Investigation of contact grid geometry for photon-enhanced thermionic emission (PETE) solar converters

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by

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Abstract

Conversion of solar radiation to electricity with Photon Enhanced Thermionic Emission (PETE) uses both photonic and thermal excitation of charge carriers in a semiconductor. This device includes a semiconductor cathode illuminated and heated by concentrated sunlight, and a cooler anode separated by a small vacuum gap. Theoretical conversion efficiency under concentrated solar radiation is predicted to reach about 45%, and with addition of a second stage that converts waste heat from the anode, the overall efficiency may exceed 50%.

In this thesis, two device configurations are investigated, where the grid of electrical contacts is placed at the front surface or the back surface. The performance of PETE converter devices as a function of the geometry of these configurations is evaluated. A two-dimensional simulation model was developed, which allowed the comparison of various device configurations. The governing equations include the 2-D continuity equations for electrons and holes coupled to Poisson’s equation. The simulation accounts for all bulk and surface recombination mechanisms. The boundary conditions describe the contact geometry, the applied voltage, and surface conditions (work function) optimized for electron emission. The simulation results include the spatial distribution of potential and charge carrier concentrations, as well as the externally measured current. While previous work presented zero- and one-dimensional models, which are incapable of addressing realistic device configurations and the impact of contacts geometry on device performance, our two-dimensional model addresses, for the first time, the important effects of shading, recombination, and ohmic resistance related to the contact configuration.

The two-dimensional simulation results show that a reduction in the contact area indeed, reduces the electron contact recombination. Moreover, the results show that the combination of a small contact area and a relatively low acceptor concentration near the contact can lead to a contact electron injection, even in relatively low operation temperature. Despite the shadow, a 2-D model with pp+ junction and a small contact predict to reach considerably higher performance than the performance that was exhibited by the 1-D model. A cathode covered by 10% contact and illuminated by 1,000 suns, attains about 15% efficiency at 550 K, and 40% at the thermal balance.
temperature. This is in comparison to about 12% and 33% efficiency, respectively, which was predicted by the one-dimensional mode.

The second goal of this thesis was to explore the influence of the transference of the electric grid to the back of the cathode. The back contact configuration has the advantage of both, to allow 100% illumination, and to absorb the sub bandgap photons that are transmitted through the semiconductor cathode (IR coupling element). Previous works assume that the IR coupling element, that absorbs all the sub-bandgap radiation, exists in the PETE cathode. Yet, an application for such a device is not suggested in these studies. Here, we propose a solution, which consists of the back configuration of a partial contact grid. In order to describe a device with a back contact, we also used a two-dimensional simulation that is different from the front contact model only in the surfaces of the boundary conditions.

The results show that the possibility to use a relatively wide contact without lowering the illumination is very effective in particular if operating in relatively low cathode temperatures. Moreover, the addition of an IR coupling has the potential to increase the PETE conversion efficiencies. The back contact configuration also leads to reduction in electron contact recombination in comparison to the front configuration.