Research on influence of parasitic resistance of InGaAs solar cells under continuous wave laser irradiation

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Abstract. InGaAs solar cells were irradiated by 1060-1080nm continuous wave (CW) laser, and studied the laser-electrical conversion and damage experiment with the power density as 97mW/cm² and 507W/cm² respectively. The result indicated that there is no obvious damage phenomenon but air layer appeared in the damaged region, and there is no direct relationship between the area and the extent of damage. Moreover, the p-n junction in the damage zone was destroyed, lost the ability of photoelectric conversion. The region acts as a resistance between the two electrodes, resulting in an increase in the leakage current of the solar cells and a decrease in the parallel resistance, which is the main reason leading to the decline of open circuit voltage, short circuit current and conversion efficiency. This paper would provide a reference for wireless energy transmission and the subsequent laser damage of solar cells.

1. Introduction
Laser wireless energy transmission has been a hot topic, as early as in 1991, Landis et al.[¹] proposed a hypothesis which based on ground laser emission system and supply energy for space vehicles. In order to reduce the influence of atmospheric turbulence and enhance the beam quality, the laser emission system was built in the cloud-free area, such as the top of the mountain, explained the feasibility theoretically. In 1997, Yugami et al.[²] carried out laser energy transmission experiments with different laser systems at ground level 500m, and tested the long time energy transfer efficiency in different weather conditions. At present, real-time charge for UAV from laser in an effective range has been realized[³].

For the receiving end of the energy, the research and design of the solar cells have also attracted much attention of scholars, especially on the photoelectric conversion efficiency of specific wavelength. Up to now, the reported laser-electrical conversion efficiency of GaAs solar cell with wavelength of 808nm has reached 53.23%[⁴]. More research in the field domestic have been on laser damage to solar cells. Qiu et al.[⁵旨] studied the damage of silicon solar cells using continuous and pulse laser respectively. They analyzed the reason of damage morphology and compared the difference between the two damage morphology. Xue et al.[⁷] studied the relationship between the laser energy and the damage depth of GaAs/Ge solar cells by femtosecond laser. Currently, the research on laser induced damage is limited to the damage morphology and photoelectric conversion efficiency, and few on other parameters of solar cells.

In this paper, the damage experiment of single junction InGaAs solar cell is carried out by using CW laser with wavelength of 1060-1080nm. The results suggest that in addition to the decrease of
open circuit voltage, short circuit current, photoelectric conversion efficiency of the solar cells, the parallel resistance is also significantly reduced. Highlights in this research: 1. Damage solar cells in small area by CW, and qualitatively explain the relationship between damage degree and damage area; 2. Measure the I-V characteristic curves of solar cells under laser irradiation, and study the effects of damage on the conversion efficiency of solar cells; 3. The laser with a wavelength of 1060-1080nm is in the atmospheric window, which provides a reference for the study of the wireless energy transmission in the atmosphere and the further study on damage to the solar cells; 4. Extract the electrical performance parameters of the solar cells according to I-V curve, analyze the reason causing the decrease of electrical properties of solar cells in the perspective of the parasitic resistance by comparing the open circuit voltage, short circuit current and photoelectric conversion efficiency.

2. Experiment

The solar cell sample is provided by the Shanghai Institute of Space Power-sources, which is 2×2cm² indium gallium arsenide (InGaAs) solar cells. The physical structure is as the following figure 1. The grid electrode and the back electrode are Ag and Al respectively, and the width of the band gap in solar cell is $E_g=1.0 \text{eV}$.

![Figure 1. Physical structure of solar cell.](image)

Laser-electrical conversion experiments are as follows (figure 2). The experiment system include continuous wave fiber laser, beam expander, source meter and temperature controller. The wavelength of the laser is 1060-1080nm, and its power is continuous controllable under 200W. The beam expander device is composed of convex lens L1 and L2, and the diameter of lens L1 is 25mm, the focal length is 40mm, the diameter of lens L2 is 50mm, the focal length is 150mm. It can be achieved that the continuous adjustment of the spot size on the surface of the solar cell through adjusting the distance between the lens L1 and L2. The positive and negative electrodes of solar cell are connected to the source meter (Keithley 2450), which is used to measure the I-V characteristic curve of the solar cell. The thermostat, cling to the back surface of the sample, controls the temperature at 25℃. Measure the laser power received by the solar cell with the German STPS-LEM2420 power meter.

![Figure 2. Schematic of measuring the I-V curve of InGaAs solar cells with 97mW/cm² laser irradiation.](image)

During the experiment, the laser beam covers the whole solar cell. Adjust the laser parameters, making the power density of the sample 97mW/cm², and record the I-V curve of solar cell. Damage experiment is shown in figure 3, and diameter of lens L3 is 50mm, focal length is 150mm. Adjust the position of lens L3 in order that the diameter of the spot on the sample surface is 2mm, and...
the power density is 507W/cm², irradiated lasting 17s. Survey the I-V curve of sample again using figure 2 after irradiation.

![Figure 3. Schematic of InGaAs solar cells irradiated by laser with the power density of 507W/cm².](image)

3. Result
The sample damaged by laser is in the following figure 4. The damage area is consistent with the light spot size, which is circular and slightly lighter than around area. Besides, there is air layer appeared inside the damage area. In this region, some of the metal wire is thickened due to melting then solidification, thus there is no distinct damage phenomenon in this area. The area laser irradiated occupies 0.79% of the total area. The I-V curve of the sample before and after laser irradiation is as follows (figure 5).

![Figure 4. Morphology of solar cell after laser with 507W/cm² power density irradiation and lasting 17s.](image)

![Figure 5. I-V curve of solar cells irradiated by laser with the density of 97W/cm² (a) before; (b) after.](image)

Figure 5 shows the I-V curves of solar cell recorded by the source meter. Figure (a) shows I-V curve before damage, from which the current flowing through the solar cell remain unchanged and then decreases rapidly along with the increase of the load voltage, and the open voltage is \( V_{oc} = 0.58 \) V, short circuit current is \( I_{sc} = 0.175 \) A, maximum output power is \( P_m = 0.059 \) W, thus it can be derivated that laser-electrical conversion efficiency of solar cells is \( \eta = 15.32\% \). The figure (b) illustrates the I-V
curve of the solar cell after laser irradiation. The current through the solar cell declines almost linear with the increase of the external voltage. It can be extracted that the open circuit voltage \( V_{oc} = 0.47V \), short circuit current \( I_{sc} = 0.153A \), and maximum output power \( P_m = 0.025W \) from the curve, thus, the laser-electrical conversion efficiency of solar cells after laser irradiation is \( \eta = 6.42\% \). Comparing figure (a) and (b), we know that the three parameters above exhibit decrease to different extent after damage, reduced to 81.0\%, 87.4\% and 41.9\% respectively. Obviously, the output power is affected mostly by the damage from CW laser. From I-V curves in figure 5 we compute the other parameters of the solar cells before and after the damaged shown in table 1.

| parameter                  | Before | After |
|----------------------------|--------|-------|
| \( V_m (V) \)             | 0.41    | 0.28  |
| \( I_m (A) \)             | 0.145   | 0.089 |
| \( R_m (\Omega) \)       | 0.53    | 0.51  |
| \( R_{sh} (\Omega) \)    | 64.41   | 4.30  |
| \( \eta(\%) \)           | 15.32   | 6.42  |

Following in table 1, the parameters of solar cell show decrease to different extent. Where, the voltage and current at maximum power point decreased to 68.3\% and 61.4\%; series resistance and parallel resistance decreased to 96.2\% and 6.7\%, respectively; and the laser-electrical conversion efficiency decreased to 41.9\%. It is clear that the decrease of parallel resistance is the most, while the series resistance is the least.

The single-diode model of solar cells is expressed by

\[
I = I_{ph} - I_0 \left\{ \exp \left[ \frac{q(V + IR_s)}{nKT} \right] - 1 \right\} \frac{V + IR_s}{R_{sh}}
\]  

(1)

Where, \( I \) and \( V \) are the current and voltage, \( R_s \) and \( R_{sh} \) are the series and parallel resistance, \( I_{ph} \) is the photocurrent, \( I_0 \) is the reverse saturated current, \( q \) is the elementary charge, \( n \), \( K \) and \( T \) are the ideality factor, Boltzmann constant and Kelvin temperature, respectively. From equation (1), we can see that the electrical properties of a solar cell is determined by series and parallel resistance under the condition of constant temperature and irradiation.

It can be seen from the above analysis, the decrease of parallel resistance is the main reason for the decline of electrical performance of the solar cell damaged by laser.

4. Conclusion

There can be air layer inside the cell, but no obvious damage phenomenon after CW laser with high power irradiation on the surface of solar cells. The damage area is 0.79\% of the total cell surface area while the laser-electrical conversion efficiency decreased by 58.6\%. From which we can know that the p-n junction is destroyed in this region and there is no direct relationship between the decrease of solar cells’ performance and the area of damage region.

The p-n junction of the damaged area is destroyed, then the cylindrical region between the two electrodes acts as resistance, which is smaller, thus leads to the increase of the leakage current and decrease of the parallel resistance of the cell. Therefore, laser induced damage of solar cells directly leads to the decrease of parallel resistance. While the change of parallel resistance has an immediate influence on the output of electrical properties of solar cell.

The series resistance decreased by 3.8\%, so CW laser with high power has little influence on series resistance of solar cell.

This research can provide reference for the research of the interaction between InGaAs solar cell and laser, and the study of laser wireless energy transmission.

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