Transmitting of Energy on the Basis of Powerful Lasers as Means for Injection on Fading Satellites

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Received: 11 December 2007; Accepted: 22 December 2007

Abstract. The article discusses the results achieved after a radiation of a solar panel with CO_2 laser and covers the short circuit, the floating voltage, and the efficiency. Theoretical deduction of the most appropriate laser wavelength, referred to the maximum of transformation of the laser energy in electrical energy for the mono crystal silicon is presented. The volt-ampere characteristics of the photo-receiver are described.

Keywords: lasers, solar panel, solar energy, photoelectric transformation

Introduction

The study of the influence of the laser radiation on photo voltage systems is important, providing energy for existing satellites in the end of their life, due to reduction of the energy system [1]. This type of radiated laser energy has a great commercial value [2]. The laser radiation is preferable because of the high efficiency of the silicon cells under monochromatic lightening [3], and the possibility of increasing the energy, in order to produce more energy outcome per area [4].

The USA is historical leader in experimenting and demonstrating the transmission of energy without cable. Developments in radio in the 1950s have led to discussions of the development of microwaves in aviation. For the first time it was G. Brown from Rayton Corp. with the help of the US Air Forces who constructed a series of electrically powered helicopters for a demonstration of the advantages of microwave driving and directing *flying vehicles* (FV).

Nevertheless, the SPS projects were not realized because no state was yet ready to finance such stations as a result of military estimates which indicated that such programs would be unworkable [7].

But the recent power black-outs in California made the USA to take a fresh look at the problem of power supply. Now the situation is rather complicated and the electricity needs begin to exceed the resources available. It is planned that at the same time the first trial electric station of 100 *kW* should be built. By 2011-2012, NASA plans the launch into outer space of a platform which would be essentially a *mega-Watt* electric station and would be capable of transmitting power both to other space vehicles and to the Earth. In future, the output of the electric station will grow and after 15-20 years it will reach 10 *mega-Watt* according to preliminary calculations.

The launch was made in 1994 in Japan of a 100-year plan called "Action Plan – Earth 21". It aims at the reduction of carbon dioxide in the Earth's atmosphere through the so-called carbon sinks. The program seeks to give electric power to photovoltaic systems based on the Earth and in space.

This blueprint envisages the installation of system which could provide power from space to the world electric grid in 2040 at the earliest.

The ground-plan envisages a series of solar power satellites, each of which will transmit 1 *GW* of electric power to ground-based stations. The satellites will use microwave radiation of 2.45 *GHz* [7].

Transmitting of Energy on the Basis of Powerful Lasers

The specific peculiarities of the transformation of solar power into a laser beam have to do with low density of solar radiation in the outer space around the Earth which presupposes the use of concentrators in the power emitting systems. But the theoretically attainable density of the stream of concentrated solar radiation does not exceed 16 mW/m^2 and is insufficient for effectively pumping the lasers. An analysis of the suitability of various substances for their use as active media for lasers of SPS with optical pumping indicates that these substances can be divided into three groups:

1. Admitting of optical pumping and radiating in the visible range.
2. Permitting pumping by visible light and radiating in the infra-red range.
3. Pumping and radiating within infra-red range.

In the first group there are molecular substances J_2, Na_2, Br_2, Te_2, Li_2, HgBr and the lasers with solutions of organic dyes. In the second group they are CF_3J, $Br+CO_2$, J_2+CO_2; in the third there are CO, CO_2, N_2O, HF, DF, G_2H_2. Of greatest interest are the substances of the third group and in particular, CO, CO_2, N_2O. The examined substances of the first and second group have considerable disadvantages – for the former an excessively high density of the radiated stream is needed; and for the latter, the efficiency is of transformation is unacceptably low because the energy transformed in the process of pumping considerably exceeds the emitted. The only exception is the molecular compound CF_3J which is regarded as one of the possible active media. At the same time, the cited results cannot be considered as final ones because the search for suitable working substances is going on.

Advantages:

- smaller ray divergence (1-10 micrometers);
- possibility of using mirror relay stations.

Shortcoming:

- high level of absorption of laser by the Earth's atmosphere.

Fig.1. General view of the CO_2 laser.

Fig.2. Transverse view of the CO_2 laser.

Fig.3. CPU of the laser.

Exposition

For calculating the most appropriate laser wavelength, relevant to the maximum of the transformation of the laser energy to electric energy, we use the following formula:

$$E = h\nu = h\frac{c}{\lambda}. \qquad (1)$$

After relevant operations one can get:

$$E[eV] = \frac{1.24}{\lambda(nm)}, \qquad (2)$$

or

$$\lambda = \frac{1.24}{E}, \qquad (3)$$

where E is the width of the forbidden area of the semi-conductor. For silicon: E = 1.11 *eV*.

Therefore for the maximum of the transformation of the laser energy to electric energy for the mono crystal silicon, the wavelength is used:

$$\lambda = \frac{1.24}{1.11} = 1.117\ nm. \qquad (4)$$

Laser with carbon dioxide

The most appropriate laser for injection on fading satellites is CO_2 – laser (Figs.1-3), where the amplification is approximately λ = 1006 *nm*, i.e. this is the closest value provided for the maximum of the transformation of the laser energy into electric energy for the silicon semi-conductor.

CO_2 – lasers generate a broad range of lines in the scope between 900 *nm* up to 1100 *nm*. The strongest amplification is at 1060 *nm*. They are characterized with strong efficiency, reaching up to 20 % for well constructed models.

The laser used (Model L 1000) has:

- longitudinal smoldering discharge and fast longitudinal channel;
- λ = 1060 *nm*;
- Output power by specification - 1000 *Watts*;
- Laser environment – carbon dioxide;
- Mod –TEM_{01};
- Diameter of the output ray – 15 *mm*;
- Beam divergence – 2 *mRad*;
- Polarization – circular.

The CO_2 has more homogeneous and active environment and provides more qualitative and direct radiation. It has better mode structure and better focusing in comparison to others [5].

Solar panel

The silicon is the main semi-conductor material for photoelectric transformation of the solar energy [6].

The direct transformation of the solar energy into electric energy can be achieved with solar batteries, consisting of multitude of photo elements, through the so called photovoltaic effect [7].

The model of the used solar panel is:

- 685-SP-120-12 V;
- Voltage – 12 V;
- Current Voc – 120 μA;
- Voltage (MAX) Voc – 16 V;
- Current (MAX) Isc;
- Size 15.9 x 27.8 x 1.7 cm

The solar panel consists of 36 consequently connected photo elements, which aim at the increasing of the output voltage.

Resistors

- R_1 = 33 κΩ;
- R_2 = 77 κΩ;
- R_3 = 143 κΩ;
- R_4 = 308 κΩ;
- R_5 = 406 κΩ;
- R_6 = 503 κΩ;
- R_0 = 0;
- R = ∞.

Meanings

- R_{el} – electric power;
- R_l – laser power of the successive line of generation;
- η, % - efficiency;
- $\eta = R_{el} / R_l \cdot 100$;
- $R_{el} = I \cdot U$ – electric power.

Experiment

In front of the CO_2 laser a defocusing lens (Fig.4) is set, that allows a spot with diameter 5 cm and 25 cm.

The photo converter is set at 150 cm distance from the lens. Ampere-meter, Volt-meter and resistors for measuring of the current are plugged into the photo converter (Fig.5).

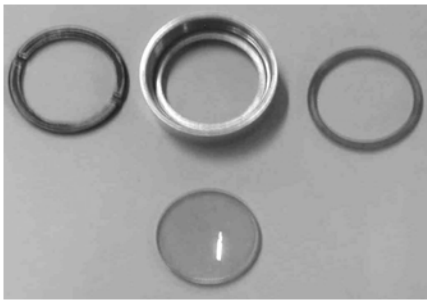

Fig.4. Defocusing lens.

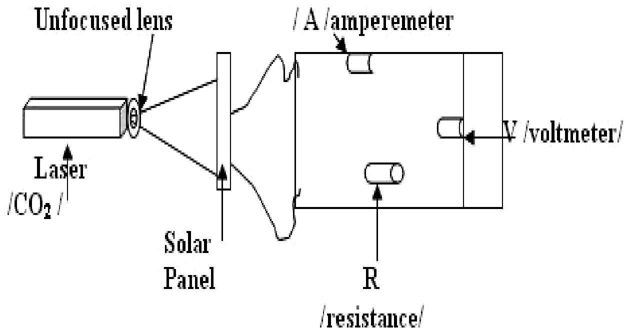

Fig.5.Scheme of the experimental setting.

TABLE 1

Electricity, voltage, electrical power and efficiency of the photo voltaic panel radiated with CO_2 laser with diameter 5 cm and 25 *cm* at 0.5 *W* power

	D= 5 cm, 10.6 μm, W = 0.5				D= 25 cm, 10.6 μm, W = 0.5			
R	I, μA	U, V	P, μW	η %	I, μA	U, V	P, μW	η %
R_1	192.15	6,1	1171,115	0.2	1381.25	32.5	44890.625	8.98
R_2	90.39	6,9	623.691	0.1	785.66	32.6	25612.516	5.12
R_3	51.62	7,2	371.664	0.07	592.342	32.6	19310.35	3.86
R_4	35.77	7,3	261.121	0.05	508.959	32.01	16291.778	3.26
R_5	26.64	7,2	191.808	0.04	482.16	32.8	15814.848	3.16
R_6	22.77	7,8	177.606	0.03	457.968	32.9	15067.148	3.02
R_0	985.75				6906.25			
R		10.01		0.082		36.08		4.567

TABLE 2

Electricity, voltage, electrical power and efficiency of the photo voltaic panel radiated with CO_2 laser with diameter 5 *cm* and 25 *cm* at 2.2 *W* power

	D= 5 cm, 10.6 μm, W = 2.2				D= 25 cm, 10.6 μm, W = 2.2			
R	I, μA	U, V	P, μW	η %	I, μA	U, V	P, μW	η %
R1	203.52	6,4	1302.53	0.04	1423.75	33.5	47695.625	2.17
R2	92.63	7,01	649.34	0.03	829.92	33.6	27885.312	1.27
R3	54.79	7,6	416.4	0.02	590.52	32.5	19191.9	0.87
R4	36.75	7,5	275.63	0.013	511.98	32.2	16485.756	0.75
R5	30.02	7,9	237.16	0.011	485.25	33.01	16018.103	0.73
R6	23.76	8,03	190.79	0.0087	460.06	33.05	15204.983	0.69
R0	1019.64				7147.225			
R		11.1		0.024		36.5		0.98

TABLE 3

Electricity, voltage, electrical power and efficiency of the photo voltaic panel radiated with CO_2 laser with diameter 5 *cm* and 25 *cm* at 50 *W* power

D= 5 cm, 10.6 µm, W = 50					D= 25 cm, 10.6 µm, W = 50			
R	I, µA	U, V	P, µW	η %	I, µA	U, V	P, µW	η %
R_1	220.8	6.9	1523.52	0.03	1478.22	34.7	51294.23	0.102
R_2	94.9	7.3	692.77	0.013	836.27	34.7	29018.57	0.058
R_3	56.72	7.9	448.08	0.0089	614.146	33.8	20758.13	0.041
R_4	40.05	8.01	320.801	0.0064	540.76	34.01	18391.25	0.036
R_5	31.16	8.2	255.51	0.0051	501.27	34.1	17093.31	0.034
R_6	24.03	8.2	197.046	0.0039	473.56	34.02	16110.51	0.032
R_0	1126.08				7234.57			
R		12.03		0.019		37.03		0.051

TABLE 4

Electricity, voltage, electrical power and efficiency of the photo voltaic panel radiated with CO_2 laser with diameter 5 *cm* and 25 cm at 100 *W* power

D= 5 cm, 10.6 µm, W = 100					D= 25 cm, 10.6 µm, W = 100			
R	I, µA	U, V	P, µW	η %	I, µA	U, V	P, µW	η %
R_1	221.7	6.9	1529.73	0.01	1403.78	33.03	46366.85	0.046
R_2	97.24	7.4	719.58	0.007	841.1	34.9	29354.39	0.029
R_3	56.81	7.9	448.8	0.0004	634.13	34.9	22131.24	0.022
R_4	40.18	8.2	329.476	0.0003	553.32	34.8	19255.54	0.019
R_5	30.7	8.3	254.81	0.0002	498.33	33.9	16893.34	0.0168
R_6	23.94	8.2	196.308	0.0001	475.7	34.1	16221.4	0.0162
R_0	1152.8				7299.66			
R		12.6		0.003		36.8		0.025

TABLE 5

Electricity, voltage, electrical power and efficiency of the photo voltaic panel radiated with CO_2 laser with diameter 5 *cm* and 25 *cm* at 250 *W* power

D= 5 cm, 10.6 µm, W = 250					D= 25 cm, 10.6 µm, W = 250			
R	I, µA	U, V	P, µW	η %	I, µA	U, V	P, µW	η %
R_1	217.35	6.9	1499.71	0.00059	1423.63	33.1	47122.15	0.018
R_2	95.63	7.3	698.1	0.00027	830.99	33.2	27589.07	0.011
R_3	56.64	7.9	447.46	0.00017	623.23	34.3	21376.79	0.0085
R_4	39.69	8.1	321.47	0.00012	545.98	34.06	18596.01	0.0074
R_5	29.97	8.1	242.76	0.000097	523.26	34.2	17895.49	0.0071
R_6	23.94	8.2	196.31	0.00078	478.42	34.1	16314.12	0.0065
R_0	1130.22				7317.81			
R		12.5		0.001		36.08		0.01

TABLE 6

Electricity, voltage, electrical power and efficiency of the photo voltaic panel radiated with CO_2 laser with diameter 5 *cm* and 25 *cm* at 500 *W* power

D= 5 cm, 10.6 µm, W = 500					D= 25 cm, 10.6 µm, W = 500			
R	I, µA	U, V	P, µW	η %	I, µA	U, V	P, µW	η %
R_1	210.8	6.8	1433.44	0.00028	1438.18	34.08	49013.17	0.0098
R_2	95.99	7.3	700.73	0.00014	849.92	33.2	28217.34	0.0056
R_3	57.58	8.02	461.79	0.00092	641.28	33.4	21418.75	0.0042
R_4	35.5	7.9	280.45	0.00056	588.12	34.8	20466.57	0.0041
R_5	31.16	8.2	255.51	0.00051	555.45	34.5	19163.02	0.0038
R_6	23.81	8.1	192.86	0.00038	519.11	34.7	18013.12	0.0036
R_0	1138.32				7622.35			
R		12.6		0.001		36.1		0.03

Results and Analysis of the Results

Results are displayed in Tables 1-6 and Figs. 6-10. The following quantities can be brought into use, that characterize the panel's quality to transform the laser light into electric one, depending on the diameter of the laser spot and the power of the laser emission. These are the ratio between the floating voltage and the laser's power U_0/Pl, and the current I_0/Pl, that results from the short circuit (Figs. 6 and 7). During laser radiation at 0.5 W the floating voltage for the 25 *cm* spot is 3.6 times greater than the one for the 5 *cm* diameter spot. The values for the short circuit current for a spot of 25 cm are approximately 7 times bigger. As the laser power increases there is no significant increase of the floating voltage and the short circuit current – 36 V and 7 mA for 25 cm and 12 V and 1 mA for 5 cm at 0.5 up to 500 W power.

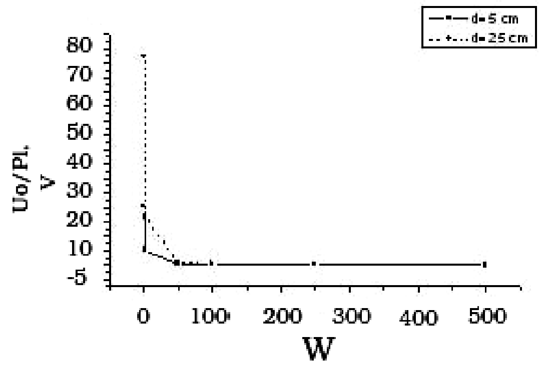

Fig. 6. Dependency of Uo/Pl from the power at various diameters of the laser spot.

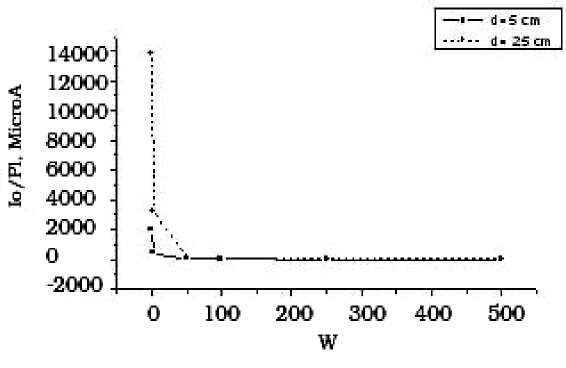

Fig. 7. Dependency of the Io/Pl from the power at various diameters of the laser spot.

The values of the electric power of the solar panel at 0.5 W radiation are more than 38 times bigger at 25 *cm* diameter of the laser spot than these at 5 cm, for resistance *R* = 33 kΩ (Table 1).

The difference between the electric power at 5 and 25 *cm* increases with the increase of the resistance and at *R*= 503 kΩ the electric power is 85 times bigger. This ratio (P5cm-P25cm) is preserved more or less unchanged at every value of the laser's power (Tables 2, 3, 4, 5).

The efficiency, which is the most important characteristic of the researched system, varies from 8.98 % for 25 *cm* diameter of the spot to 0,2 % for 5 *cm* diameter of the spot at *R* = 33 kΩ. The efficiency gradually decreases with the increase of the resistance reaching 3.02 % for 25 *cm* and 0.03 % for 5 *cm* (Table 1).

With the gradual increase of the laser's power from 0.5 *W* to 500 *W* the electrical power of the photo converter increases as well with approximately 3 *mW*, but thus reducing the efficiency. The lowest efficiency values of the photo converter are achieved at the highest level of the laser emission's power (Table 5, Fig. 8).

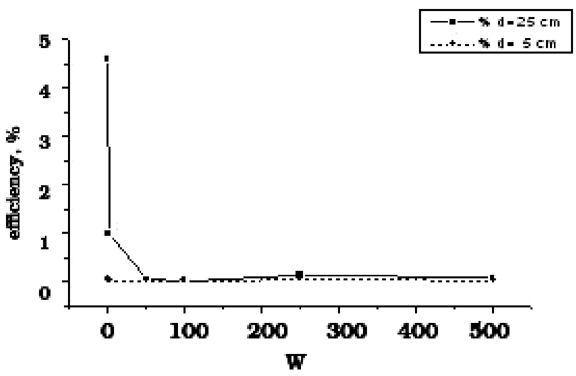

Fig. 8. Dependency of the efficiency at various diameters of the laser spot.

The Volt-Ampere characteristic of the photo element, at 5 *cm* laser spot diameter (Fig. 9) shows relative nonlinearity. Certain saturation is indicated at the higher voltage values. For 25 cm laser spot the volt-ampere characteristic is S-shaped, and the saturation is measured again at the lower current and the higher voltage values. Nonlinearity probably results from the raised temperature of the selective coverage, which causes emission of heat, thus increasing the resistance causing the current to stop decreasing linearly, but keep same values (Fig. 10).

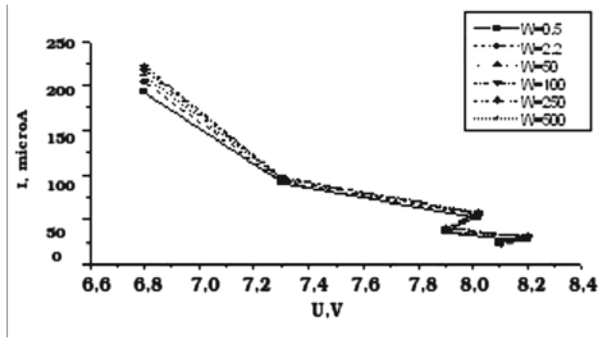

Fig. 9. Volt-Ampere characteristics for CO_2 laser at various power and diameter of 5 cm.

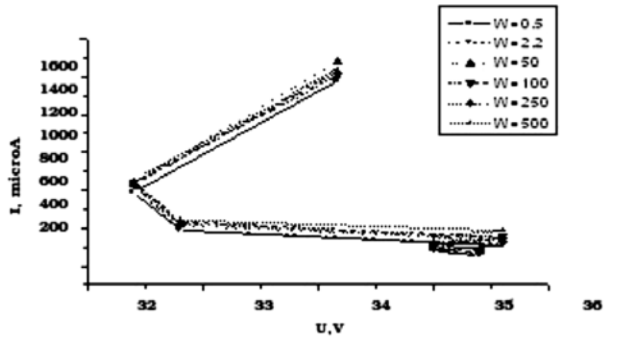

Fig.10. Volt-Ampere characteristics for CO_2 laser at various power and diameter of 25 cm.

Conclusions

The analysis of the results shows that the usage of a wavelength, close to the theoretically deduced one, increases the photo element efficiency. In the same time the results suggest that for producing high efficiency higher power is not necessary.

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