Diamonds are a Sun's Best Friend:
Examining the Photoconductive Properties of Diamond to Improve TEC Efficiency

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Introduction:

- Thermionic Energy Conversion (TEC) is a means by which thermal energy can be directly converted into electrical energy, bypassing the conventional need to go through the medium of mechanical energy via a generator. When a material is heated, electrons with sufficient energy will be emitted through a process known as thermionic emission. A current can be established using this principle by engineering a "hot" cathode nanometers away from a "cooler" anode thus capitalizing on the flow of electrons from hot to cold surfaces.

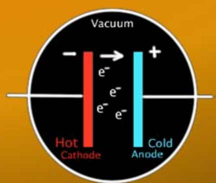


Figure 1
The process of thermionic emission. Electrons flow from a hot cathode to a cooler anode to create a current.

- In the phenomena of photoconductivity, photons are absorbed by electrons, imparting them with sufficient energy to excite from the valence band (E_V) to the conduction band (E_C). Both the excited electrons or the holes they create can then drift or diffuse creating current.

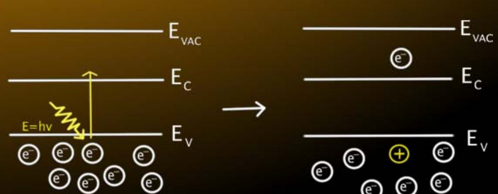


Figure 2
Generation of electron-hole pairs resulting from photon excitation

- Diamond is one of the most efficient electron emitting materials and is being studied as a candidate for TEC devices. In this study, we examined the photoconductivity and the effect of temperature on a boron doped diamond film deposited via MPCVD on a molybdenum substrate as a means to create a more efficient TEC device capable of using solar energy as both the thermal and photonic energy source.

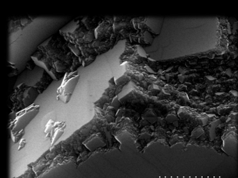


Figure 3
SEM picture of diamond film magnified to 10,000x. The polycrystalline nature is easily apparent at this magnification.

Experiment:

- Our experiments used two different configurations, one biasing the sample through the diamond films as shown in Figure 4 and the other biasing the sample across the diamond film as shown in Figure 5.
- Both positive and negative current can be achieved with this set up by switching the leads attached to the diamond-molybdenum substrate.
- A separate experiment was completed that did not involve the voltage source, rather we recorded current and voltage that arose strictly from turning the solar emulator on.
- Thermal characterization was performed similarly, the only differences being the light source was removed and the sample was placed on a hot plate.

Figure 4

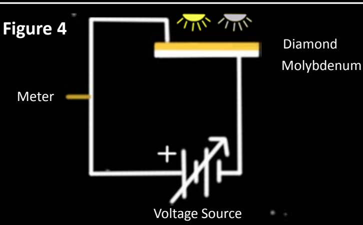
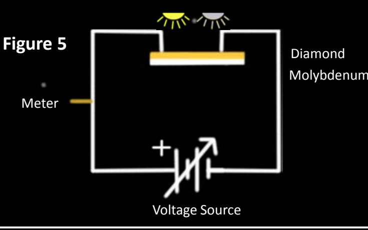


Figure 5



Results:

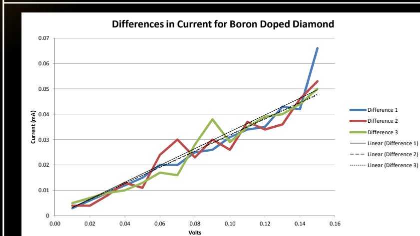


Chart 1
This is a plot of the difference in current (mA) between having the emulator on and off. Notice the larger difference as voltage rises.

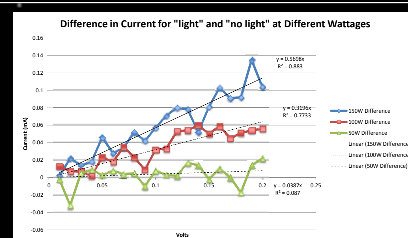


Chart 3
Observed IV data at varying light intensities. The graph implies that the solar emulator did indeed have a photoconductive effect on the diamond film by the decreasing trend in the difference as the wattage was decreased.

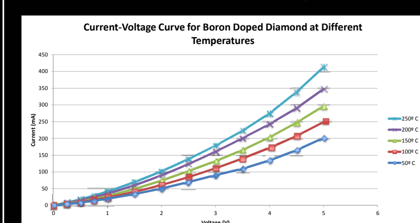


Chart 2
This graph shows the IV curves for the boron doped diamond film at different temperatures. Note the increase in current flow as temperature increases.

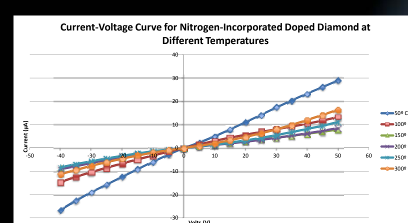


Chart 4
A comparison test for temperature effects was run on a nitrogen-incorporated diamond film. There was a linear correlation at lower temperatures and a non-linear correlation at higher temperatures.

Conclusion:

- It is apparent from Charts 1 and 3 that sunlight does have an observable effect on boron doped diamond films. The photoconductivity could enhance the efficiency of a TEC device that uses a diamond-molybdenum cathode as its electron source.
- Chart 4 shows the effects of heat on a nitrogen-incorporated diamond film. A similar effect is seen only as temperature is relatively high. Photoconductive test were run on the nitrogen-incorporated sample that produced very little change in current density. This shows that boron doped diamond acts more like a traditional semiconductor material than nitrogen-incorporated diamond.
- Current photovoltaic cells suffer from dramatically decreased efficiency when heated to temperatures exceeding 100ºC, rendering them useless at high temperatures. Chart 2 shows that the diamond's effectiveness actually increases with temperature, making it desirable to use in a device that uses TEC and solar energy conversion.
- Eliminating the need for a heat source in TEC devices by using the sun makes the device more efficient. This research has shown that diamond films are enhanced by photoconductivity. If the sun was used to drive a TEC device that uses diamond films as its material, it could benefit from using solar energy to heat the device as well as the increase in current density arising from the photoconductivity of the films. Incorporating these two elements together provides a pathway to a more efficient TEC device that could be developed into a device competitive with commercial photovoltaic systems.

Figure 6
Shown here is a parabolic solar collector designed to use the suns energy to heat a Stirling engine*. This concept could be used to heat a diamond TEC device.

*Picture modified from http://en.wikipedia.org/wiki/File:EuroDishSBP_front.jpg. Original in the Public domain.