HOLOGRAPHIC LIGHT FILTERING WITH PHOTOVOLTAIC CONCENTRATOR SYSTEMS

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ABSTRACT

Photovoltaic concentrator systems are limited by a cell's responsivity. Light that does not meet the bandgap requirements increases the temperature of the solar cells. This temperature gain may decrease a cell's efficiency by approximately 0.5%/°C. Rejecting a certain range of the electromagnetic spectrum may reduce the temperature gain of solar cells. This research used 5X, 15X, and 30X Fresnel lenses in combination with three holographic light filters centered at 950 nm, 1100 nm, and 1200 nm with a 200 nm bandwidth. Measurements of the 16 treatments consisted of open-circuit voltage (Voc), short-circuit current (Isc), and temperature. The average Isc of the cells was increased by all three concentrations. The holographic light filters reduced current by up to 16%. The temperature was decreased by up to 5.7 °C due to the holograms. The 30X, 1100 nm treatment performed best of all the treatments.

1. INTRODUCTION

Photovoltaic solar power is a potential renewable energy source that may reduce consumption of traditional fossil fuels. However, the low efficiency of 15-18% and high initial and upkeep costs tend to prevent people from using this energy source. If efficiency is improved, solar energy will decrease in price and may become more practical for private, commercial, and public use.

1.1 Previous Research

Attempts have been made to increase the efficiency of photovoltaic solar cells that approach the problem from several angles. Many of these solutions include increasing the light intensity upon solar cells [5,6], increasing the optical path length of photons within the semiconductor material [1,7], and altering the spectrum of light that passes through a solar cell [2,4,5]. A common factor of each of these solutions is the attempt to increase the number of photons absorbed by the semiconductor to generate a greater power output.

1.2 Effects of Concentration

By increasing the concentration of light upon a solar cell, the current increases; however, the temperature also increases which leads to a drop in efficiency of 0.5%/°C. This effect is due to the light longer in wavelength than the bandgap energy of the cell and light with wavelength much shorter than the bandgap wavelength. Both are not absorbed efficiently or at all. Removing these wavelengths of light would reduce this derogatory effect on the cells.

This experiment uses a variety of Fresnel lenses acting as light concentrators and holograms as light filters. It has been estimated that the optimal area of light that should reach silicon cells is between 450 nm and 920 nm [5].The dichromated gelatin (DCG) holographic light filters were developed to reflect different portions of the electromagnetic spectrum at 950 nm, 1100 nm, and 1200 nm, all with a bandwidth of 200 nm.

2. OBJECTIVES AND GOALS

The purpose of this research was to determine the effect of filtering specific ranges of light in combination with concentration on the short-circuit current (I_{sc}) and temperature of monocrystalline photovoltaic cells.

3. EXPERIMENTATION

3.1 Holographic Light Filters

Three dichromated gelatin (DCG) reflection holograms were developed to reflect ranges centered at 950 nm, 1100 nm, and 1200 nm in wavelength with each having a 200 nm bandwidth and high diffraction efficiency. The holograms were sealed using glass and optical glue. All three holograms had a secondary reflection peak at half the primary peak wavelength. This small range with low diffraction efficiency reflects light that usually contributes toward electrical output (Fig. 1).

3.2 Sun Tracking

A two axis sun tracking system was constructed using an Arduino Mega 2560, an Adafruit Motor Shield, and two unipolar stepper motors. This system was capable of holding four 20 mm by 25 mm monocrystalline photovoltaic cells, three Fresnel lenses, and holographic light filters. The four concentrations of light used were 1X, 5X, 15X, and 30X.

3.3 Data Logging

The Arduino microcontroller was used to collect data from the four solar cells during testing. Every 30 seconds, the open-circuit voltage, I_{sc}, and temperature in degrees Celsius was measured. I_{sc} was collected using a hall effect sensor and temperature collected using a 10,000 ohm thermistor. A relay switched between an open circuit and a short circuit.

3.4 Testing

The 16 possible treatments of light concentration and holographic filter were each tested for 30 minutes. Only four treatments were tested at any given time, and one was always the control. Table 1 lists the five different trials required to test all the treatments.

TABLE 1: Five different tests conducted

Test 1	**Test 2**	**Test 3**	**Test 4**	**Test 5**
Control	Control	Control	Control	Control
950nm hologram	30X; 950 nm	30X; 1100 nm	30X; 1200 nm	30X lens
1100nm hologram	15X ; 1100 nm	15X; 1200 nm	15X; 950 nm	15X lens
1200nm hologram	5X; 1200 nm	5X; 950 nm	5X; 1100 nm	5X lens

4. RESULTS

The current of the solar cells was increased by all three concentrations of light. The 5X, 15X, and 30X Fresnel lenses increased the short-circuit current by 2.2 times, 6.7 times, and 7.2 times, respectively. The holographic light filters decreased the current by up to 16%, which does not include the effect of the glass plate the holograms are on. The temperature was decreased by 0.6 °C, 5.7 °C, and 3.4 °C by the 950 nm light filter, 1100 nm light filter, and 1200

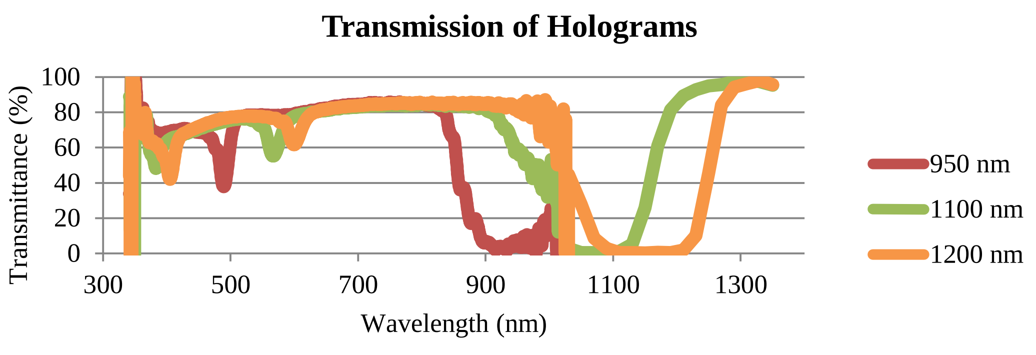

Fig. 1: Transmission of the holographic light filters versus wavelength. The blue regions are wavelengths that contribute to electrical production and the red regions are wavelengths that contribute to temperature gain in conventional panels [5].

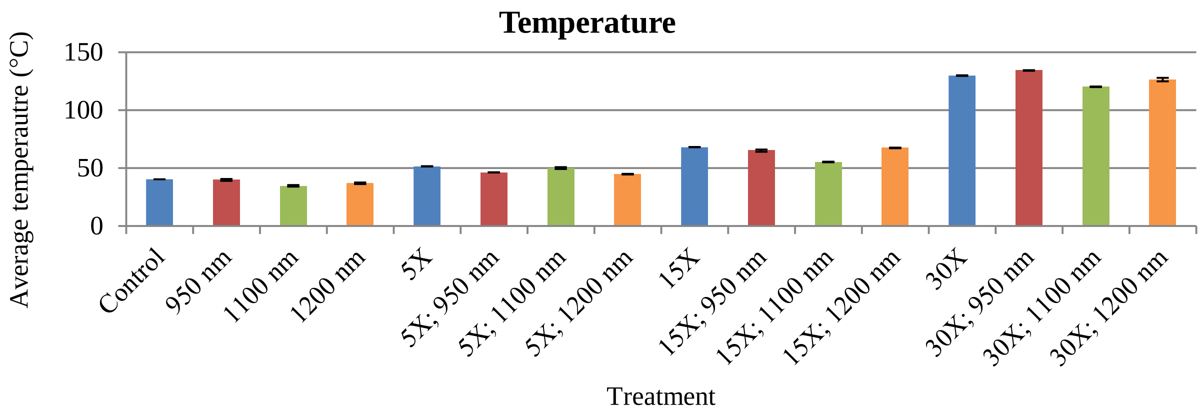

Fig. 2: Average temperature in degrees Celsius for the 16 different treatments.

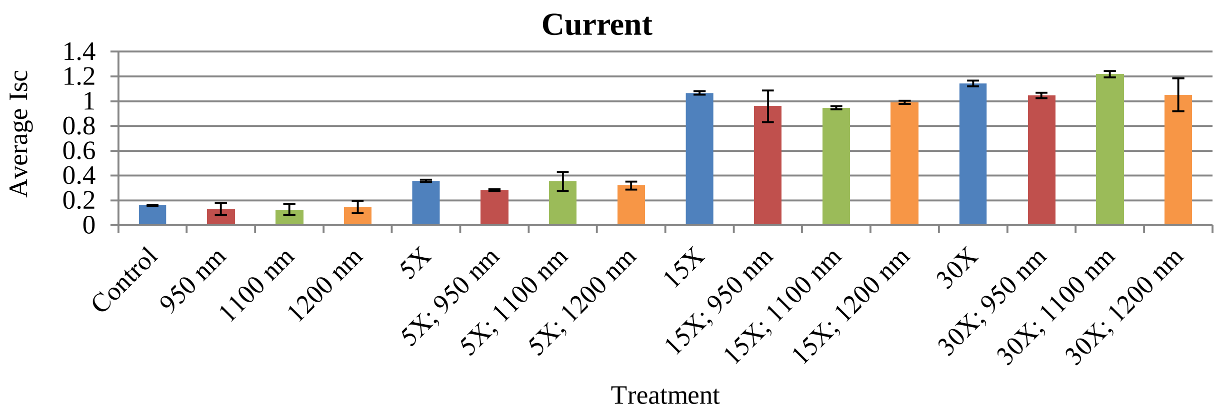

Fig. 3: Average short-circuit current of the 16 treatments.

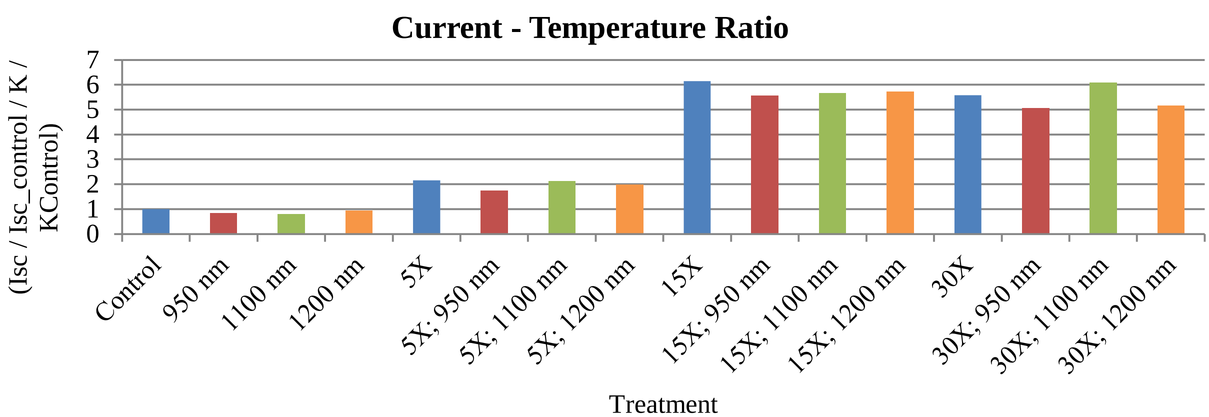

Fig. 4: Current-temperature ratio of the 16 treatments

nm light filter respectively when compared to the control. In terms of the current-temperature ratio, the 30X, 1100 nm light filter performed best of all the treatments with a light filter with a gain of six times.

5. DISCUSSION

5.1 Efficiency of Light Filters

The goal of this research was to develop three reflection holograms to be used as light filters, to construct a sun tracking system to allow the use of Fresnel lens concentrators, and to determine the best combination of light filter and concentration of light. The reduction in current was predictable, as the holograms do remove light within the 500-700 nm wavelength range due to the secondary reflection peak (Fig. 1). However, this reduction does not restrict the use of holographic light filtering. The glass plate can be improved to not reflect or absorb as much useful light and the holograms' efficiency can be improved. If these improvements are made, then the light filters will be more efficient.

5.2 Increases in Current

All concentrators improved the Isc with respect to the 1X control. Although the 30X system provides twice the amount of photons that interact with the semiconductor, the current is similar to that of the 15X treatment. Both systems provide an approximate increase in Isc of seven times compared to the control. This increase in current is also supported by researchers' attempts at improving the output of solar cells [5]. With 7X – no filter and 11 X –filter concentrators used by Sabry, the total power output of their photovoltaic system was increased by over four times. In current research, the 15X and 30X concentration of light increased short-circuit current by seven times.

5.3 Light filtering

Other researchers showed that filtering light in both the infrared and ultraviolet ranges only reduces temperature gain by 2-4 °C for both monofacial and bifacial silicon solar cells [4]. This is consistent with the results of the current research. Although ~200 nm in wavelength is being reflected by the holograms, the temperature gain has not been reduced by a significant amount. One possible explanation for this is the size and structure of the solar cells used. In most cases, photovoltaic cells are used in modules which have larger masses, larger surface areas, more glass, and an aluminum frame compared to the smaller mass of the cells used in the current research. These additions may change the total temperature of a panel , as the extra mass may act as a heat sink.

5.4 Current-temperature Ratio

The current-temperature ratio analyzed was found using the ratio of the average short-circuit current of any given treatment to that of the control divided by the ratio of the average temperature in Kelvin of any given treatment to that of the control. This result allowed each treatment to be accurately compared as a whole and not just in terms of one variable. This measurement was used to determine which combination of concentration and light filter was most effective. Both the 15X and 30X treatments had the largest value of current-temperature.

5.5 Hologram Disappearance

After the first complete set of testing was conducted, the holograms used to filter the light were either partially or completely destroyed. The gelatin in DCG holograms degrades rapidly at temperatures over 110 degrees Celsius, which the 30X concentrator contributed to. Materials other than gelatin can be used to increase the degradation temperature.

6. CONCLUSION

The Fresnel lens concentrators all improved the current output of the cells and the light filters decreased the current and temperature. However, the most effective treatments include the 15X and 30X treatments. Although some of the light filters were less effective than others, it is shown through the current-temperature ratio that the 30X, 1100 nm treatment was the most effective treatment with a light filter.

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