UNIVERSITY OF FLORIDA

A Low Cost CIGS Thin Film Hot Carrier Solar Cells

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Description: PV has entered into a period of record growth. Most of the current production is based on crystalline Si technology. However, there are fundamental limits to the ultimate Si costs that may inhibit it from achieving the desired level of contribution to worldwide energy production. In contrast, thin-film PV technology can reach the desired outcome due to fast deposition rates and lower cost. USF, UCF and UF play a lead role in developing these technologies. The world record 16% efficiency for CdTe was set by USF and held for 10 yrs. The time has come to coordinate the leading-edge resources within the SUS and establish a Florida PV industry. To achieve the desired level of energy generation, efficiency has to be >13%, which has been achieved in the laboratory; however, there is an inability to transfer laboratory success into manufacturing success. The transfer process has been the purview of industry, with limited success. What is needed is a fundamental understanding of this process, which can best be done in a university environment with industry cooperation. It is proposed to combine SUS expertise with local industry to develop this foundation. We will build and operate a pilot line that includes all aspects of module fabrication and characterization for the SUS/industry partners to develop manufacturing processes.

Budget: $450,000

Universities: UF

External Collaborators: NA

Progress Summary

Research Objective: Low cost CIGS based hot carrier solar cells are studied for cell conversion efficiency improvement. To extract hot photogenerated carriers we plan on using phonon engineering in the absorber layer and device engineering for optimizing energy selective contacts. To increase throughput, a CVD approach is explored.

Progress: Phonon engineering in the CIS absorber layer was studied to reduce the thermalization of hot carriers. Hot photogenerated carriers transfer their excess energy to the lattice in the form of an optical phonon. Typically an optical phonon decays into two, equal energy, acoustic phonons, via what is known as the Klemens mechanism[1]. Optical phonons are high-energy stationary lattice waves and are actually able to transfer energy back to the carriers to keep them hot. Acoustic phonons on the other hand are low energy propagating waves. Once energy is in the form of an acoustic phonon, it cannot be recovered to re-heat carriers.

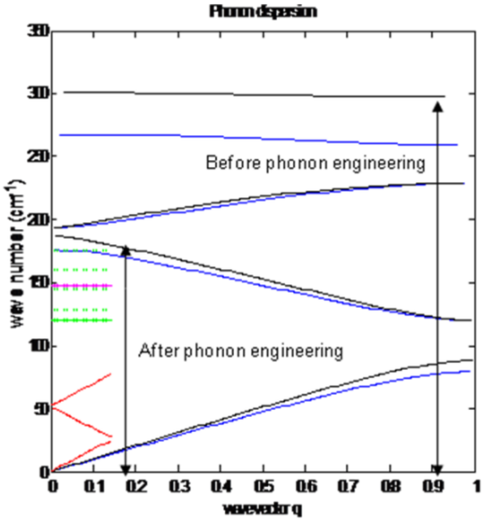

Fig.1 Phonon Dispersion Curve

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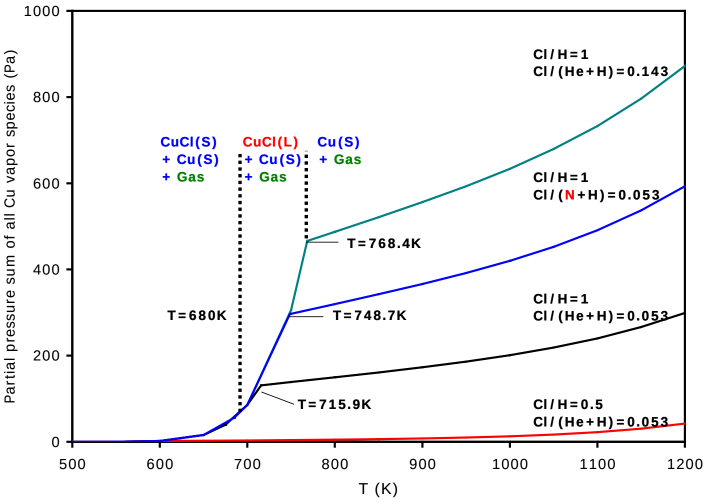
[1] P. G. Klemens, "Anharmonic decay of optical phonons," Phys. Review, vol. 148, no. 2, 845 (1966)

Phonon engineering was studied in this period to block the Klemens mechanism so as to keep the high energy photoexited carriers hot until they reach the contacts. As an example the phonon dispersion curves of bulk CIS and CIGS and a CIS/CIGS super lattice with layer widths of 5 and 12.5 Å, respectively, were calculated as shown in Fig. 1. In the superlattice phonon mini gaps result in the acoustic phonon branch. Obviously optical phonon decay into acoustic phonons whose energy would fall into these gaps is forbidden since there is no allowed acoustic phonon state. By optimizing material composition and feature size, the Klemens mechanism can be blocked. Also the optical phonon branch of the superlattice becomes discrete, reducing the likelihood of Klemens transitions.

We are in the process to validate simulation results with experimental data. Raman and FTIR spectroscopy experiments to measure phonon energies are underway in collaboration with the Chemical Engineering and Physics Departments at UF, respectively.

Device engineering of energy selective contacts[22] was investigated for the purpose of extracting hot carriers at the contacts without energy loss. Firstly, the contacts are required to be very thin so that carriers are collected before they interact with the lattice. Secondly, the design should allow for the collection of carriers in an optimal energy range. Carriers having energies outside this range are rejected to prevent scattering loss. Energy confinement can be realized by quantum mechanism tunneling or interband resonant tunneling such as in Esaki diodes. Quantum dots also provide total energy confinement but it is hard to control the size uniformly[2]. Alternatively, Esaki tunneling junctions are easy to fabricate and provide energy selective properties. We are currently simulating germanium Esaki diodes to study how material properties (band gap, affinity and carrier density) affect the energy selective range. Subsequently Esaki diode contacts of material compositions compatible with the CIGS matrix will be integrated with a phonon engineered CIGS absorber. Via simulation optimal energy selection and device structures will be analyzed to achieve higher efficiencies.



The goal of this proposal is to evaluate the feasibility of the envisioned process. This will be accomplished in a 2-phase investigation supported by process modeling. The first phase aims to demonstrate the individual deposition stages in the envisioned process to understand their process characteristics and define the limits of operation. The next phase is to emulate the countercurrent process to grow a CIGS layer, fabricate devices, and characterize their performance. A complex chemical equilibrium description of the process has been completed to identify the feasible operating ranges. The figure to right shows the transport efficiencies for Cu as a function of temperature for 4 different inlet conditions. As can be seen there exists a minimum operating temperature for which Cu can be effectively transported. A reactor has been designed and constructed to explore this process and Cu transport and deposition has been verified.

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[2] Gavin Conibeer, Nicholas Ekins-Daukes , Jean-Francois Guillemoles , Dirk Koenig , Eun-Chel Cho, Chu-Wei Jiang, Santosh Shrestha , and Martin Green, " Progress on hot carrier cells," Solar Energy Materials & Solar Cells 93, 713, (2009)