NASA Technical Memorandum 100482

Mathematical Modeling of a Photovoltaic–Laser Energy Converter for Iodine Laser Radiation

Gilbert H. Walker and John H. Heinbockel

July 1987

(NASA-TM-100482) MATHEMATICAL MODELING OF A PHOTOVOLTAIC-LASER ENERGY CONVERTER FOR IODINE LASER RADIATION (NASA) 15 p Avail: NTIS HC A02/MF A01 CSCL 10A

N87-28178

Unclas

G3/44 0094129

National Aeronautics and Space Administration

Langley Research Center
Hampton, Virginia 23665

Mathematical Modeling of a Photovoltaic-Laser Energy Converter For Iodine Laser Radiation

Gilbert H. Walker

NASA Langley Research Center, Hampton, VA 23665-5225

and

John H. Heinbockel

Old Dominion University, Norfolk, VA 23508

Space-based laser power systems will require converters on power receiving spacecraft to convert laser radiation to electricity. Candidate converters are: magnetohydrodynamic (MHD) generators; heat engines; optical rectifiers; reverse free electron lasers; and photovoltaic converters (refs. 1 and 2). This report will emphasize the calculated characteristics of one type of photovoltaic converter.

Properly designed silicon laser-photovoltaic converters have calculated conversion efficiences greater than 50 percent (ref. 3) for 1.06 μm, high intensity laser radiation. Vertical junctions were used for these laser-photovoltaic converters (ref. 3).

A candidate laser for power system applications is the iodide t-C_4F_9I laser (ref. 4). This laser emits radiation at a wavelength of 1.315 μm or 0.943 eV. The semiconductor for a photovoltaic converter used at this wavelength should, for efficient conversion, have a bandgap energy slightly less than the laser photon energy (ref. 5). None of the commonly used elemental and binary semiconductors have bandgap energies near 0.943 eV (ref. 6). By adjusting the amount of GaAs and InAs in the ternary semiconductor $Ga_{1-x}In_xAs$, bandgap energies from 0.36 eV to 1.42 eV can be realized. A bandgap energy of 0.94 eV has been reported for the semiconductor $Ga_{.53}In_{.47}As$ (ref. 7). This bandgap energy was near the laser photon energy. Absorption coefficients and material parameters for $Ga_{.53}In_{.47}As$ are not available in the literature. However, since $Ga_{.53}In_{.47}As$ is a III-V, direct bandgap semiconductor containing GaAs, the absorption coefficients and material parameters were approximated by shifting GaAs parameters to correspond to the 0.94 eV bandgap energy of $Ga_{.53}In_{.47}As$ (ref. 8 and a private communication with M.F. Lamorte). Figure 1 shows the absorption coefficients used in this study (ref. 9).

The model described in reference 5 was used along with the material parameters for $Ga_{.53}In_{.47}As$ to define optimum converter design parameters. A set of baseline converter parameters shown in Table I was assigned. Each of these parameters was then optimized individually. Figure 2 shows the configuration of a single vertical junction converter mounted on a heat pipe. For the bandgap energy of 0.94 eV, the baseline efficiency was 40.3 percent.

Converter Width

Figure 3 shows the effect of increasing the converter width with the p-n junction located 2.5×10^{-4} cm (2.5 μm) from one edge. The efficiency increases from 21.9 percent at a width of 1×10^{-3} cm (10 μm) to 50.0 percent at a width of 3.0×10^{-4} cm (3.0 μm). Although narrower converters have a slightly higher efficiency, from a fabrication viewpoint, 3.0×10^{-4} cm (3.0 μm) is taken as the optimum converter width.

Junction Position

The junction position must be optimized for each converter width. Figure 4 shows the effect of changing the junction position for our optimum width of 3.0×10^{-4} cm (3.0 μm). The efficiency increases from 33.7 percent at a junction position of 5.0×10^{-5} cm (0.5 μm) to a peak of 50.5 percent at a junction position of 2.5×10^{-4}cm (2.5 μm). The efficiency increases because of an increase in the width of the higher diffusion length p material. The efficiency is optimum for a junction position of 2.5×10^{-4} cm (2.5 μm). We choose this value for our optimum converter.

Converter Thickness

Figure 5 shows the effect of converter thickness on converter efficiency. The efficiency increases from 9.8 percent at a thickness of 1×10^{-4} cm (1.0 μm) to 40.3 percent at a thickness of 3×10^{-3} cm (30.0 μm). For our optimized converter, we choose a thickness of 3×10^{-3} cm (30.0 μm).

Series Resistance

Figure 6 shows the effect of varying the series resistance for our baseline converter. The efficiency varies from 40.3 percent for a series resistance of 1×10^{-3} ohms to 20.7 percent for a series resistance of 1.0 ohms. The $Ga_{.53}In_{.47}As$ material in our optimized converter has a calculated resistance of 1.14×10^{-4} ohms. To allow for some contact resistance, we have chosen 2.0×10^{-4} ohms as the series resistance of our single element, optimized converter.

Converter Temperature

The converter for this study is assumed to be mounted on a heat pipe for temperature control under conditions of high incident power density. The temperature of the converter is controlled by the temperature of the heat pipe and by the heat transfer coefficient for the converter-heat pipe interface. Figure 7 shows the converter efficiency as a function of temperature. The efficiency at 250 K is 41.4 percent while the efficiency at 480 K is 18.2 percent. We specify that our optimum converter operate at a heat pipe temperature of 20°C.

Carrier Concentration

Figure 8 shows the effect of acceptor concentration on converter efficiency. The peak efficiency of 41.2 percent occurs for an acceptor concentration of 1×10^{18} carriers/cm^3. Figure 9 shows that the peak efficiency of 48.7 percent occurs for a donor concentration of 1×10^{17} carriers/cm^3. For our optimum converter, we choose an acceptor concentration of 1×10^{18} carriers/cm^3 and a donor concentration of 1×10^{17} carriers/cm^3 corresponding to the peak efficiencies.

Surface Recombination Velocity

Figures 10 and 11 show the effect of surface recombination velocity on the converter efficiency. For the n-contact surface, the efficiency decreases from 40.4 percent at a surface recombination velocity of 1 cm/sec to 26.4 percent at a surface recombination velocity of 1×10^7 cm/sec. For the p-contact surface, the efficiency decreases from 40.7 percent at a surface recombination velocity of 1 cm/sec to 36.4 percent at a surface recombination velocity of 1×10^7 cm/sec. According to reference 10, GaAs interfaces have surface recombination velocities of 1×10^4 cm/sec; therefore, we have chosen 1×10^4 cm/sec as a realistic value of the surface recombination velocity for our optimum converter.

Optimized Converter

Table II shows the parameters of our optimized converter. Figure 12 shows the efficiency of this optimized converter as a function of input power density. The efficiency increases from 33.4 percent at 1 w/cm^2 to an efficiency of 48.6 percent at 1×10^3 w/cm^2.

Multijunction Converter

The above calculations are for a single element, vertical junction converter, whereas in reality, a practical device would consist of many of these optimized vertical junctions connected in series as is shown in figure 13. Applying the parameters for our optimized, single element converter to a 1000 junction converter gives the efficiency as a function of power density shown in figure 14. The efficiency varies from 27.4 percent at 1 w/cm^2 to 42.5 percent at 1×10^3 w/cm^2.

Conclusions

Our mathematical model has been applied to a 0.94 eV photovoltaic converter designed for the 1.315 μm line of an iodine laser. The semiconductor that has a bandgap suitable for use with this laser was $Ga_{.53}In_{.47}As$. By assuming that this III-V direct bandgap semiconductor has absorption coefficients similar to that of GaAs, an optimized converter has been designed. The efficiency of our optimized 1000 junction converter was 42.5 percent at a power density of 1.0×10^3 w/cm^2. This converter was conceived for use with a solar-pumped iodine laser as part of a space-based laser power system.

Table I

Baseline Parameters

Series Resistance	0
Heat Pipe Temperature	20°C
Heat Transfer Coefficient	100
Recombination Velocity on n-surface	1000 cm/sec
Recombination Velocity on p-surface	1000 cm/sec
Input Power Density	1 kw/cm^2
Laser Wavelength	1.315 μm
Converter Thickness	3.0×10^{-3} cm
Converter Width	5.0×10^{-4} cm
Converter Length	1 cm
Junction Position	2.5×10^{-4} cm
Acceptor Carrier Concentration	2×10^{18} carriers/cm^3
Donor Carrier Concentration	6.0×10^{17} carriers/cm^3
Reflection Coefficient	0.05
Shunt Resistance	1×10^6 ohms

Table II

Optimized Parameters

Series Resistance	2×10^{-4} ohms
Heat Pipe Temperature	20°C
Recombination Velocity on n-surface	1×10^{4} cm/sec
Recombination Velocity on p-surface	1×10^{4} cm/sec
Laser Wavelength	1.315 μm
Converter Thickness	3×10^{-3} cm
Converter Width	3.0×10^{-4} cm
Converter Length	1.0 cm
Junction Position	2.5×10^{-4} cm
Acceptor Carrier Concentration	1×10^{18} carriers/cm^3
Donor Carrier Concentration	1×10^{17} carriers/cm^3
Reflection Coefficient	0.05
Shunt Resistance	1×10^{6} ohms

References

1. De Young, R. J., Walberg, G. D., Conway, E. J., and Jones, L. W.: "A NASA High-Power Space-Based Laser Research and Applications Program." NASA SP-464, 1983.

2. Jalufka, N. W.: "Laser Powered MHD Generators For Space Application." NASA TP 2621, October 1986.

3. Walker, Gilbert H.: "Photovoltaic Conversion of Laser to Electrical Power." Proceedings of the 18th Intersociety Energy Conversion Engineering Conference, Orlando, Florida, August 1983, p. 1194-1198.

4. De Young, R. J., Walker, G. H., Williams, M. D., Schuster, G. L., and Conway, E. J.: "Preliminary Design and Cost of a One Megawatt Solar Pumped Iodide Laser Space-to-Space Transmission Station." NASA TM - 4002, 1987.

5. Walker, Gilbert H. and Heinbockel, John H.: "Parametric Study of Laser-Photovoltaic Energy Converters." Accepted for publication in Solar Cells, 1987.

6. Sze, S. M.: "Physics of Semiconductor Devices." Second Edition, John Wiley & Sons, New York, 1981, p. 849.

7. Manasevit, H. M., Simpson, W. I., and Ruth, R. P.: "Study of the Preparation of III-V Alloy Semiconductors with Controlled Bandgaps." AFCRL-71-0299, Air Force Cambridge Research Labs, Report N72-15706, April 1, 1970 through March 31, 1971.

8. Lamorte, M. F. and Abbott, D.: "Two-Junction Cascade Solar Cell Characteristics Under 10^3 Concentration Ratio and AMO - AM5 Spectral Conditions." Conference Record of the 13th IEEE Photovoltaic Specialist Conference, Washington, DC, June 1978, p. 874-880.

9. Casey, H. C., Jr., Sell, D. D., and K. W. Wecht: "Concentration Dependence of the Absorption Coefficient for n- and p-type GaAs Between 1.3 and 1.6 eV." Journal of Applied Physics, 46, No. 1, January 1975, p. 250-257.

10. Hovel, Harold J.: "Semiconductors and Semimetals." Volume 11, Solar Cells, Academic Press, New York, 1975, p. 84.

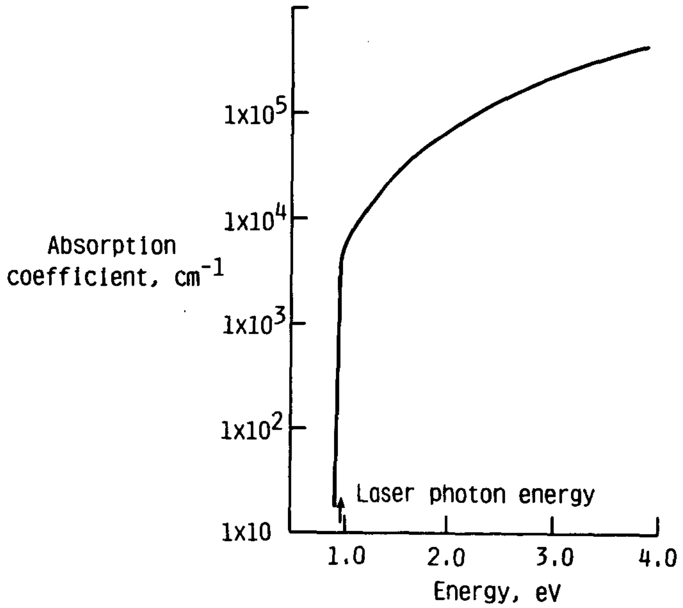

Figure 1 - Absorption coefficients for $Ga_{53}In_{47}As$

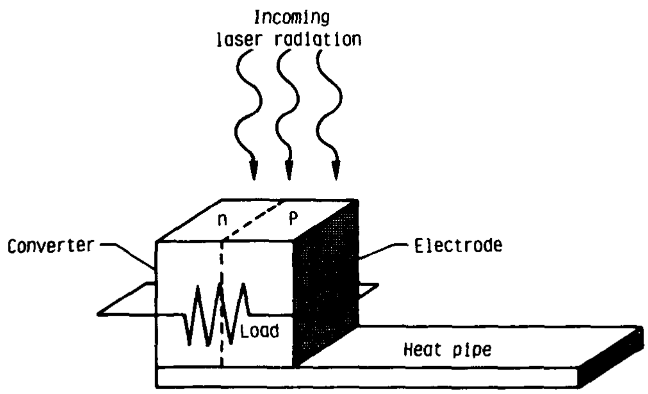

Figure 2 - Single vertical junction converter mounted on a heat pipe

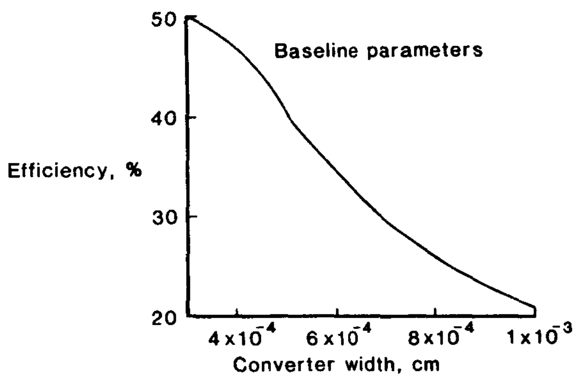

Figure 3 - Efficiency vs. converter width

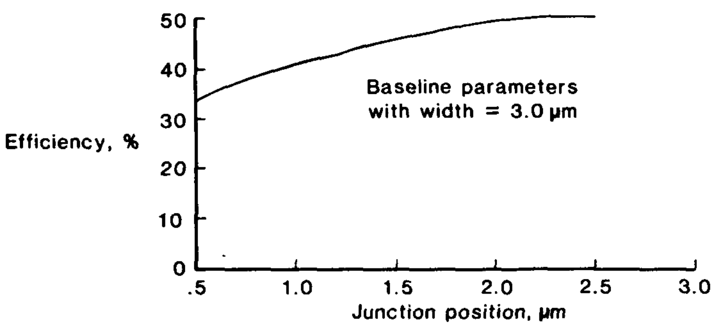

Figure 4 - Efficiency vs. junction position

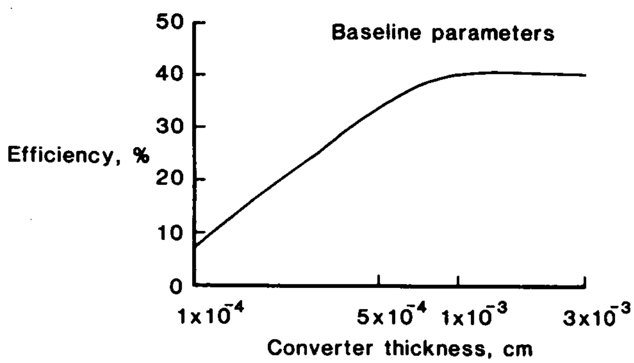

Figure 5 - Efficiency vs. converter thickness

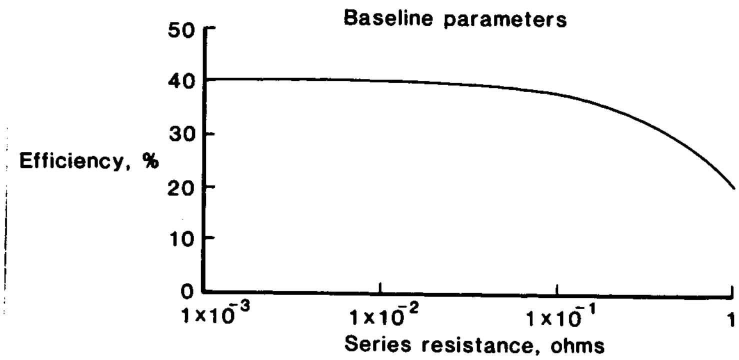

Figure 6 - Efficiency vs. series resistance

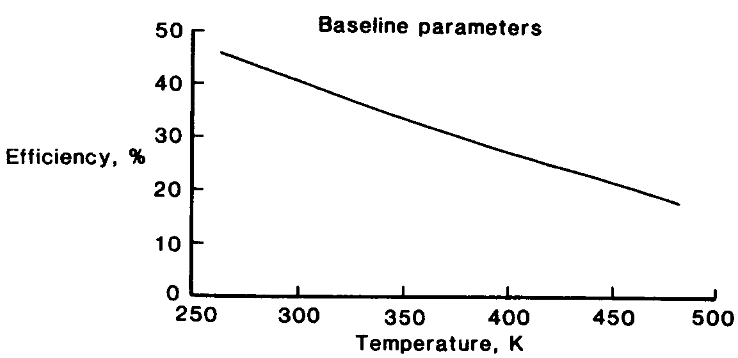

Figure 7 - Efficiency vs. converter temperature

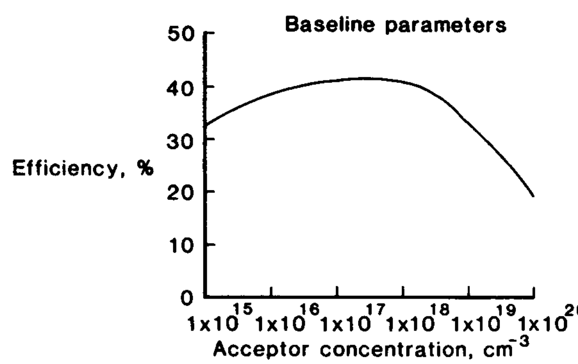

Figure 8 - Efficiency vs. acceptor concentration

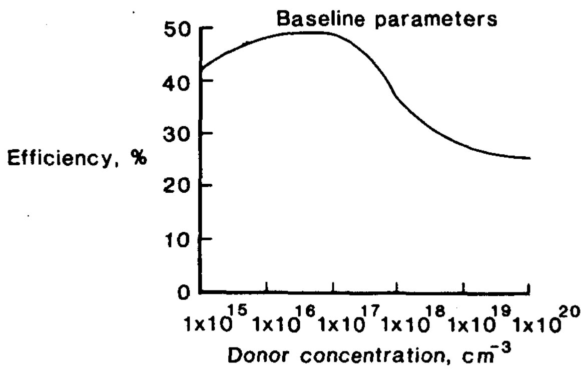

Figure 9 - Efficiency vs. donor concentration

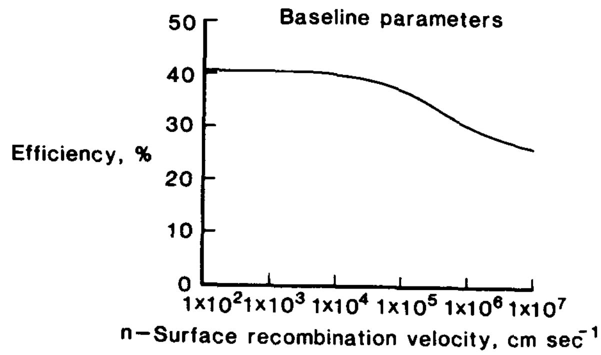

Figure 10 - Efficiency vs. recombination velocity on n - surface

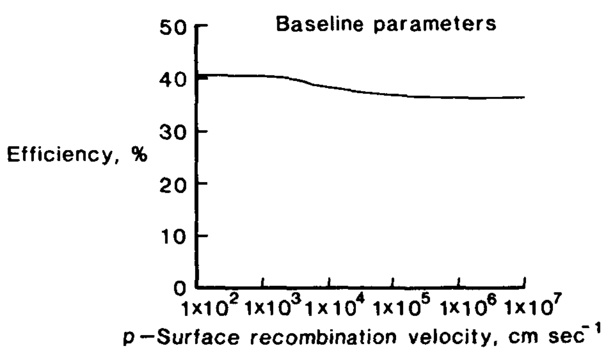

Figure 11 - Efficiency vs. recombination velocity on p - surface

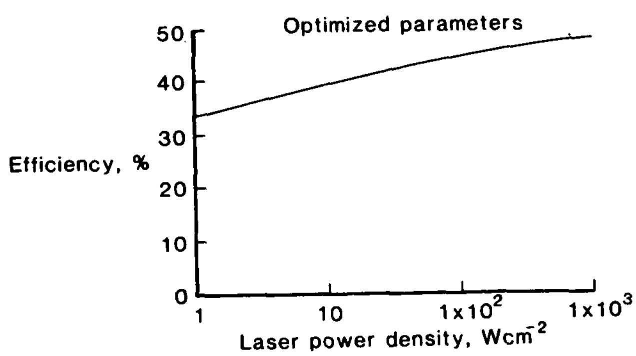

Figure 12 - Efficiency of optimized single junction converter as a function of incident power density

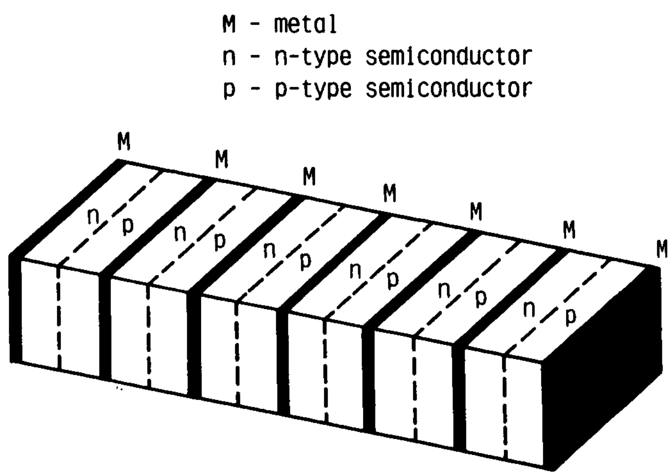

Figure 13 - Schematic diagram of series - connected, multiple junction converter

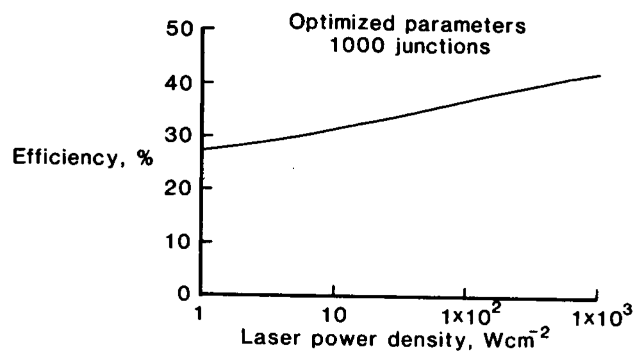

Figure 14 - Effeciency vs. input power density for an optimized, 1000 junction, series - connected converter

Standard Bibliographic Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA TM-100482		

4. Title and Subtitle
Mathematical Modeling of a Photovoltaic-Laser Energy Converter for Iodine Laser Radiation

5. Report Date July 1987

6. Performing Organization Code

7. Author(s)
Gilbert H. Walker and *John H. Heinbockel

8. Performing Organization Report No.

9. Performing Organization Name and Address
NASA Langley Research Center
Hampton, VA 23665-5225

10. Work Unit No. 506-41-41-01

11. Contract or Grant No.

12. Sponsoring Agency Name and Address
National Aeronautics and Space Administration
Washington, DC 20546

13. Type of Report and Period Covered Technical Memorandum

14. Sponsoring Agency Code

15. Supplementary Notes
*Old Dominion University, Norfolk, Virginia 23508

16. Abstract Space-based laser power systems will require converters to convert laser radiation to electricity. Vertical junction photovoltaic converters are promising devices for this use. A promising laser for the laser power station is the t-C_4F_9I laser which emits radiation at a wavelength of 1.315 μm. This paper describes the results of mathematical modeling of a photovoltaic-laser energy converter for use with this laser. The material for this photovoltaic converter is $Ga_{.53}In_{.47}As$ which has a bandgap energy of 0.94 eV, slightly below the energy of the laser photons (0.943 eV). Results of a study optimizing the converter parameters are presented. Calculated efficiency for a 1000 vertical junction converter is 42.5 percent at a power density of 1×10^3 w/cm^2.

17. Key Words (Suggested by Authors(s))	18. Distribution Statement
Energy conversion Photovoltaic converters Solid-State devices Laser-Energy conversion	Unclassified-Unlimited Subject Category - 44

19. Security Classif.(of this report)	20. Security Classif.(of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	14	A02

For sale by the National Technical Information Service, Springfield, Virginia 22161

NASA Langley Form 63 (June 1985)