N94-11396

RESPONSE OF SILICON SOLAR CELL TO PULSED LASER ILLUMINATION

D. Willowby, D. Alexander, T. Edge, K. Herren
National Aeronautics and Space Administration
George C. Marshall Space Flight Center
Information and Electronic Systems Laboratory
Marshall Space Flight Center, AL 35812

This paper deals with the response of silicon solar cell(s) to pulsed laser illumination. The motivation for this work was due to the interest of Earth to space/Moon power beaming applications. When this work began, it was not known if solar cells would respond to laser light with pulse lengths in the nanosecond range and a repetition frequency in the kHz range. This is because the laser pulse would be shorter than the minority carrier lifetime of silicon. A 20-nanosecond (ns) full width half max (FWHM) pulse from an aluminum-gallium/arsenide (Al-Ga-As) diode laser was used to illuminate silicon solar cells at a wavelength of 885 nanometers (nm). Using a high-speed digital oscilloscope, the response of the solar cells to individual pulses across various resistive loads was observed and recorded.

INTRODUCTION

The SpacE Laser ENErgy program (SELENE) has proposed using an Earth-based induction linac free electron laser (FEL) to provide energy to users in space. This relatively cheap laser energy from Earth would then be converted back into electrical energy by solar cells. Battelle Pacific Northwest Laboratory and Washington State University have already done research with gallium arsenide(Ga-As) cells and continuous wave laser at 806 nm and demonstrated 53-percent efficiency.[1] The induction linac FEL proposed would have a high-intensity pulse lasting 20 ns with a peak-to-peak spacing of 50 microseconds (ms), a rep rate of 20,000 Hz (fig. 1).

When this was put forth, there was some uncertainty whether silicon or Ga-As solar cells would respond to the laser pulse train. The minority carrier lifetime of silicon ranges from 10 to 100 ms and 10 to 100 ns for Ga-As, which is shorter than the pulse separation of the induction FEL. It was not clear whether the solar cells would respond to individual pulses, average the pulses, or respond at all. This experiment was conducted to determine what the response would be.

EXPERIMENT

The test setup is shown in figure 2. A Tektronix high-speed digital oscilloscope was used to measure the output of the solar cell. A converging lens was used to focus the laser light into a circle and the distance to the solar cell adjusted so that the entire cell would be illuminated. An Al-Ga-As diode laser with a wavelength of 0.885 microns was used for this experiment. The laser produced eighty 20-ns FWHM pulses at a 10-kHz rate.

Figure 3 shows the output of the Al-Ga-As laser with the characteristic "tail" of diode lasers as seen by an Antel Optronics model AR-S2 ultra-high-speed photodetector. The laser had a very low intensity, with the majority of the energy in the peak of the pulse.

Several attempts were made with 2- by 4-cm Ga-As solar cells. We believe we did not get a response from the Ga-As solar cells due to the low energy and the wavelength of the laser being close to the cutoff (0.9 microns) of Ga-As. Several 2- by 2-cm silicon Apollo telescope mount (ATM) cells were used in this test. The current-voltage (I-V) curve of the 2- by 2-cm ATM silicon solar cell is shown in figure 4.

In addition to verifying that a silicon cell would respond to pulsed laser illumination, we wanted to develop an I-V curve for the cell under laser light. To accomplish this, resistors of varying values were used. Wire-wound resistors were avoided so as to minimize problems with inductance.

RESULTS

Measurements were taken from short-circuit to open-circuit conditions. In each case, a resistor was used and it was soldered in place. The laser pulses were displayed, and the last pulse was recorded by the oscilloscope and printed. Figure 5 shows the response of the ATM cell in open circuit as measured by a current probe. An important thing to note about these plots is the time scale of the response curves compared to the laser pulse. As can be seen here, the silicon cell integrated a nanosecond laser pulse into a several microsecond response.

Figure 6 shows the cell's response across a 0.53-ohm wire-wound resistor. This is still close to open circuit and shows a pronounced secondary response which is due to the increased induction brought about by the wire-wound resistor.

Figure 7 shows the response of the cell across a 5.3-ohm load. Here, both an exponential and a capacitance decay can be seen.

In figure 8, the cell is loaded with a 10-ohm load. The cell's response has greatly increased, and it should be noted that the time scale has been increased.

Figure 9 shows the response of a silicon cell to 20-ns FWHM pulses at a 10-kHz rep rate. The sample rate of the oscilloscope at this time scale is such that not all the cell response is captured.

Figure 10 puts the laser pulse, silicon cell response to multiple pulses, and the response across a 4.3-ohm load together for comparison. Note that the time scales are all different.

An I-V curve was constructed from the data collected which shows high series resistance in the silicon cell's response to laser illumination (fig. 11). The I-V curve also shows the response of the cell under one-Sun conditions.

The efficiency of the silicon cell under illumination was difficult to determine due to uncertainty of the total amount of laser energy on the cell. However, the efficiency did seem to increase with increasing load value. The cell losses appear to be due to high series resistance, cell capacitance and inductance, and inductance in the circuit.

CONCLUSIONS

This experiment verified that silicon solar cells will respond to light pulses shorter than silicon's minority carrier lifetime. For silicon cells to operate under pulsed laser illumination where the pulse separation is greater than the minority carrier lifetime, the cells will need to have low series resistance, to have minimum inductance, and to be designed to respond to peak pulse power, as well as have protection from dark reverse current flow when the cell is not illuminated. The power system will have to minimize inductance as well as be designed to handle power pulses.

REFERENCES

1. Olsen, L.C.; Dunham, G.; Huber, D.A.; Addis, F.W.; Annheier, N.; and Coomes, E.P.: "GaAs Solar Cells for Laser Power Beaming," Proc. of the 11th Space Photovoltaic Research and Technology Conference, Cleveland, OH, 1991, p. 26-1.

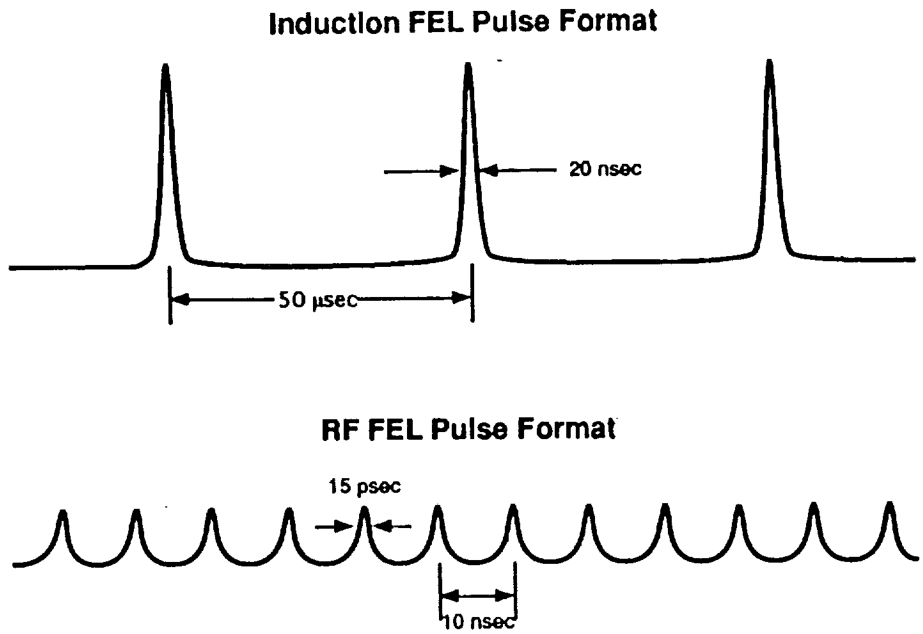


Figure 1. Typical optical pulse train formats for FEL's.

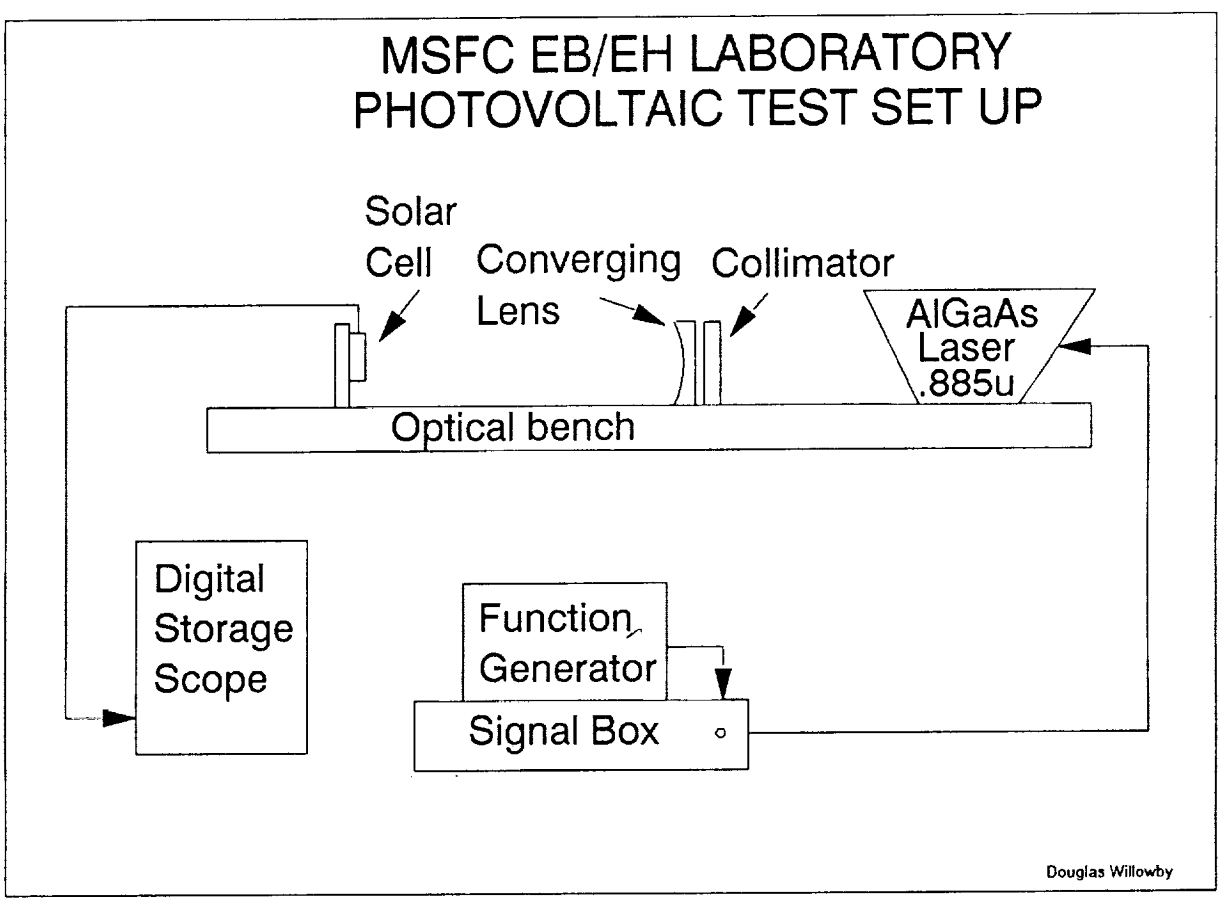


Figure 2. MSFC test setup.

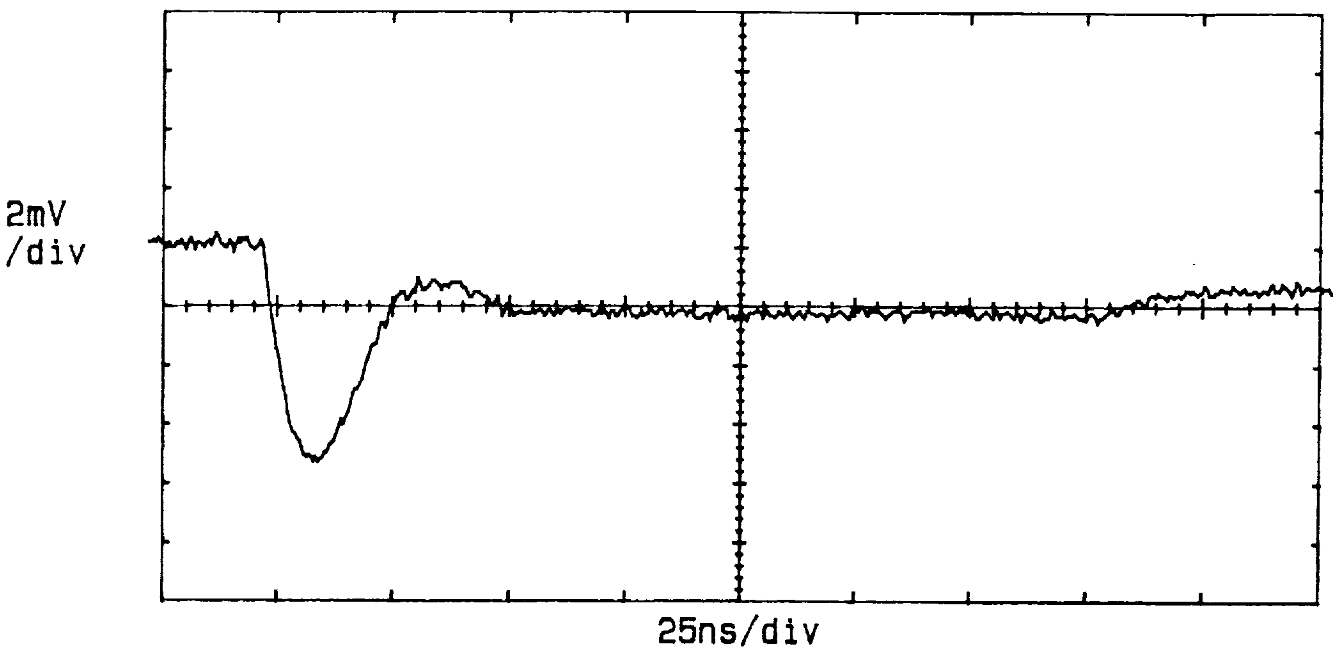


Figure 3. Al-Ga-As laser pulse.

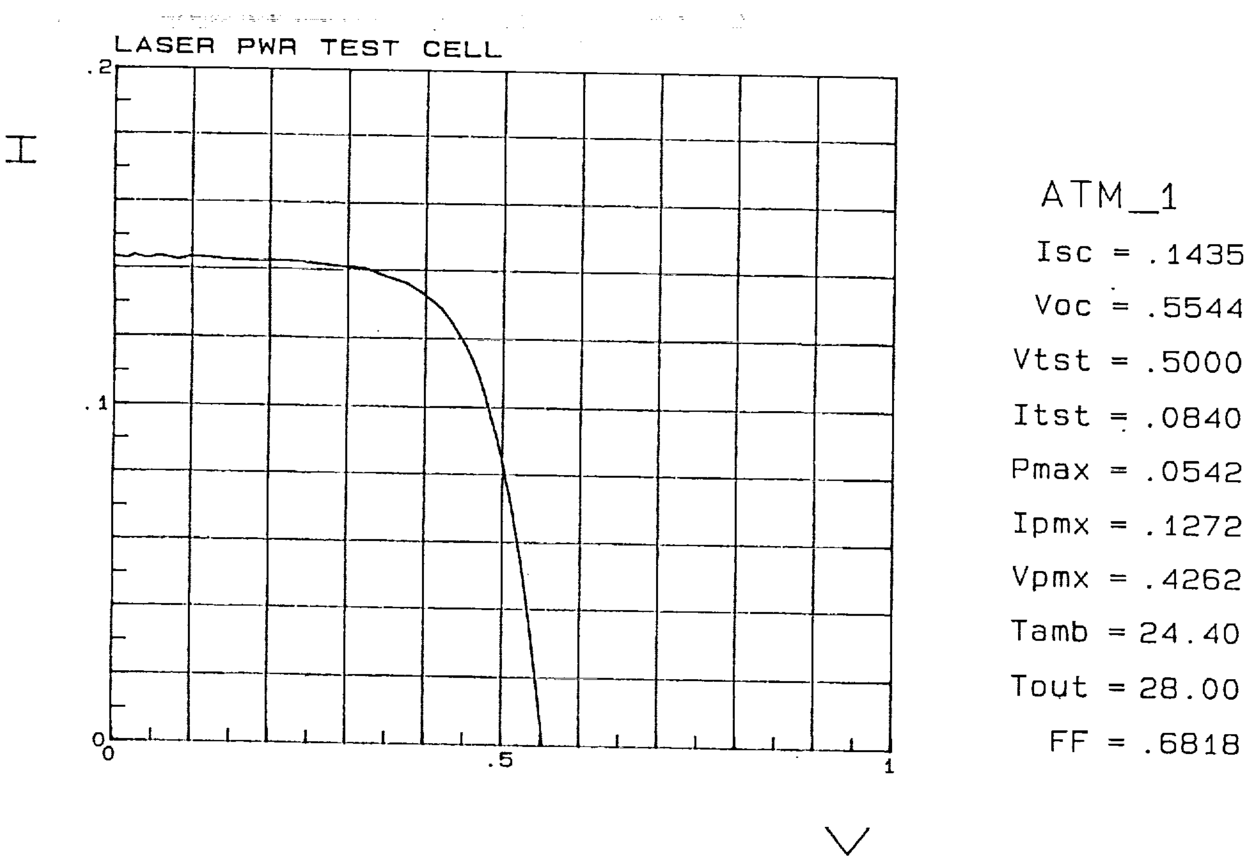


Figure 4. AM0 I-V curve of 2- by 2-cm ATM cell.

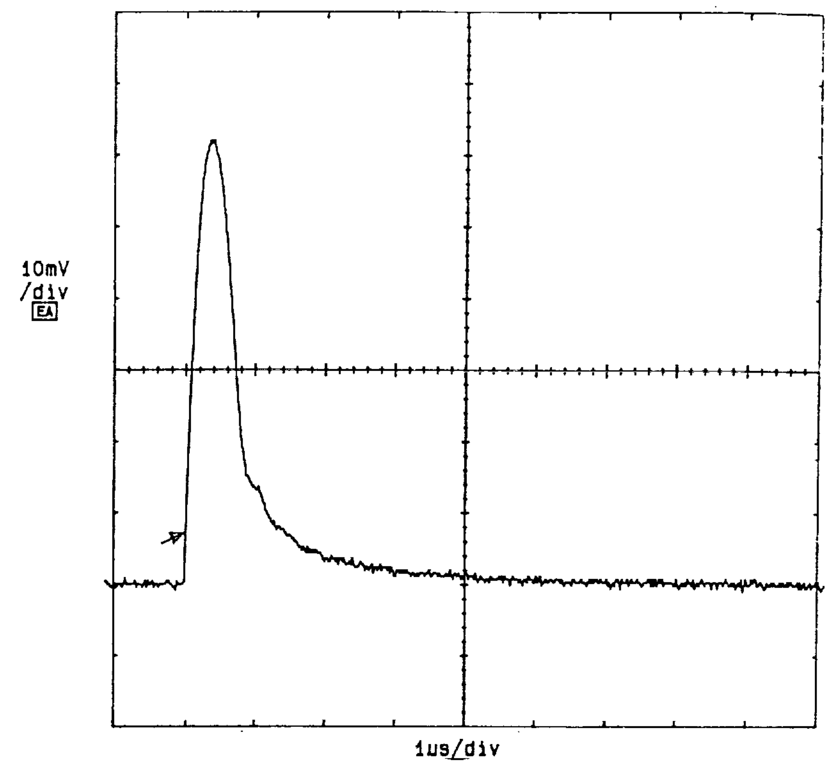


Figure 5. ATM cells current.

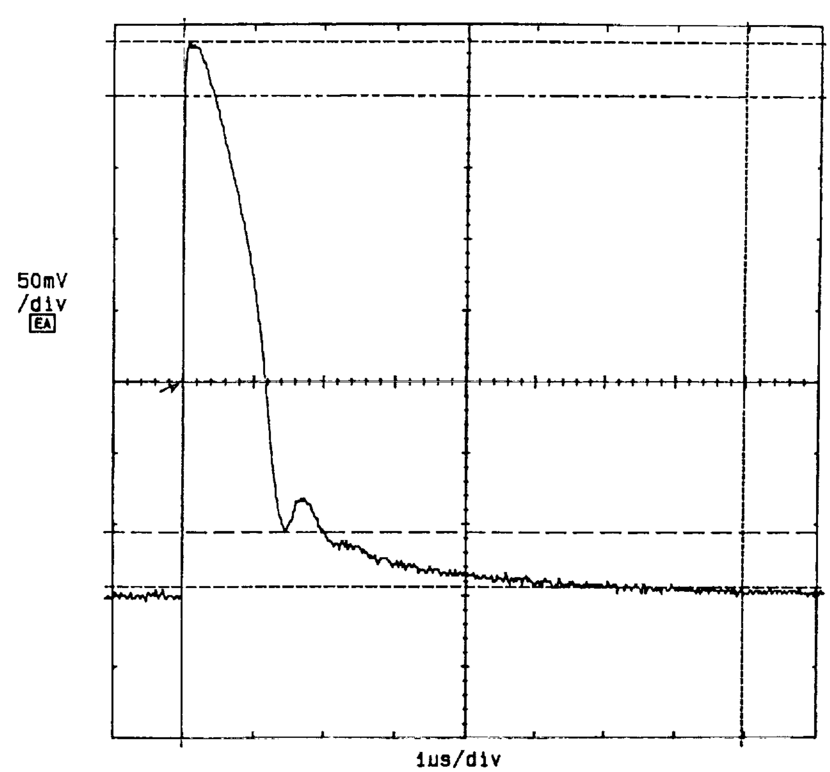


Figure 6. 0.53-ohm response.

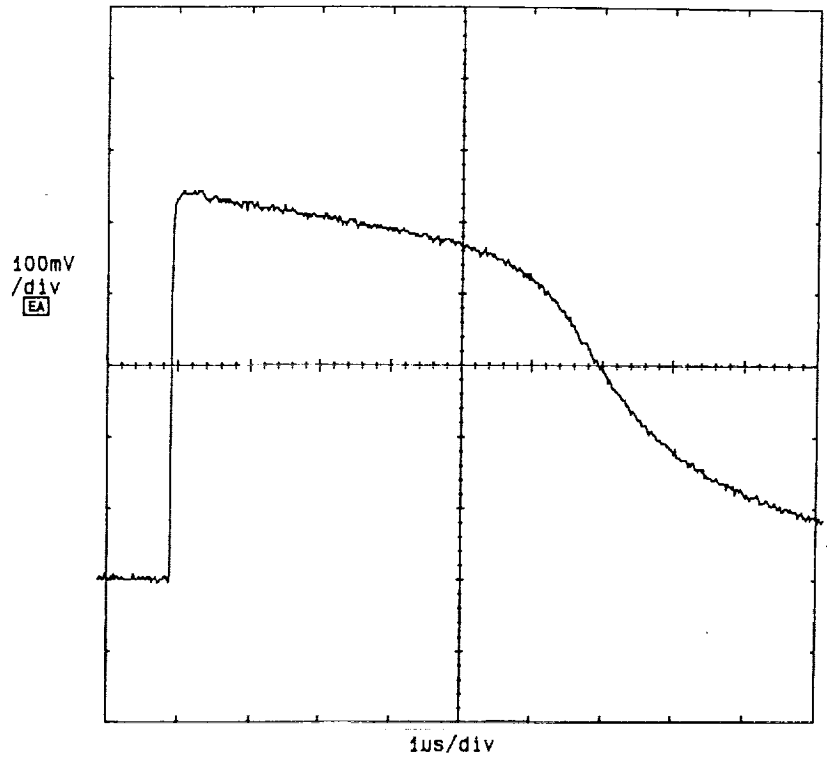


Figure 7. 5.3-ohm response.

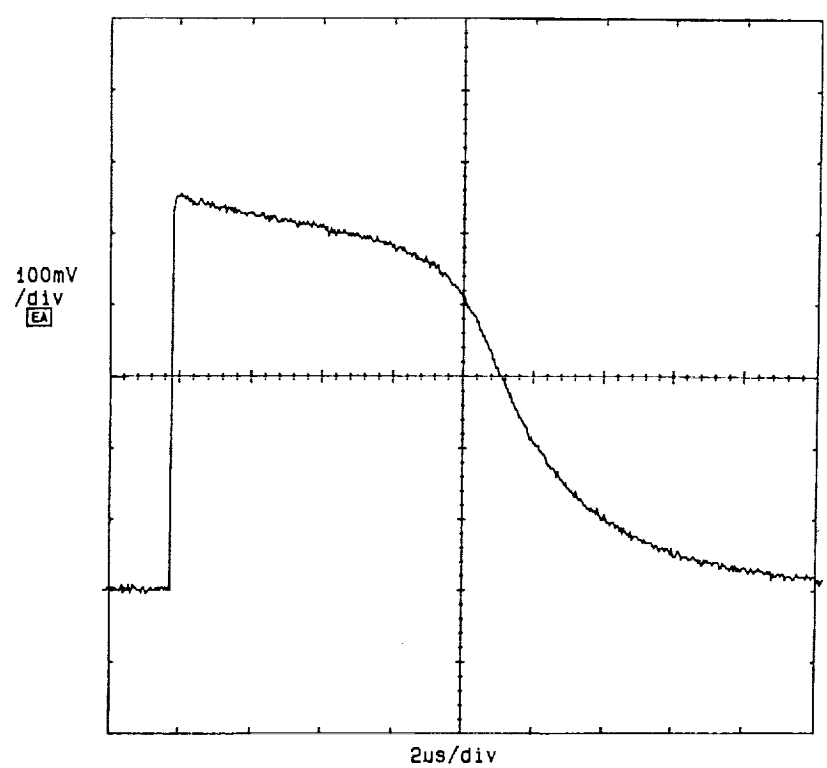
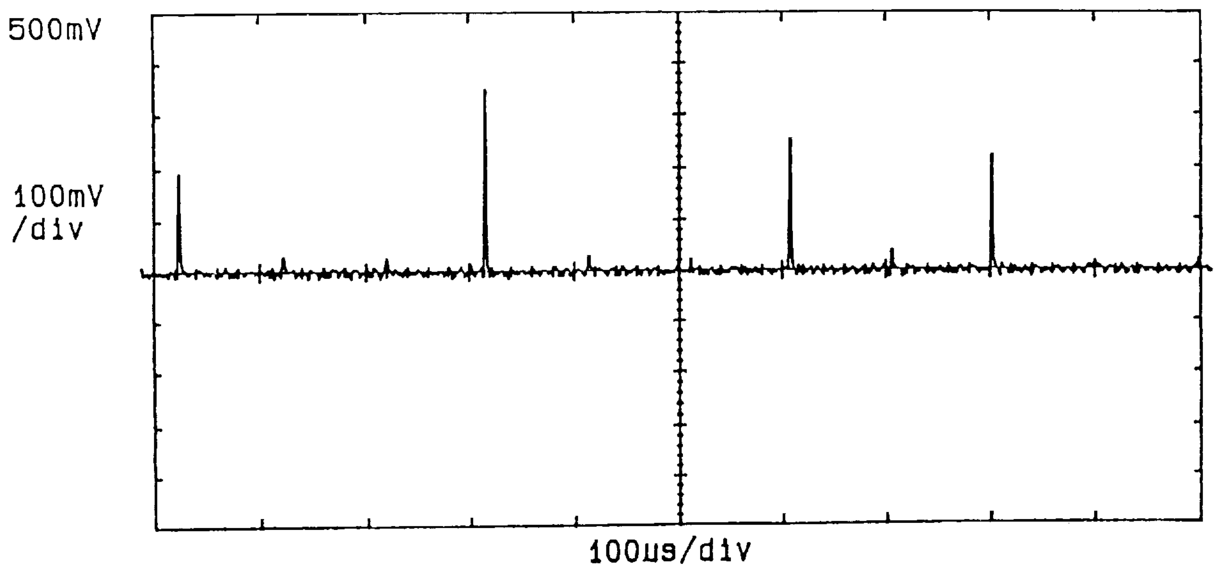


Figure 8. 10-ohm response.



Silicon solar cell being pulsed by laser at a rep rate of 10 KHz
Low sample rate does not always catch peak power

Figure 9. Response to pulse train.

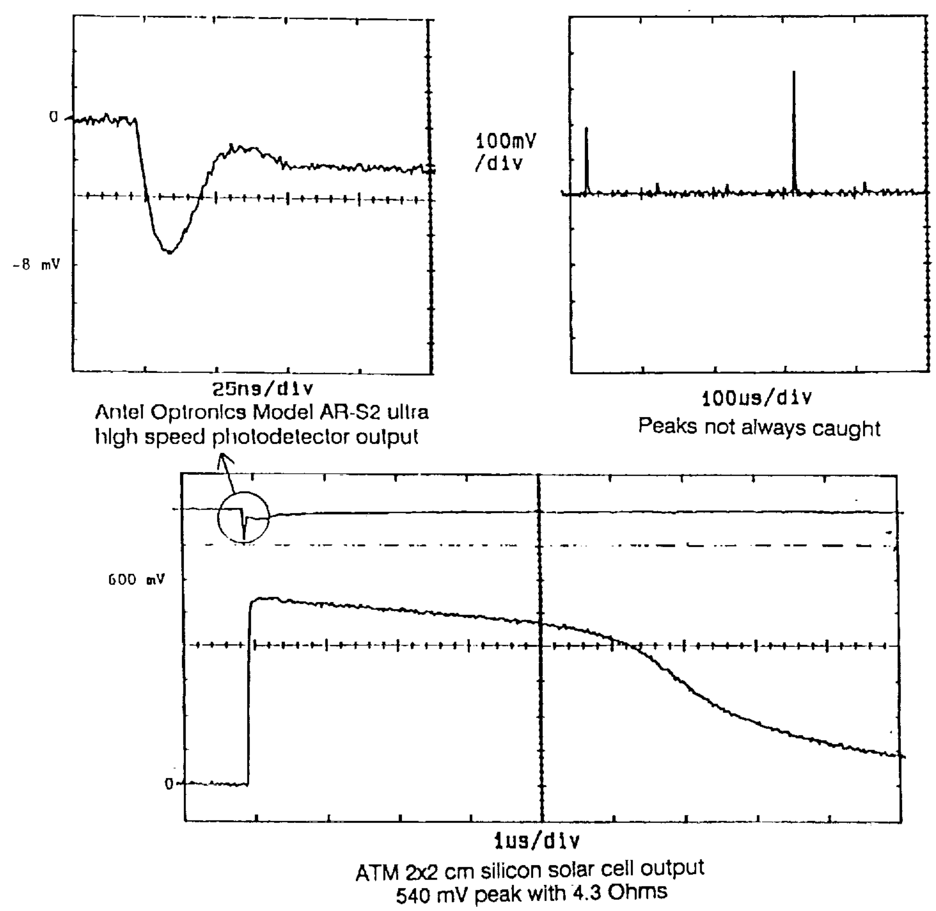


Figure 10. Laser pulse and cell response comparison.

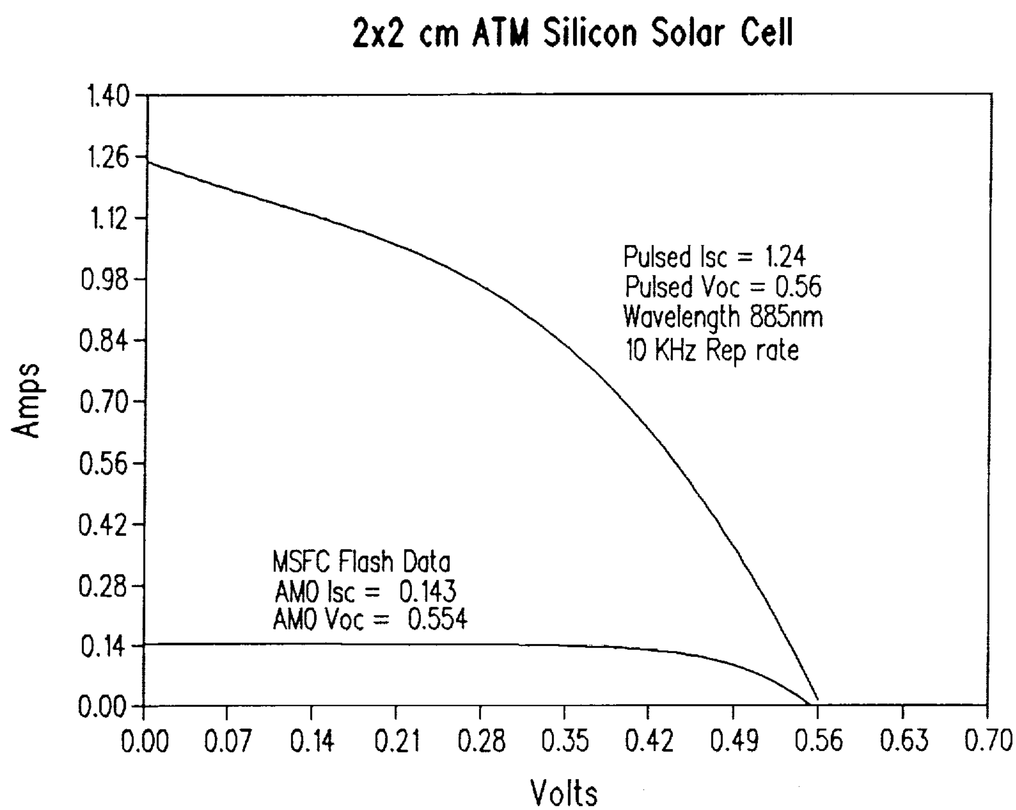


Figure 11. ATM pulse and AM0 I-V curves.