Project LaMaR:
Laser-powered Mars Rover

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Presented to:
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1.0 Abstract

Rover exploration on the Martian and lunar surfaces is limited to areas where direct sunlight can recharge secondary rover batteries. The task of Project LaMaR is to design a laser-power receiving system that can allow the rover to be operated in a shadowed crater or canyon. The design driver is to find a photovoltaic (PV) cell and laser combination that will achieve the greatest power conversion efficiency. In order to minimize the power conversion loss, it is necessary to closely match the laser wavelength and the cell material bandgap.

Power efficiency tests were performed with Silicon (Si), single-junction Gallium Arsenide (GaAs) and dual-junction Gallium Indium Phosphide (GaInP)/GaAs cells. Experimentation was performed using lasers with wavelengths of 632 nm, 720 nm, 830 nm, 1064 nm and 10000 nm. The maximum power conversion efficiency obtained was 68.5% when applying an 830-nm beam to a single-junction GaAs cell. To illustrate the concept for public outreach purposes, a small laser-pointer demonstration model was built.

2.0 Introduction – Design Problem

Advances in robotic technology have had a significant effect on surface exploration and the prospect of human arrival on Mars. Robotic precursors on Mars will allow for enhanced research before human habitation, as well as aid in continual exploration during future missions. According to the Mars Reference Mission [1], the use of robots will play roles in several important areas of human exploration on Mars including, but not limited to, gathering surface information, demonstrating technological advancements, and maintaining a significant portion of surface systems prior to crew arrival.

Powering devices using photovoltaics is a topic of high importance throughout the aerospace industry and significant research has been performed to improve them. However, with current PV technology, there is no practical way to improve mission duration when the rover is not in direct sunlight. Recent discoveries have shown that sources of water may exist on both the Moon and Mars in the form of polar ice. It stands to reason that to reach this ice, an alternative power source needs to be provided to the vehicles to continue to be fully functional in low temperatures and complete darkness. Using laser-photovoltaic power transmission, it should become possible for rovers to explore areas such as craters and deep canyons [8,9]. The focus of Project LaMaR is to present a possible solution to this specific problem and intends on demonstrating that a rover can be operated for extended periods of time in total darkness by harnessing laser-beam energy transmitted from a base station at the crater/canyon rim. The objective is to create a longer life span for both the vehicle and the mission and Project LaMaR will provide a proof-of-concept of this laser-powered rover.

Note that the project does not focus on the technical aspects of the base-station laser, or the method by which the rover and base-station communicate with each other. In the case that obstacles may block the line of sight between the rover and base station, the rover is expected to continue forth only when it is sure that there is sufficient battery power to get back to line of sight again. Further research must investigate the feasibility of building the base-station.

3.0 Approach to the Problem

The proof-of-concept design approach of Project LaMaR can be designated by four areas:

- Background research into PV applications and processes
- Experimentation with different laser and PV cell combinations
- Design for a Martian or lunar application
- Build a demonstration model for outreach and presentation use

3.1 Background Research

The initial project requirements as defined by corporate advisors were as follows:

- Rover operates with 28-volt DC bus and ranging in power from 15 to 50 watts
- Base-station laser specifications: Nd:YAG – 1060 nm and 1000 watt output power
- Expected 50% power loss of laser beam during transmission, therefore the cells will receive 500 watts

From these design specifications, it became evident that traditional solar cell information and resources would not be applicable to the project. Power efficiencies are determined under the full solar spectrum and often the entire area of the cell is covered. In the case of Project LaMaR, monochromatic light is being harnessed and will probably not cover the entire cell area. Therefore, previously generated efficiency curves and data could not be applied. A new set of data must be built to take these never-before-tested factors into account.

Having never taken an undergraduate class to learn the PV process, it was necessary to fulfill the knowledge void by learning what types of solar cells exist and how they work. In doing so, it became evident that Project LaMaR must complete experiments with several types of cells when looking for the optimal design solution.

The sun emits photons across the full spectrum of wavelengths. For this reason multiple-junction cells give the best response for use in the sun because their multiple band gaps cover a wider solar spectrum. Each layer covers a different range of wavelengths. The level of photons that the sun produces at those wavelengths is known when the cells are manufactured. Figure 3.1-1 below shows the spectral response of the 3 layers that make up a triple-junction cell as well as the photon energy of the sun of the spectrum. This graph shows how the range of the three layers help to design a cell where all the layers are producing close to the same power. Understanding this makes it easy to see whey as PV cell technology has improved the industry has stopped making single junction cells and started making advances in double, triple, and even quadruple junction cells.

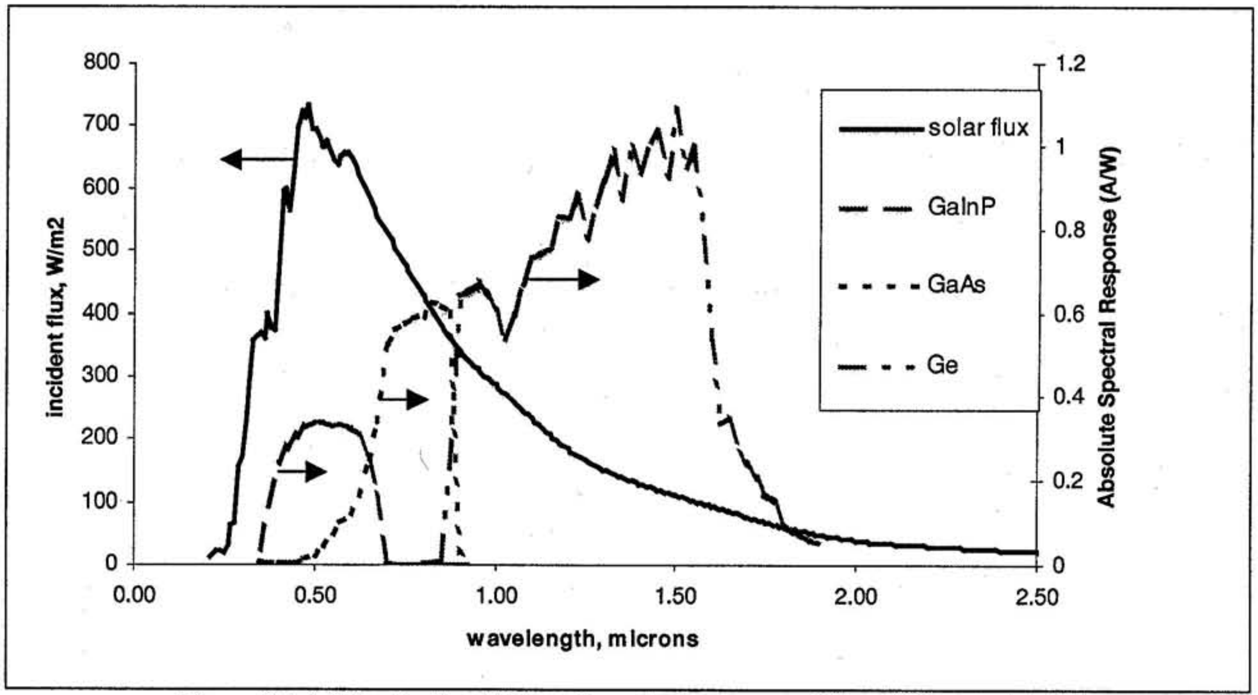


Figure 3.1-1 Solar incident flux and spectral response of three PV materials [7]

3.2 Experimentation

In order to find the best solution (highest power efficiency), experimentation with many types of lasers and selected PV cells was necessary. Commonly used PV cells like Silicon (Si), Gallium Arsenide (GaAs) and Gallium Indium Phosphide (GaInP) cover the broad section of the solar spectrum from below 400 nm to above 1000 nm. Therefore, Project LaMaR decided to test with laser wavelengths falling into this range. Also of concern in the experimentation process is the efficiency performance of single-junction cells versus dual-junction cells.

3.3 Mars Rover Design

Knowing very little about Mars surface conditions and having only one previous Mars rover to refer to (Sojourner, 1997), many assumptions had to be made about the proof-of-concept design. In addition to the previously mentioned 50% laser power loss during beaming, other atmospheric conditions such as dust accumulation on the cells and low operating temperatures must be considered.

The purpose of the Mars design model is to provide an accurate depiction of the laser and PV cell requirements necessary to achieve the goal of highest power efficiency. Project LaMaR intends to create an example for real-world application on Mars based upon the results demonstrated in the experimental phase of the project.

3.4 Demonstration Model

The rationale for having a demonstration model is to achieve a high level of understanding about the project for public observers. This particularly applies to Project LaMaR's outreach at both the University of Colorado Design Expo as well as the presentations given to Boulder-area, high school physics classes. The model is a remote control car mounted with a solar cell, which can be driven when laser beams are applied to the cell.

4.0 Results

Seven different lasers were used for testing, each having different wavelength and power properties. Refer to table 4.0-1 for a complete list of laser specifications.

Table 4.0-1 Summary of laser specifications

Laser #	Wavelength	Power	Type	Location	Technician
1	632 nm	5 mW	HeNe	Handheld	Team LaMaR
2	632 nm	10 mW	HeNe	Portable	Daniel Vigliotti
3	632 nm	30 mW	HeNe	NIST	Tim Quinn
4	720 nm	52 mW	Ti-Sapphire	NREL	Don Selmarten
5	830 nm	48 mW	SDL 800 Diode	NREL	Pat Dippo
6	1064 nm	490 mW	Nd:YAG	NIST	Donna Hurley
7	10,000 nm	5 W	CO_2	NIST	Andrew Slivka

Laser 7 was used only to heat cells for conducting thermal tests. It also served to prove that there is no power generated with a laser at this wavelength. Results from the thermal tests are discussed in section 4.6.

Tests were performed using Silicon, single-junction GaAs and dual-junction GaInP/GaAs cells. The experimental conditions for all tests were held at room temperature and in near complete darkness. Dark readings were taken to ensure that any ambient room lighting was at a minimum. Safety goggles were worn when using the 720 nm, 830 nm, 1060 nm and 10000 nm lasers. Up to five voltage and current readings were taken during all tests to achieve an average value. Each cell was reoriented slightly so that the beam would strike a different area on it when the testing apparatus permitted. The distance between the laser aperture and the cell varied between 10 and 40 cm for the different lasers depending on the equipment setup. The diameter of the beam hitting the cell was typically 1 to 3 mm unless otherwise stated as in section 4.5 where beam expansion and its effect on performance is discussed. Also, the cells were tested with no applied load, and therefore voltage measurements are "open-circuit" and current measurements are considered "short-circuit".

4.1 Dual-Junction Test Results

Four dual-junction solar cells were mounted and had leads soldered for use in the experiment and labeled 'Cell A' through 'Cell D'. Used in the test were lasers 1 through 4 as denoted in table 4.0-1 above. Average voltage and current output were calculated from five separate tests for each cell/laser combination. The maximum power efficiency performance was seen with Cell C; table 4.1-1 displays the data results for Cell C.

Table 4.1-1 Dual-junction test results

Laser Characteristics			Dual-junction Output (Cell C)			
Type	Power (mW)	λ (nm)	Voltage (V)	Current (mA)	Power (mW)	Power Efficiency (%)
HeNe	5	632	1.35	0.52	0.71	14.11
HeNe	10	632	1.40	0.92	1.29	12.86
HeNe	30	632	1.66	3.40	5.64	18.81
Ti-sapphire	52	720	1.11	0.55	0.61	1.16

Although the power efficiency for each of the 632-nm lasers are lower than expected, they are not necessarily abnormal. However, the next concern is trying to explain the extremely poor efficiency at 720 nm. In doing so, it is necessary to analyze what is happening within each individual layer of the dual-junction cell. Figure 4.1-1 displays a view of the layers in a dual-junction GaInP/GaAs cell.

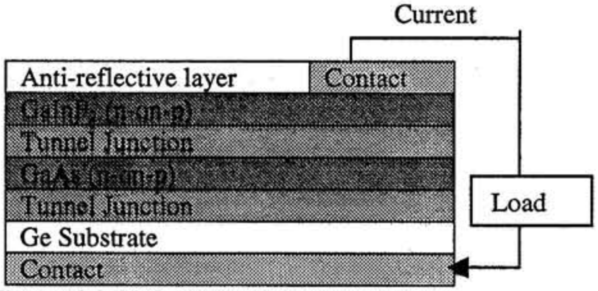


Figure 4.1-1 Diagram of dual-junction cell

The dual-junction cell is a circuit when it is functioning properly. The individual layers act like two batteries linked in series. When light photons strike electrons within the layer, current is generated between the n and p layer of the material. The important characteristic for achieving high power efficiency is to match the current generated within each layer. If a significantly different current is created in each cell, the overall efficiency of the system decreases.

Now that the issue of current matching within dual-junction cells has been discussed, it is possible to visually demonstrate why the power efficiency at 720 nm was so low (1.16%). Looking at the quantum efficiency (QE) (photons/electrons) curves in figure 4.1-2 for GaInP and GaAs, it becomes all too clear why the cell at 720 nm generated such little current.

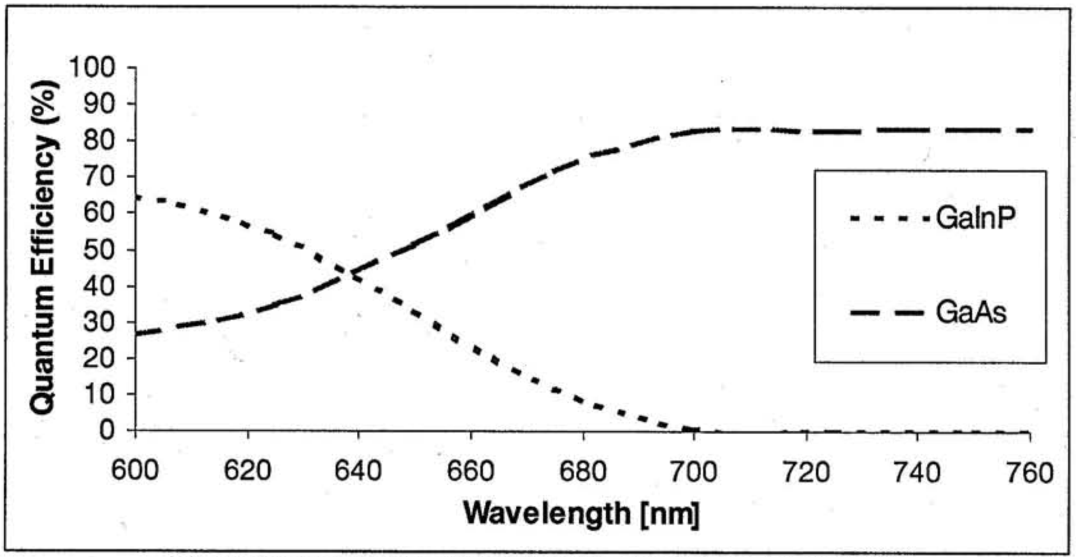


Figure 4.1-2 Quantum efficiency curves for GaInP and GaAs [7]

At 632 nm, it can be seen in the figure that a current response (QE of about 35 to 55%) is generated within each of the individual layers of the cell. However, at 720 nm the GaInP does not respond to the incoming photon and is a transparent layer; the photons go right through the material. Minimal current is generated within the layer and the overall efficiency of the entire cell is decreased significantly. With only one junction generating current, the circuit cannot be completed.

Having witnessed the problem of current matching within a multi-junction cell, the next step is to confirm that single-junction GaAs cells will respond as expected with much higher power efficiency. The next section displays the repeat experiments on the single-junction cells which will allow for a comparison of the two cell types and their power efficiency performance.

4.2 Single-Junction Test Results

Four single-junction GaAs solar cells were also mounted and had leads soldered for use in the experiment ('Cell A' through 'Cell D'). Used in the test were lasers 1 through 6 as denoted in table 4.0-1 above. Average voltage and current output were calculated from five separate tests for each cell/laser combination. The maximum power efficiency performance was seen with Cell B; table 4.2-1 displays the data results for Cell B.

Table 4.2-1 Single-junction GaAs test results

Laser Characteristics			Dual-junction GaInP/GaAs Cell Output (Cell C)			
Type	**Power (mW)**	**λ (nm)**	**Voltage (V)**	**Current (mA)**	**Power (mW)**	**Power Efficiency (%)**
HeNe	10	632	0.65	1.88	1.23	12.30
Ti-sapphire	52	720	0.80	24.88	19.81	38.10
SDL 800 Diode	48	830	0.82	39.92	32.88	68.50
Nd:YAG	490	1064	0	0	0	0

What is important to note is the 68.5% power efficiency achieved with the 830-nm laser. Also note that the relationship between increasing wavelength (632 nm up to 830 nm) and power efficiency is nearly linear. Due to the fact that the bandgap energy of GaAs occurs at a wavelength of 886 nm (1.4 eV) it might be possible to predict that an even higher efficiency will be seen up to the bandgap wavelength. However, Project LaMaR did not want to theorize about this possibility unless the experimentation with a laser wavelength between 830 nm and 886 nm could be performed. The power efficiency at 632 nm (12.3%) is lower than that seen in the dual-junction results (~15 %).

4.3 Silicon Test Results

For a complete analysis, it was necessary to experiment with the most commonly used solar cell – Silicon. They are cheaper, easier to manufacture, and cover a wider range of wavelengths than a single-junction GaAs cell. However, optimum efficiencies for this cell occur at shorter wavelengths, i.e. below 632 nm. Due to the fact that Si operates more efficiently below the red spectrum, it is not a viable choice for a Mars rover application. The dust in Mars' atmosphere alters the spectrum; it is blue deficient. Even though Silicon has lower overall efficiencies, it will be the only cell that responds if a 1064 nm laser must be used. Test results for the one silicon cell are shown in table 4.3-1.

Table 4.3-1 Results of the Si cell tests

Laser Characteristics			Silicon Output			
Type	**Power (mW)**	**λ (nm)**	**Voltage (V)**	**Current (mA)**	**Power (mW)**	**Power Efficiency (%)**
HeNe	10	632	0.38	1.83	0.70	6.95
HeNe	30	632	0.42	6.87	2.88	9.62
Ti-Saphire	81	720	0.46	36.47	16.70	20.62
Nd:YAG	490	1064	0.47	57.1	27.08	5.53

The silicon cell was not available during the time that testing was performed on the 830 nm laser. For the lasers that were tested the maximum power efficiency was seen on the 720 nm laser. If silicon would be used, it would probably be with a 1064 nm laser, but the efficiency here is only 5.53% this would not serve as viable rover mission selection.

4.4 Using Multiple Laser Beams

The purpose of this section is to explore the effect of beaming more than one laser on a cell. Using Cell B from the single-junction GaAs experiment up to five handheld, 632-nm lasers were added. The results of this experiment are shown in table 4.4-1.

Table 4.4-1 Results of multi-laser test

	Voltage (V)	Current (mA)	Power (mW)	Power Efficiency (%)
Dark Reading	0.01	0.00	0.00	0.0
5mW	0.63	1.13	0.70	14.1
2 x 5mW	0.67	2.33	1.56	15.6
3 x 5mW	0.70	3.51	2.44	16.2
4 x 5mW	0.71	4.59	3.26	16.3
5 x 5mW	0.72	5.75	4.16	16.6

The maximum power efficiency of 16.6% was achieved with all five lasers. The voltage changed very minimally (0.63 V to 0.72 V) as the lasers were added but the current increased from an average of 1.13 to 5.75 mA. The voltage, current and efficiency trends are displayed in figure 4.4-1.

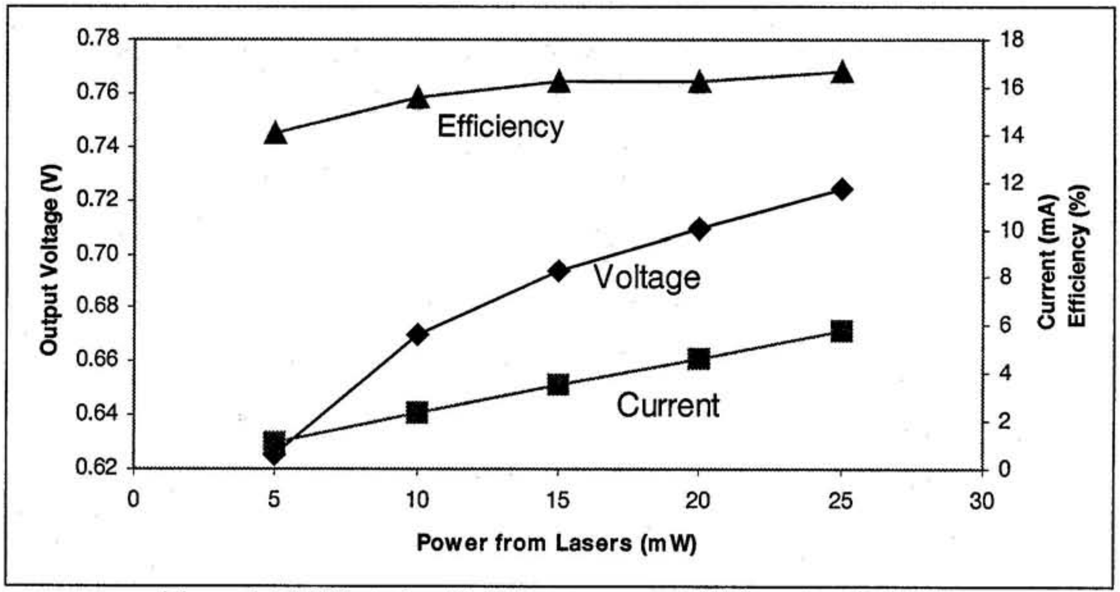


Figure 4.4-1 Effect of multiple lasers on one single-junction GaAs cell

The results of this experiment redefined one of the original Mars rover design requirements. Instead of using one 1000-watt laser, it would be more beneficial to use additional lasers at lower power output. The power efficiency of two 5-watt lasers from table 4.4-1 is 15.6%, whereas the efficiency of one 10-watt laser in table 4.2-1 is only 12.3%. Section 5.1 discusses the real-world application of multiple laser beams for the laser-powered Mars rover.

4.5 Effects of Beam Expansion

Lasers 3 and 6 were collimated, and lasers 4 and 5 had adjustable beam diameters. The effect of beam expansion was analyzed using the latter two. The beam diameter of the 720-nm laser went from 1mm to 1cm and that of the 830-nm laser increased from a 5 mm circle to an oval about 2.5 cm x 0.75 cm. In both cases the power efficiency decreased when the beam was expanded (see figure 4.5-1) on single-junction GaAs cells.

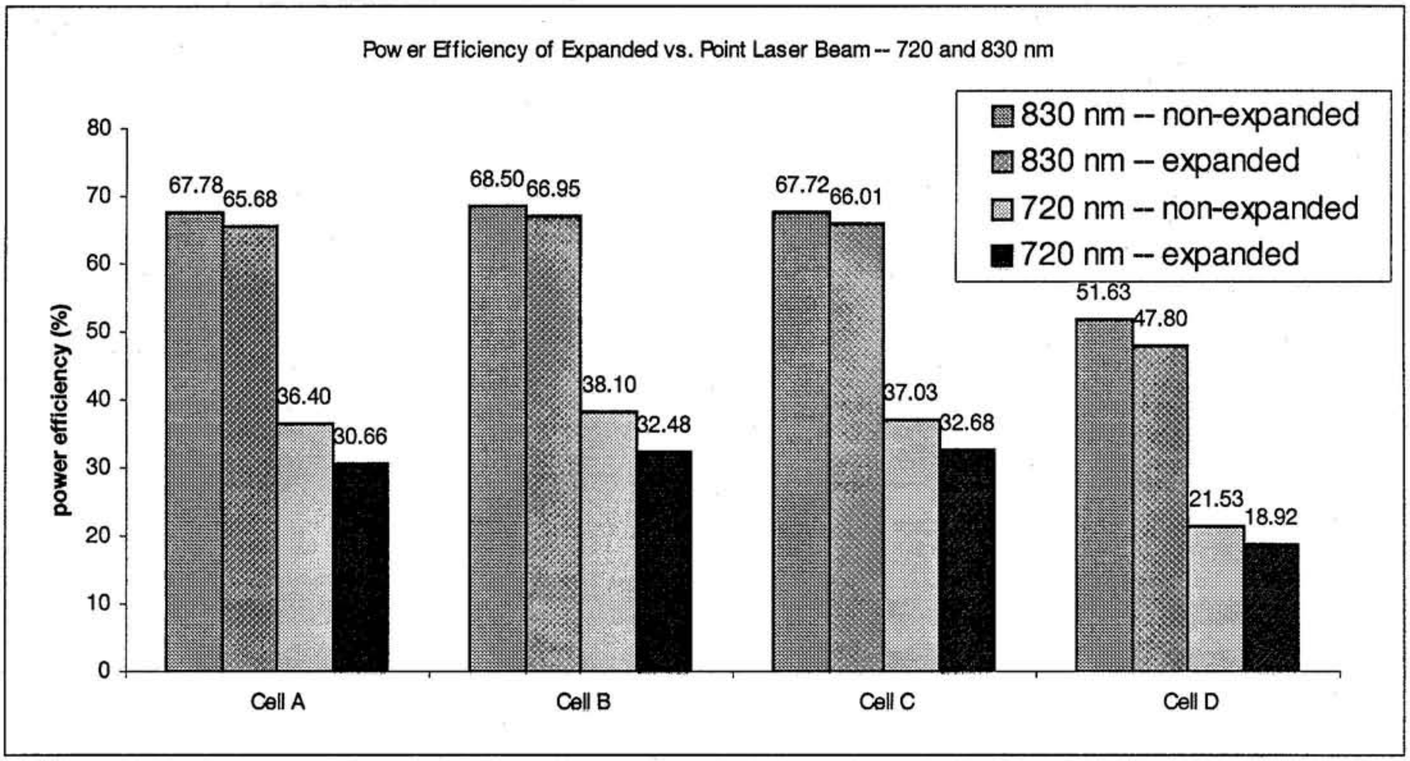


Figure 4.5-1 Effect of beam expansion on power efficiency

The fact that the power density decreases as the beam expands, less current is generated in return. The efficiency decreases more quickly at the 720-nm wavelength because it is farther away from the bandgap of GaAs than the 830-nm wavelength. This is also relative to the size of the cell and power of the beam.

4.6 Thermal Testing

In order to investigate the effects of thermal changes as a cell heats up, tests were performed with a 5-W laser (# 7, table 4.0-1). With a wavelength of 10μm, the cell appears transparent to the laser beam, and therefore the cell heats without current generation. A thermocouple was positioned on the backside of a single-junction GaAs and Si cell. Figure 4.6-1 shows the relationship between voltage and temperature. The source of the voltage being generated is due to a small desk lamp that facilitated data taking.

The GaAs seems to be affected more significantly by the temperature change. This indicates that it will operate more efficiently when used in a colder environment. The Si cell is not affected as much by the change in temperature from the high intensity beam. From these tests trend lines were created which were compared with the thermal coefficient data obtained from Spectrolab data sheets (see table 4.6-1). The Spectrolab test simulates the solar spectrum of AMO conditions, or 135.3 mW/cm^2 (1 sun). The intensity of the laser used for thermal testing in figure 4.6-1 was 20,000 mW/cm^2 (~148 suns).

Table 4.6-1 Thermal coefficients of GaAs and Si cells

Cell Type	Spectrolab	Team LaMaR
Silicon	-2.2 mV/°C	-3.89 mV/°C
Single-Junction GaAs	-1.9 mV/°C	-0.94 mV/°C

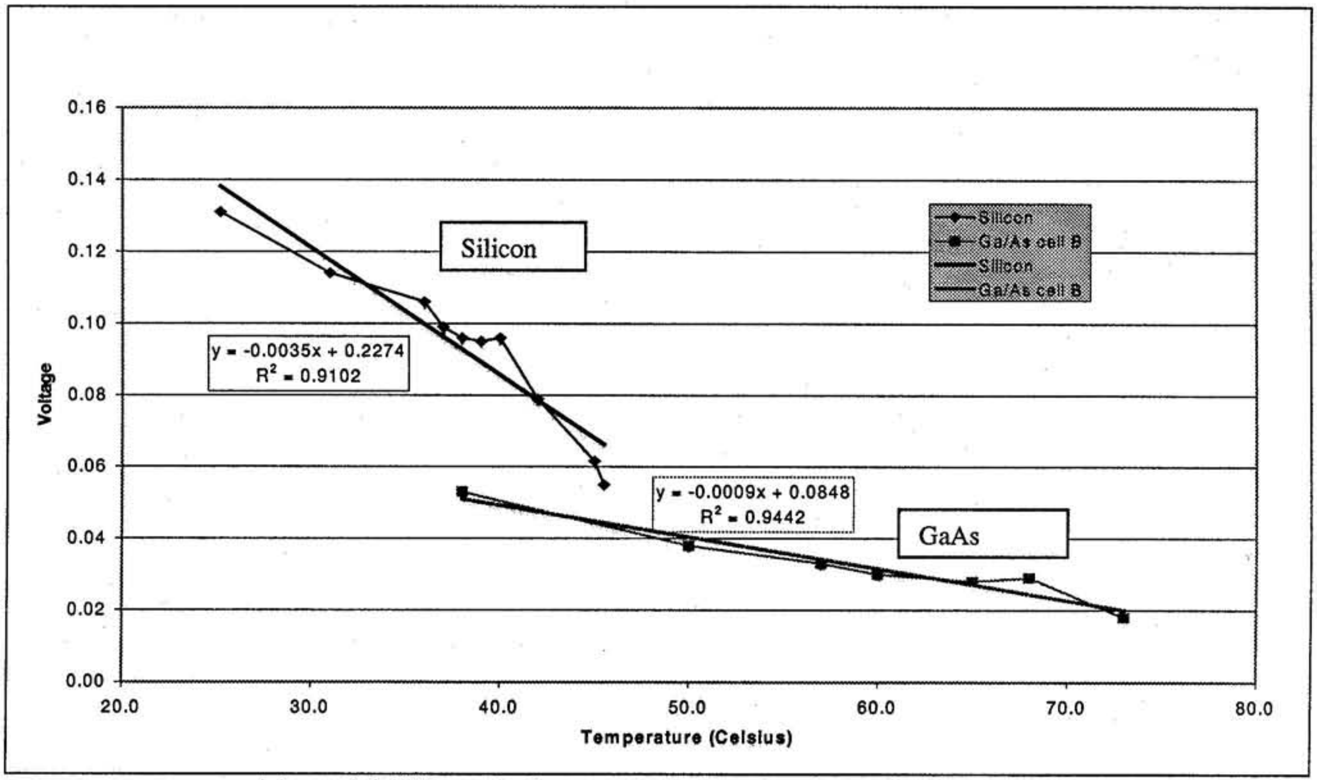


Figure 4.6-1 Thermal effects on single-junction GaAs and Si cells

The discrepancies in table 4.6-1 between experimental results and Spectrolab values can be attributed to several factors. First, the Spectrolab test illuminates the entire cell whereas the laser beam only covers a spot about 5 mm in diameter. Also, the thermocouple was placed on the back of the cell as close to the area where the beam was hitting. Therefore the temperature reading was not uniform across the cell, but local to that spot. The thermal coefficients obtained using the 5-W laser are only localized results, but are useful in determining how a single laser will affect the thermal properties of the cells.

5.0 Conclusions

Although the optimal results were achieved using single-junction GaAs cells, the testing on dual-junction cells turned out to be very useful. It provided a clearer understanding of how multi-junction cells function when subjected to monochromatic light, and it clarified the issue of current matching.

5.1 Mars/Moon Application Conclusions

Based on the results obtained from testing with dual-junction and single-junction cells, the overall proof-of-concept Mars/Moon rover was designed. To do so, atmospheric effects as well as surface conditions were taken into consideration.

The design assumptions are as follows; (1) the maximum efficiency can to be achieved by closely matching the laser wavelength and cell bandgap, (2) the laser power output should be enough to produce the needed requirements for the rover, (3) excess heat generation should be avoided, and (4) the surface and atmospheric conditions must be estimated. The significant atmospheric problem on Mars is the dust. In a typical 30-day mission, dust will deposit on 6.6% of a horizontal array [6]. One goal of this project is to increase the mission life to 1 year or more. This would mean that over 50% of a horizontal array would be covered in dust. Therefore, a vertically mounted array would be beneficial in reducing this negative effect. As a best estimate, it is assumed that the laser beam power will be reduced by 50% during transmission to the rover. Dust factors can be eliminated for a moon application.

Temperature is also an important factor in the performance of the cells. The minimum predicted temperature on Mars is -112°C. Fortunately, based on our thermal studies, single-junction GaAs cells have enhanced performance at lower temperatures.

From the data collected, the application assumptions were devised. A minimum of 68% power efficiency is expected when using single-junction GaAs cells and an 830-nm laser. This forms the basis for determining the power of the lasers and the cells area. Multiple lasers with small diameters have shown to interact better with cells than one laser with an expanded beam. Multiple lasers also offer a degree of redundancy, enhancing system level reliability in the event that one of the lasers might not perform as expected. Low-power lasers are also less costly than a single, high-power laser. One benefit of using lasers instead of sunlight is that the angle at which the beam hits the solar array does not produces significant losses in power. They are small enough to be considered negligible. Based upon the power requirements of Sojourner (max 16.5 W at noon), it is predicted that 30 W would be desired for a larger rover with increased functionality.

The final step of the design was to determine the type of cell, power and wavelength of the laser, and the array size. The cell selected was a single-junction GaAs cell. This was based on the efficiency, ease of manufacturing, atmosphere constraints, and experimental performance. To generate 30 W for the rover, and considering a 68% power efficiency conversion, a total of 45 W must be striking the photovoltaic cell. However, taking the 50% transmission loss into account results in a total of 90 W to be beamed from the base station. Since multiple lasers were desired, 4 lasers of 22.5 W per laser were selected to achieve the 90 W. The laser must be designed for the arriving beam diameter of 10 cm (when the rover is 10 km from the base station), and therefore a total cell array of 400 cm^2 has been selected to capture all four beams. Each beam creates about one sun of illumination, and therefore ensures that the cells are not heated to any abnormal degree. With this design, all of the requirements and objectives have been met. Figure 5.1-1 shows a schematic of this design concept.

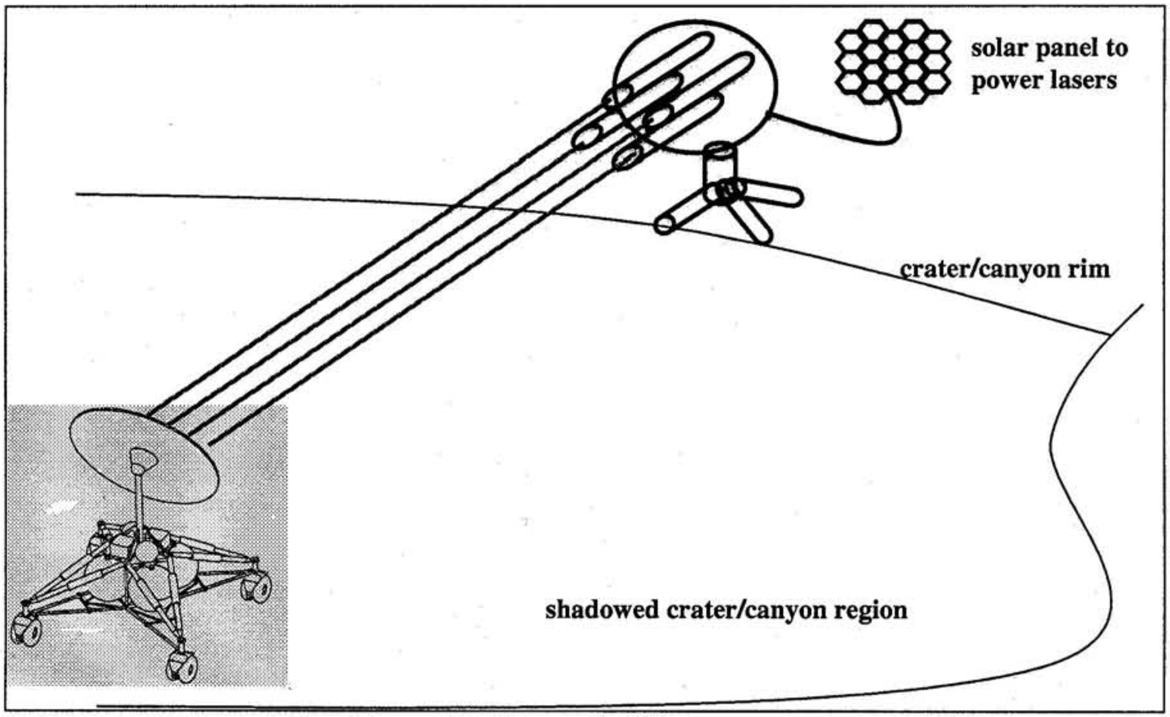


Figure 5.1-1 Schematic of design concept

This design incorporates a base station equipped with the four lasers and a rover that can move up to a distance of 10 km away from the base and operate is the darkest crater or canyon (farther distances would be possible, with reduced power levels). The rover will not be much larger than the Sojourner rover, but can be equipped with digging tools and other collection and analysis mechanisms. The rover will also be equipped with a secondary source of battery power for use when the rover does not have line of sight with the base station. The solar array will be mounted as shown in Figure 5.1-1. It will be mounted in such a way to minimize dust collection and will be able to rotate for maintaining line of sight with the base. A gimble attachment allows for angle deflection and minimizing dust deposits.

5.2 Demo Conclusions

For both our outreach efforts and the HEDS-UP Forum we wanted to physically demonstrate the capabilities of the system with a toy, such as a remote control car. Lasers for the demonstration were selected based on safety, portability, cost, and availability. The design driver for selecting a toy car was to minimizing the required power to run it. Conveniently this also minimized the safety concerns as well as the portability concerns for the presentation. It was decided that the best laser for our demo would be not be just one laser, but multiple handheld lasers. They were small, did not cause permanent damage to the eye, inexpensive, and already demonstrated positive results when combined on one cell. The lasers for the demo were 632nm wavelength, so the best cells to use were the Dual-Junction cells with an efficiency of 14%.

A small remote control car that normally operates on two AA batteries was the first selection. This car was tested to determine the exact voltage and current requirements. Even though the combined voltage of the batteries was 3.0 V it was shown that the car could run on low batteries down to approximately 2.5 V. An ammeter was used to determine that the car run will run on anywhere from 190 to 210mA of current. Obviously this was well out of the range for an application with the 5mW lasers. A different demonstration was needed. Searches for a toy that ran on only one AAA battery proved useless. It was determined that we the demonstration effectiveness can be achieved by simply moving the car, as opposed to directly powering it with the laser beam power. A circuit board was designed to replace the existing circuitry in the car.

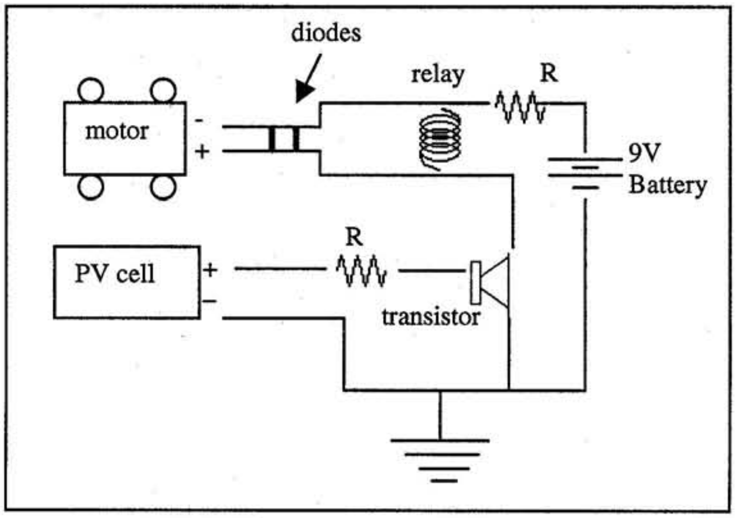


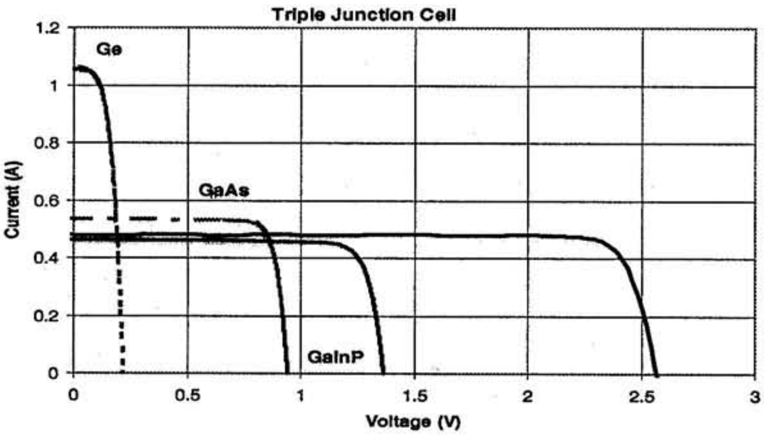
Figure 4.3-2 Demo circuit

The circuit uses the power from the solar cells to close the switch in the transistor. When the transistor is closed the power from the 9V battery operates the circuit, and the relay closes the circuit to the car. Two diodes were used to help prevent the relay from welding permanently. Resistance was added to control the power flow in the circuit. After the circuit was working it was noticed that the ambient florescent room lighting was enough to power the transistor. To increase the amount of power required from the cells a second resister was added. This allowed for a clearly defined demonstration. When the lasers are on the cells the transistor is closed and the motor runs, but it does not when just the room lights hit the cells. Depending on the ambient lights in the room where the demo is being displayed, the cells may require more lasers, or the resistance may need to be increased to ensure that the cells are not activated without lasers.

6.0 Future Studies & Lessons Learned

Possible additional testing for this system would use a tunable laser that is adjustable to both wavelength and power. This would allow for studies into the best possible wavelength for each type of cell. Of interest are the efficiencies generated between the wavelengths of 831 nm and 890 nm. Above 890 nm, a significant decrease in power efficiency would be expected in the single-junction GaAs cell. The efficiencies that we have witnessed in these tests could be increased by perhaps another 10 to 20%.

Based on the QE and Spectral Response curves for the three materials, it looks like the obvious choice cell material would be Germanium. If a laser could be designed to match the exact desired wavelength in Germanium's band gap, it should have an excellent efficiency. Single junction Germanium cells have never been manufactured because, when the solar spectrum in analyzed, there are relatively few photons emitted in Germanium's range. This vehicle will not be dependent on the sun's photon emittance, however, considering the total system requirements for the vehicle, this may not be the best choice. Figure 6.0-1 below shows that there may be other issues to consider



Light IV curves of GaInP, GaAs, and Ge subcells, and a production Triple Junction solar cell.

Figure 6.0-1 Quality of power produced [7]

It is well known that that power is the product of voltage and current. The power generated by each junction of cell type is not always made up of the same proportion of voltage and current. The figure clearly shows that Germanium converts most of the power into current while the other two materials create more voltage than current. It is common practice in building circuits to use voltage dividers when the voltage is too high. To do the reverse and turn the current into voltage is usually much harder. For this reason, even though the overall efficiency for Germanium may be higher, it might make more engineering sense to select GaInP or GaAs for the application.

7.0 Project LaMaR Outreach

In late April of every year, the University of Colorado Engineering Council (UCEC) sponsors a design expo as part of its Engineering-Days celebrations. Undergraduate design teams are given the opportunity to present their project and be judged by industry leaders and faculty. Members of the local press, community and industry representatives were invited to see the 73 groups that presented. Projects are grouped into similar disciplines and experience levels. Some of the more popular categories are the Assisted Technology group, Rube Goldberg Machines, and interactive children learning stations. Project LaMaR received the award for Best Aerospace Project.

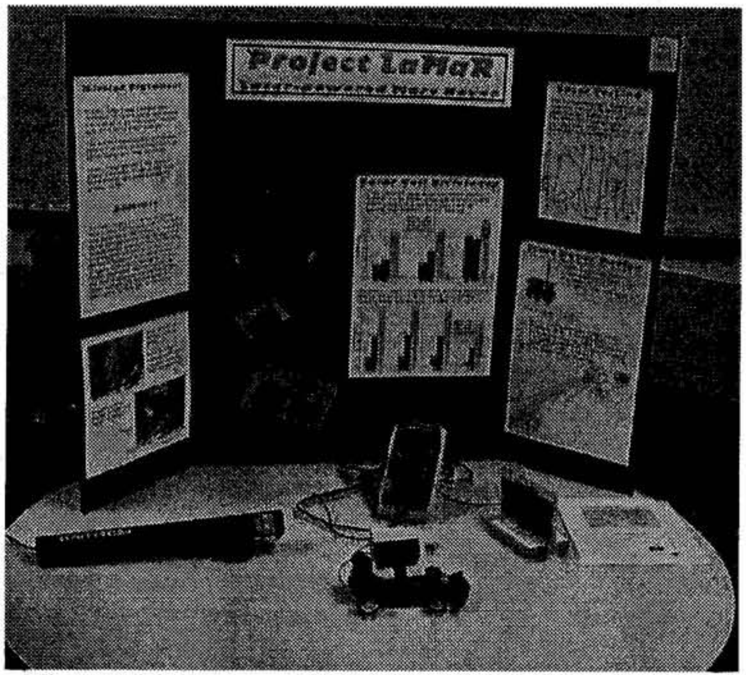


Figure 7.0-1 Display at University of Colorado Design Expo

Whereas the design expo brought people to CU, Project LaMaR extended its outreach into the community by visiting a Boulder-area high school. Presenting to a senior-level physics class at Fairview High School, the demonstration appealed to scientific, college-bound students. This generated interest in the engineering profession in addition to showing the public what projects aerospace students are involved in at the University of Colorado. The short presentation was well received by the students and was followed with a question and answer session. As was predicted, the demonstration model proved to be the most useful aspect of the presentation, generating interest in all of the students. In addition, the students were given an opportunity to ask questions about college life in general.

Project LaMaR will also be presented at the International Space Development Conference being held May 24-28, 2001 in Albuquerque, NM. This is the National Space Society's (NSS) annual conference and is being co-sponsored by AIAA. See the following site for more information: http://www.isdc2001.org/.

8.0 Acknowledgements

Many thanks go out to the following individuals for their time, effort and knowledge. This project could not have succeeded without the encouragement we received from the many people we had helping us.

Faculty and other technical advisors:

Dr. Lisa Hardaway – project faculty advisor
Dr. John Sunkel – CU senior design class coordinator – will be attending the HEDS-UP Forum
Walt Lund – hardware and electronics advisor
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Ron Diamond and Jennifer Granada of Spectrolab

Lasers were borrowed from:

Pat Dippo, NREL
Donna Hurley, NIST (National Institute of Standards and Technology) Boulder, CO
Timothy Quinn, NIST
Don Selmarten, NREL
Andrew Slivka, NIST
Daniel Vigliotti, NIST

Visit Project LaMaR at <http://rtt.colorado.edu/~ickler/lamar.html>

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