

Experimental study on solar cell arrays of trough concentrating PV/T system

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Abstract

The series experiment works have been done with single crystalline silicon solar cell array, polysilicon solar cell array, Super cell array and GaAs cell array through the trough concentrating PV/T system. The experimental results show that the I-V curve of the crystalline silicon, polysilicon and Super cell arrays are linear in concentrating solar irradiance, which leads the drop of efficiency and the decrease of output power. However the I-V curve of GaAs cell array is very good in the concentrating solar irradiance, the efficiency of GaAs cell array increases from 23.66% to 26.50%, the output of GaAs magnifies 12 times. So it is considerable to improve the efficiency if the GaAs cell has been adopted in the concentrating PV/T system. The temperature coefficients of P_m , FF and η of GaAs cell array are -0.12W/K, -0.10%/K, -0.21%/K. In order to keep better efficiency, the forced cooling must be applied. At the same time, the quantity of heat can be recovered for domestic using. All those work are benefits to further study in improving the efficiency of solar concentrating trough system and cosmically making use of concentrating PVT system.

Key words: concentrating PV/T system; output power; fill factor; temperature coefficient

1 Introduction

At present, the mostly stratagem decision-making of the continuable development is to utilize solar energy all over the world [1]. But the main obstacle is the decentralization of energy in utilizing solar energy, so using concentrating can improve the density of solar radiation to several times or several hundred times, the power output of solar cell can be increased, and the cost of photovoltaic industry can be reduced. Therefore the concentrating of

solar energy has a preferable foreground [2]. PV/T systems have not seen the intensive research and development activity documented for thermal and photovoltaic collectors separately (Duffie and Beckman, 1991; de Winter, 1990; Fahrenbruch and Bube, 1983; Zweibel, 1990). Work has however included some experimental (Fujisawa and Tani, 1997; Garg *et al.*, 1994; Lalovic' *et al.*, 1986) and also theoretical modeling of PV/T systems (Bergene and Løvvik, 1995; Florschuetz, 1979; Sopian *et al.*, 1996) giving performance results and predictions for different collector designs and model parameters. The trough collector has been used in this paper, the short current and the out put power of cell arrays increase, but the temperature of cell arrays is very high, there is negative infection to cell. The cooling fluid must be adopted to keep the efficiency of the cell arrays. With controlling the speed of cooling liquid, the cell arrays' optimal working temperature can be found out. Taking single crystalline silicon solar cell array, polysilicon solar cell array, Super cell array and GaAs cell array as cells, the experiments have been done based on the trough concentrating PV/T system. The effect factor can be found out and analyzed according to the characteristic curve of cell arrays. All those work are benefits to further study in optimizing the trough concentrating system and offering practicality value to large scale concentrating PV/T power station.

2 The experimental equipment and working principle

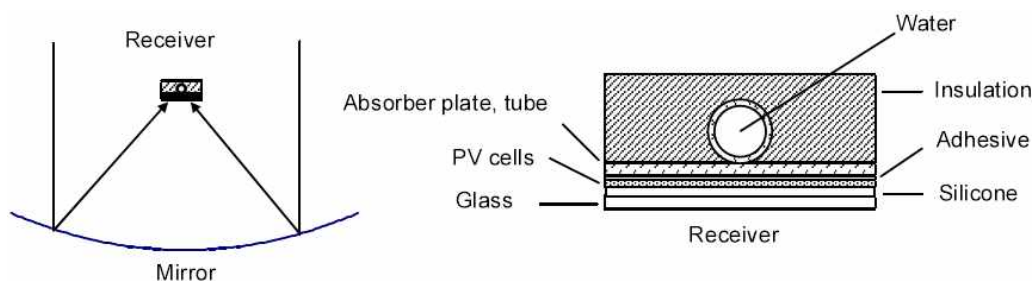


Fig.1 The diagram of collector of the trough concentrating solar system

Fig.1 shows schematic diagram of trough concentrating PV/T system, the trough reflecting collector is made up with parabolic curved mirror, solar collector and cooling fluid tube, PV cell arrays glued on the receiver by the insulated and diathermanous adhesive tape. Fig.2 is the photographs of the trough concentrating PV/T system. The trough concentrating solar system works as follow, the cooling fluid flows in the tube get the heat transfer via solar collector which is heated by concentrating sunlight, which is used to cooling the cell arrays. The PV cell arrays produce electricity, so both the heat and power can be obtained with solar concentrating PV system.



Fig.2 Photographs of the trough concentrating PV/T system

3. The result and the analysis of experiment

3.1 measuring the concentrating irradiance

The reflecting surface is a parabolic curved mirror, the area of it is $1440 \times 1450 \text{ mm}^2$, and the theoretic concentrating times are 16.92. Because there is 4 mm thickness of the mirror, the reflected light departure the focus, so measuring the practical concentrating times is very necessary. This paper focus on laser power meter which is the best tool to measure solar irradiance, the result is shown in table 1.

Tab.1 The current translated by photons of different wavelengths

wavelength	the current of common intensity light	the current of concentrating intensity light
488	14	141
514.5	57	577
632.8	50	511
904.0	35	360
1064.0	27	280
total	19936	204722

The practical concentrating times are 10.269 by simulation calculating the data of the table 1.

3.2 The parameter of cell arrays

The standard of cell arrays used in the concentrating solar system is shown in table 2.

Tab.2 The standard of cell arrays

	single crystalline silicon solar cell array	polysilicon solar cell array	Super cell array	GaAs cell array
area/ mm^2	103*51.5	117*75	71*62	40*30
number join	10 in series	10 in series	16 in series	5 in series

When the cell arrays are lied in the concentrating irradiance, the parameters of them are

different from in 1 sun, so it must to find out the parameters of cell arrays, such as R_s , FF and η due to the I_{sc} , V_{oc} and the I-V curve. In 1 sun, the R_s is defined as [3]

$$R_s = \frac{AkT}{q} \frac{1}{I_2 - I_1} \ln \left[\frac{m\Phi - I_2}{m\Phi - I_1} \right] - \left(\frac{V_2 - V_1}{I_2 - I_1} \right) \quad (1)$$

In x suns, the R_s is defined by [4]

$$R_{es} = \frac{V_o - V_{oc1}}{I_{scx}} - \frac{VV_{oc}}{I_{scx}}$$

$$VV_{oc} = (T_1 - T_2) \frac{dV_{oc}}{dT}$$

(2)

x is the concentrating times, T_1 is the cell arrays' working temperature in concentrating, T_2 is the cell arrays' temperature measured with the dark characteristic curve. V_{oc1} is the open circuit voltage in x suns, V_o is the open circuit voltage of forward characteristic curve.

The R_s of GaAs cell is shown by [5]

$$R_s = \frac{V_1 - V_{oc}}{I_{sc}}$$

(3)

V_1 is the forward voltage when the forward current of dark field is equal to the short current of cell.

The fill factor and the efficiency of cell are given:

$$FF = \frac{P_m}{V_{oc} \cdot I_{sc}}$$

(4)

$$\eta = \frac{P_m}{A_t \cdot P_{in}}$$

(5)

The calculation dates are shown in table 3

Tab.3 The parameters of different cell arrays

		single crystalline silicon solar cell array	polysilicon solar cell array	super cell array	GaAs cell array
FF	common	59.22%	40.90%	75.34%	78.52%
	concentrating	25.60%	33.98%	36.28%	73.74%
η	common	7.5%	7.66%	13.28%	23.66%
	concentrating	1.77%	1.12%	6.67%	26.50%
P_m/W	common	3.8988	6.5031	8.8265	1.3631
	concentrating	9.1793	9.5152	44.3166	15.264
R_s/Ω	common	0.88255	0.96305	0.41942	0.06667
	concentrating	0.99201	0.98671	0.43184	0.08597

From the Table 3, it can be seen that the FF of all cell arrays descends, P_m and R_s increase, the η

of the silicon cell arrays drops a lot but that of GaAs cell array rises in the concentrating solar irradiance. In concentrating solar irradiance, photogenerated carrier increase in the cell, short current of the cell arrays increase. At the same time the arrays' temperature rise very much,

then this lead the drop of the FF.

3.3 The I-V curve of different kinds of cell arrays in different concentrating solar irradiance

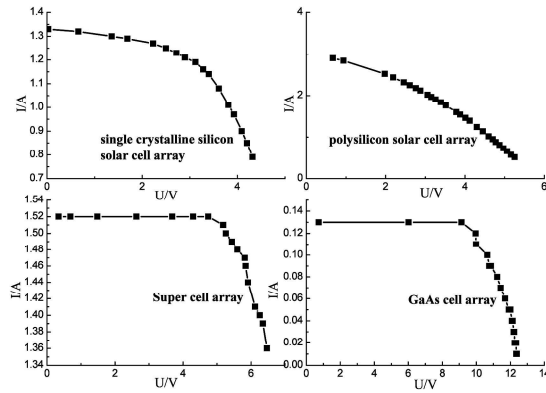


Fig.3 The I-V curve of different cell arrays in common irradiance

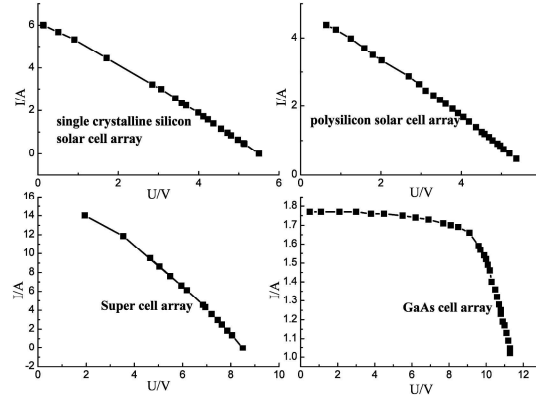


Fig.4 The I-V curve of different cell arrays in concentrating irradiance

Fig.3 is the I-V curve contrastive chart of single crystalline silicon solar cell array, polysilicon solar cell array, Super cell array and GaAs cell array in 1 sun. It shows that GaAs cell array has a better I-V curve, the I-V curve of polysilicon solar cell array is so poor, under condition of concentrating solar irradiance it can not be applied in the concentrating solar system. When the arrays work in 16.92 suns in Fig.4, only the I-V curve of GaAs cell array is rectangular, the other silicon cell arrays' I-V curve are linear. I-V characteristic expression of solar cell is given by [6]

$$I = I_0 \left\{ \exp \left[\frac{q}{nKT} (V + IR_S) \right] - 1 \right\} + \frac{V + IR_S}{R_p} - I_L \quad (7)$$

And the output power is given by

$$P_m = \frac{InKT}{q} \ln \left(\frac{I_L - I}{I_0} + 1 \right) - I^2 R_S \quad (8)$$

It can be seen from the expression (8) that if solar cell has a large R_S , the power loss much on R_S when there is a large current in the cells. The P_m , FF and η of silicon solar cell arrays reduce very much in concentrating solar irradiance due to their large R_S . The R_S of GaAs cell array is 0.08597Ω , it is very small so GaAs cell array has much better output power. In order to compare the characteristic curve of GaAs cell array, the comparative Fig.5 is given, It shows that the I-V curve are very good when the array work in 1 sun and 16.92 suns. I_{sc} increases much from 0.15A to 1.80A, V_{oc} descends a little from 12.95V to 11.50V, output power magnifies 11.2 times. Because GaAs has main features of bandwidth ($E_g=1.43\text{eV}$) matching solar spectrum all right, large absorption coefficient, strong anti-radiation and good performance in high temperature and so on [7]. When GaAs cell work in sun, the photogenerated carrier is direct transition, corresponding absorption is large, so the I_{sc} of GaAs cell array increases much along with the increasing of photogenerated carrier. Otherwise, the V_{oc} of cell has negative temperature efficiency, the V_{oc} of GaAs cell array descends a little when it works in concentrating solar irradiance.

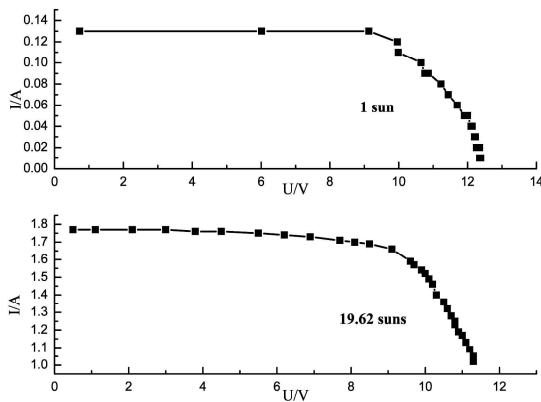


Fig.5 The I-V curve contrast of GaAs cell array in different irradiance

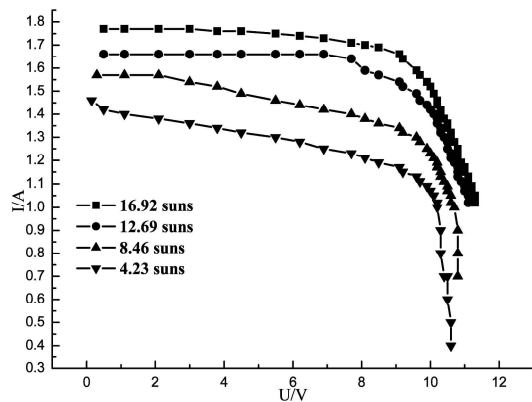


Fig.6 The I-V curve of GaAs cell array in different irradiance

In order to preferably apply silicon cell used in the concentrating PV system, the best concentrating times of silicon cell must be found out. The experiment about investigating the output characteristic curve in different solar irradiance has been done. From Fig.6, it can be seen that the I-V curve graph of GaAs cell array keep the same always when the concentrating times increases, the maximal power point rise step by step.

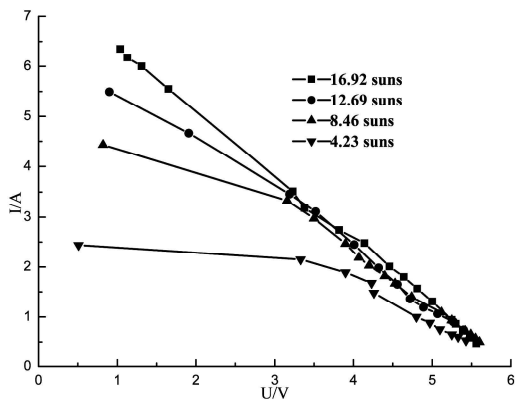


Fig.7 The I-V curve of single crystalline silicon solar cell array in different irradiance

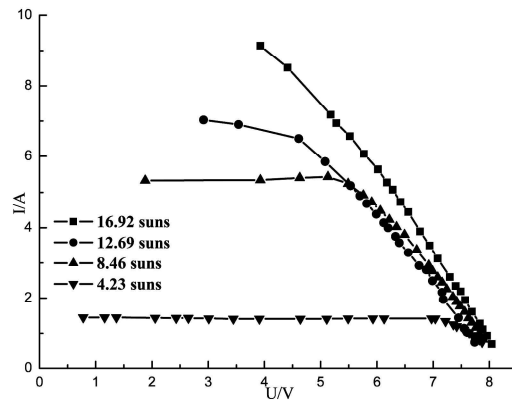


Fig.8 The I-V curve of super cell array in different irradiance

In china, the investigation about concentrating solar system shows that single solar cell can work in 10-20suns, this paper focus on the cell arrays, the R_s of cell arrays is larger than single solar cell, so the investigation is benefit to further study in large PV/T station system. The results are shown in Figs.7 and 8, single crystalline silicon solar cell array has a good I-V curve in 4.23 suns and the best working concentrating times of Super cell array is 8.46.

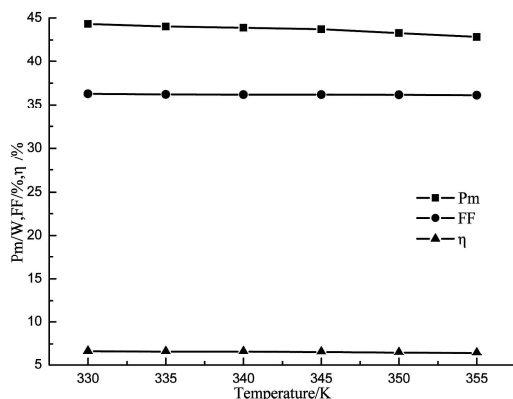


Fig.9 The change of P_m , FF and η of super cell array in different temperature

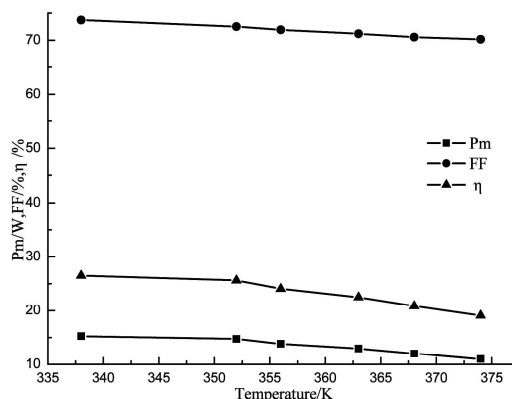


Fig.10 The change of P_m , FF and η of GaAs cell array in different temperature

Temperature has a bad infection on solar cell in concentrating irradiance, all of V_{oc} , FF and η have negative temperature coefficient. The research work about temperature infection to conventional silicon cells in concentrating irradiance has been done in the references of [2],[8]and[9], this paper focus on the experiments about temperature of Super cell array and GaAs cell array, the results are shown in Figs.9 and 10. The temperature of coefficient of P_m , FF and η of Super cell array are -0.07W/K, -0.007%/K, -0.01%/K; The temperature of coefficient of P_m , FF and η of GaAs cell array are -0.12W/K, -0.10%/K, -0.21%/K. Super cell is used in space planet, it is very stability in high temperature; the output performance of GaAs cell array is not influenced by temperature very much, it has a high efficiency, so the GaAs cell array is best conformable for the concentrating PV system. In order to keep better efficiency, the forced cooling must be applied. The results of the experiment show that the thermal efficiency of collector is 42.03% and the electricity efficiency of GaAs cell array is 26.05%.

4 Conclusion

1. GaAs cell array is best suitable cell array for the concentrating PV/T system through the series experiment study about single crystalline silicon solar cell array, polysilicon solar cell array, Super cell array and GaAs cell array. Single crystalline silicon solar cell array and Super cell array can be used the in low concentrating times PV system.
2. The series resistance is a huge obstacle in using concentrating PV/T system. One piece of solar cell can work in 10-20 suns, single crystalline silicon solar cell array has a good I-V curve in 4.23 suns and the best working concentrating times of Super cell array is 8.46. In order to keep better efficiency, the forced cooling must be applied. At the same time, the quantity of heat can been recovered for using.
3. All those series experiment works are benefits to further study in optimizing the trough concentrating system and offering practicality value to large scale concentrating PV/T power station.

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