Power generation characteristics of a Si PV cell under high-intensity near-infrared light irradiation

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Abstract: Power generation characteristics of a mono-crystalline Si PV cell under extremely high-intensity near-infrared light irradiation were investigated by using high-power LED light sources with different wavelengths of 730 nm, 850 nm and 940 nm. More than 0.2 W electrical power was generated from less than 1 cm² Si PV cell under 1 W/cm² power density (10 times higher for sunlight) LED light irradiation. Even in this condition, power generation efficiency exceeding 23% which indicating high power transmission with near-infrared light.

Keywords: wireless power transfer; near infrared light; high power density

I. Introduction

Optical wireless power transfer approach is considered as a promising solution for providing convenient and perpetual energy to electronics (like moving electric vehicles (EV) and flying drones), for example, a PV cell installed on a moving EV's roof or bonnet [1]. In this paper, we reported on power generation properties by using a mono-crystalline Si PV cell as a light power receiver under irradiating extremely strong near-infrared LED light. We also evaluated the effect of heat generation in the PV cell when irradiating extremely strong light with 1 W/cm² power density which is comparable to 10 times higher irradiation power of sunlight.

II. Configuration of the experiment

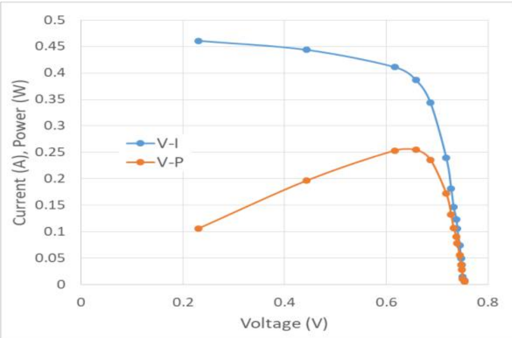
In order to investigate the relationship between power generation of a Si PV cell and irradiation wavelength, we used 730 nm, 850 nm and 940 nm of three different wavelengths of high-power LED light sources. A mono-crystalline Si single PV cell with the size of 9.65 mm × 9.55 mm (active area is 0.922 cm²) attached to a 2 cm square heat sink was also used for the experiment. The size of light emitting surface of the LED light sources was about 11.56 cm² (3.4 cm square). It was confirmed that almost uniform irradiation profiles could be obtained for about 1 cm square PV cell at a distance of 1 cm or 2 cm away from the LED light source.

III-I. Power generation characteristics for 730 nm LED

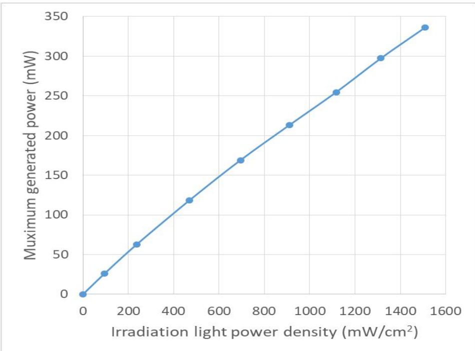
First, the power generation characteristics of 730 nm LED light were investigated. In order to prevent effects of heat generated from the high-power LED and the rising temperature of the PV cell during irradiation, the PV cell was placed at a distance of 2 cm away from the LED light source and only irradiated for a few seconds. Figure 1 (a) illustrates the PV cell terminal voltage vs. generated current (V-I) and terminal voltage vs. generated power (V-P) curve when irradiated light with 1120 mW/cm² power density. The maximum generation power about 255 mW was obtained for 1.7 Ω of road resister. The terminal voltage at the moment was 0.658 V.

Next, we measured maximum generation powers from the PV cell by changing LED irradiation power density up to 1500 mW/cm². Measured maximum generation power under various irradiation power density were presented in Fig.1 (b), it is clearly to see almost linear increasing property of generated output, when the irradiation light density is up to 1500 mW/cm².

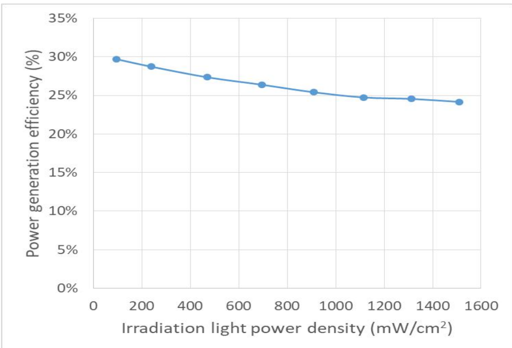
Figure 1 (c) shows power generation efficiency under various irradiation power density. As it increases, the power generation efficiency gradually decreases from the maximum value around 30% to minimum value around 24%.



(a) V-I and V-P characteristics at irradiation power density of 1120 mW / cm²



(b) Maximum generation power under various irradiation power density



(c) Power generation efficiency under various irradiation power density

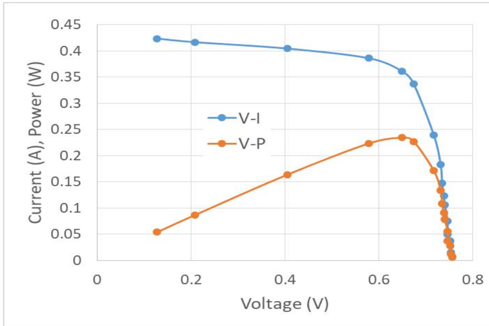
Fig. 1 Power generation characteristics for 730 nm LED

III-II. Power generation characteristics for 850 nm LED

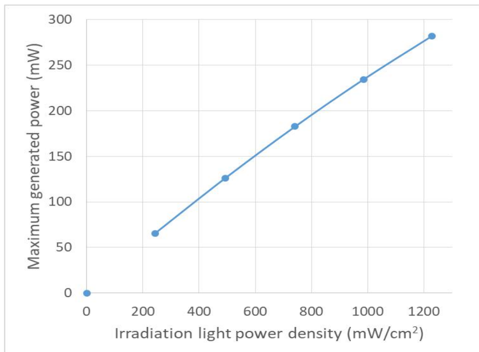
Next, the power generation characteristics for 850 nm LED light were investigated by using the same method as the case of measurement in 730 nm. Figure 2 (a) PV cell terminal voltage vs. generated current (V-I) and terminal voltage vs. generated power (V-P) curve. (under 986 mW/cm² irradiation). The maximum generation power was obtained when the load resistance was 1.8 Ω, and the terminal voltage at the moment was 0.65 V. In order to drop the voltage of the lead wire, the PV cell's endpoint voltage shown in Fig.2 (a) is actually higher than the actual value. In that case, the maximum generation power about 235 mW could be obtained by calculation.

With the irradiation power density was changing up to maximum value of 1230 mW/cm², we recorded the maximum generation power under different irradiation power density, which is presented in Fig.2 (b). The linear increasing property of generated output can also clearly to be seen.

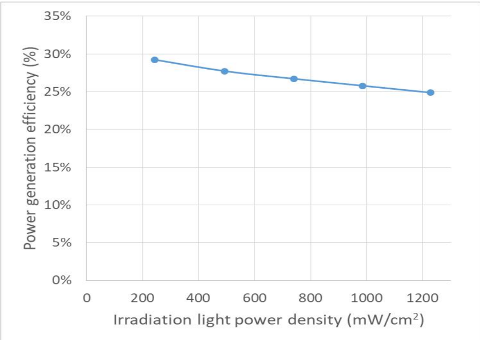
Figure 2 (c) shows the power generation efficiency of various irradiation power density. As the irradiation power density increases, the power generation efficiency gradually decreases from the maximum value around 30% to minimum value around 25%.



(a) V-I and V-P characteristics at irradiation power density of 986 mW / cm²



(b) Maximum generation power under various irradiation power density



(c) Power generation efficiency under various irradiation power density

Fig. 2 Power generation characteristics for 850 nm LED

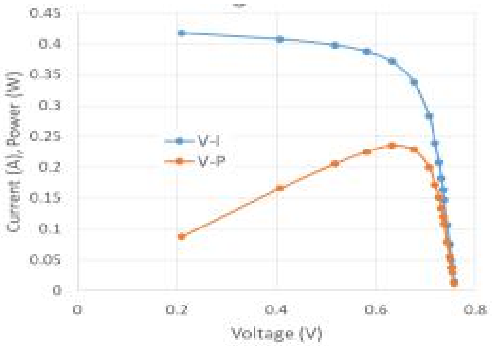
III-III. Power generation characteristics for 940 nm wavelength LED light

Finally, the power generation characteristics of 940 nm LED light were investigated. Because of the limitation of rated output of 940 nm LED, the irradiation power density was only changing up to about 400 mW/cm² at 2 cm away. So we also confirmed the properties measured at 1 cm away. Therefore, through the combination of measurement data in both cases, we gained various data when the irradiation power density reached to 850 nm.

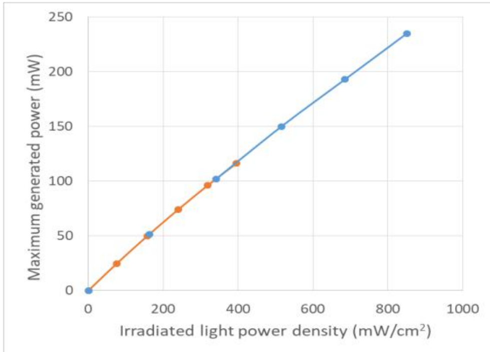
Figure 3 (a) illustrates PV cell terminal voltage vs. generated current (V-I) and terminal voltage vs. generated power (V-P) curve (under 850 mW/cm² irradiation). The maximum generation power was obtained when the load resistance was 1.7 Ω, and the terminal voltage at the moment was 0.632 V. In that case, the maximum generation power about 235 mW could be obtained by calculation.

With the irradiation light density was changing up to maximum value of 850 mW/cm². We recorded the maximum generation power under different irradiation power density, which is presented in Fig.3 (b). In the diagram, the orange dots are data measured at a distance of 2 cm, and the blue dots are data measured at a distance of 1 cm, both of them indicate linear increasing property.

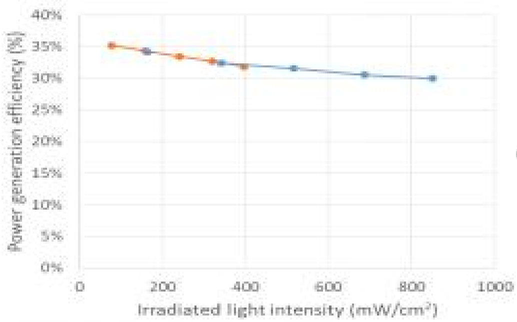
Further, Fig.3 (c) shows the power generation efficiency of various irradiation power intensity. As it increases, the power generation efficiency gradually decrease from the maximum value around 35% to minimum value around 30%.



(a) V-I and V-P characteristics at irradiation power density of 850 mW / cm²



(b) Maximum generation power under various irradiation power density



(c) Power generation efficiency under various irradiation power density

Fig. 3 Power generation characteristics for 940 nm LED

Comparing the data of three different wavelengths above, the highest power generation efficiency was obtained by 940 nm.

IV. Influence from heat generation

When the PV cell is irradiated by very strong light, the effect of heat generation seems to be unavoidable. In the previous section, we basically eliminated the effect of temperature rising. However, for practical use, since the light constantly radiate for a long time, the heat generation is inevitable. Therefore, we also measured the temperature rising of the PV cell and the power generation efficiency changing due to the influence from the heat generation .

First, we used a 850 nm LED with 1 W/cm² power to continuously irradiate a PV cell which was placed at 2 cm away (no load was connected to the PV's endpoints). Figure 4 records the measuring results of the rising temperature during irradiation period. Two types of infrared radiation thermometers which can measure surface temperature in a non-contact way were utilized (MASTECH MS6530 infrared thermo-graphy-camera FLIR ONE Pro).

As it shown in the Fig.4, there is only a slight difference between the two measurement. The temperature of PV cell increased immediately about 10-15 °C at the first minute, and keep constantly for the next 4 minutes.

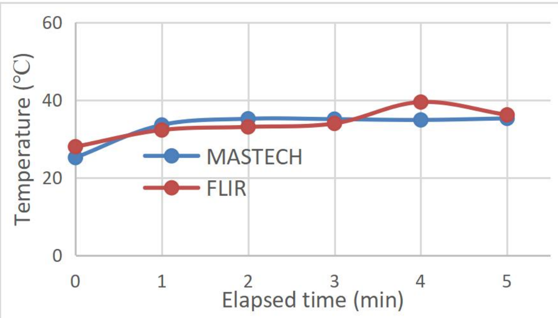


Fig. 4 Thermal changing of PV cell during light irradiation

Figure 5 shows the terminal voltage and generated power changing by 850 nm LED light irradiation for 10 minutes. Although the generated power decreases rapidly at the first minutes, it remains almost stable for the rest of time, which verify the coherence with the temporal changing of PV cell during light irradiation. Thus, it indicates that the heat generation of PV cell is one of facts to decrease the generation power.

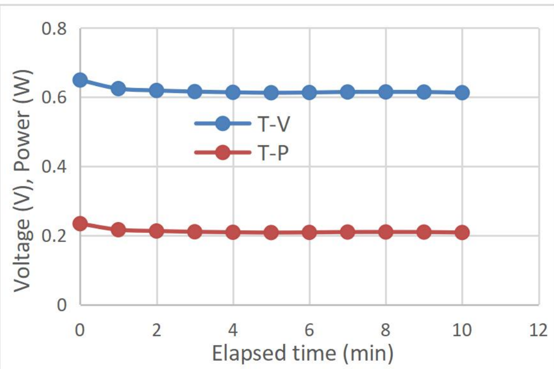


Fig. 5 Terminal voltage and generated power changing by 850 nm LED light irradiation for 10 minutes

V. Conclusions

The idea of wireless charging comes from that we believes the battery capacity limits functionality of many electronics, therefore, the aim is to replace batteries or connective charges which diminish users experience [2]. For the implementation of optical wireless power transmission, the power generation characteristics of Si PV cell under high-power-density near-infrared light irradiation were experimentally investigated. A powerful LED light source of 1 W/cm² power which is comparable to the irradiation power of sunlight about 10 times higher was used. Even for continuous irradiation from strong light source, the rising temperature is limited (about 10-15 °C), and high power generation efficiency exceeding 23% is obtained (which is about 12% lower than the generation efficiency under no effect of temperature rise). Therefore, we can make a conclusion that the practical application of optical wireless power transmission by using near infrared light is promising [3].

Reference

[1] X. Lu, D. Niyato, P. Wang, D. I. Kim, and Z. Han, "Wireless charger net working for mobile devices: Fundamentals, standards, and applications," Apr. 2015.

[2] Ortal Alpert, Wi-charge LTD, 3 Pekeris Street Rehovot, Israel. "Long-range wireless power delivery by infrared light beam-New applications for homes, offices, factories and public spaces," OPTICS & PHOTONICS International Congress 2019.

[3] www.wi-charge.com