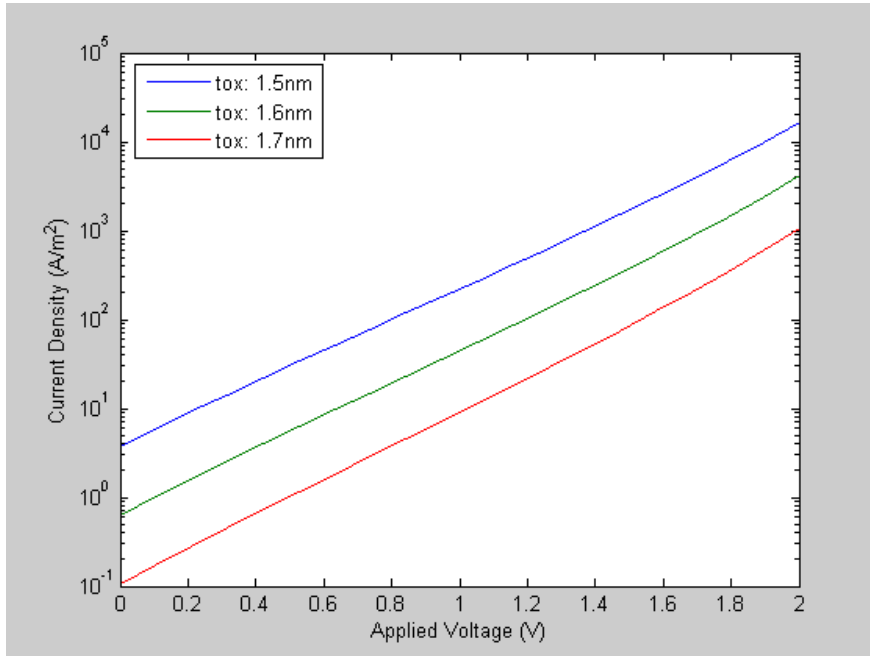


Figure 2: MatLab simulation for oxide thicknesses representing tunneling currents for the proposed device

A combination of layers must be optimized to improve the transfer of heat from the diamond material to the compound semiconductor materials. It is known however, that the discontinuity at the interface of two solids introduces thermal resistance which is a function of the acoustic velocity of the phonons in the two media. The maximum transfer of the thermal phonons across the discontinuity occurs when the acoustic impedance of the two match. Figure 3 shows that the Diamond material exhibits the highest thermal conductivity among the good thermal conducting materials. In our simulation, the following assumptions may be considered:

1. The source of heat is assumed to be at the diamond material. This is due to the high thermal conductivity of the diamond as compared to the GeSn (Germanium Tin) compound materials.
2. The source of heat induces an acoustic pressure in one dimensional towards the compound semiconductor. In other words, only conduction heat transfer is considered.
3. The wavelength of the phonons is too short compared to the dimension of the semiconductor materials. In all practical consideration, we deal with the problem as a one dimensional problem (plane wave).

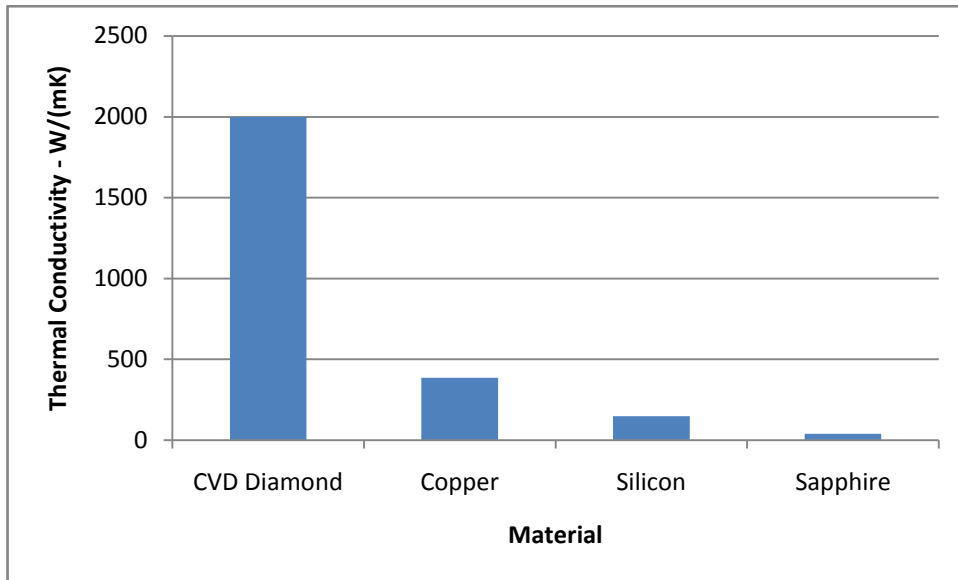


Figure 3: High thermal conducting materials that shows diamond thermal conductivity

The methodology proposed here is summarized as follows:

1. Electronic semiconductor compound structure that lead to
 - a. high electric field strength
 - b. maximum generated current
 - c. maximum tunneling probability through the semiconductor dioxide materials.
2. The thermal simulation of the diamond interface with the compound semiconductors.

III. Acknowledgement:

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