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MODELING OF HIGH EFFICIENCY SOLAR CELLS UNDER LASER PULSE FOR POWER BEAMING APPLICATIONS

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SUMMARY

Solar cells may be used as receivers for laser power beaming. To understand the behavior of solar cells when illuminated by a pulsed laser, the time response of gallium arsenide and silicon solar cells to pulsed monochromatic input has been modeled using a finite element solar cell model.

INTRODUCTION

Solar cells have been used to convert sunlight to electrical energy for many years and also offer great potential for non-solar energy conversion applications. Their greatly improved performance under monochromatic light compared to sunlight, makes them suitable as photovoltaic (PV) receivers in laser power beaming applications. Laser beamed power to a PV array receiver could provide power to satellites, an orbital transfer vehicle, or a lunar base (ref. 1). Gallium arsenide (GaAs) and indium phosphide (InP) solar cells have calculated efficiencies of more than 50% under continuous illumination at the optimum wavelength (ref. 2). Currently high power free-electron lasers are being developed which operate in pulsed conditions. Understanding cell behavior under a laser pulse is important in the selection of the solar cell material and the laser.

An experiment by NASA Lewis and JPL at the AVLIS laser facility in Livermore, CA presented experimental data on cell performance under pulsed laser illumination (refs. 3 and 4). Reference 5 contains an overview of technical issues concerning the use of solar cells for laser power conversion, written before the experiments were performed. As the experimental results showed, the actual effects of pulsed operation are more complicated. Reference 6 discusses simulations of the output of GaAs concentrator solar cells under pulsed laser illumination. The present paper continues this work, and compares the output of Si and GaAs solar cells.

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CELL SIMULATION RESULTS

Figure 1 shows the cell designs and the laser pulse simulated. For simplicity, the laser pulse was assumed to be square. Most of the results have been calculated for a peak intensity of 50 W/cm^2, which corresponds to nearly 1000 suns concentration. The PC-1D computer code, a finite-element simulation of carrier transport in semiconductor devices (ref. 7), was used to analyze the cell current during and after the pulse for various conditions.

The GaAs solar cell simulated was a concentrator p$^+$n cell with an efficiency of 27.5% under AM1.5D, 1000 sun illumination. The current output was observed to be linear with laser intensity from 500 mW/cm^2 to 500 W/cm^2. Figure 2 shows the cell short circuit current during and after the laser pulse, for a laser at three different wavelengths. The 511 nm wavelength corresponds to the available copper-vapor laser, 840 nm corresponds to the optimum wavelength for GaAs and also proposed operating wavelength in NASA SELENE project, and 870 nm is near the band edge of GaAs. The decay of the current can clearly be seent to have two distinct components: an initial rapid decay immediately following the laser pulse, followed by an exponential decay with much longer time constant. The amount of initial decay is greatest for the light with the strongest (hence, shallowest) absorption, 511 nm, and is least for the weakly absorbed light at 870 nm. Figure 3 shows this initial decay on a shorter time scale. Here the parameter varied is the operating voltage of the cell. Further results of this simulation can be found in reference 5.

Compared to GaAs, silicon solar cells have much longer minority carrier lifetimes and much weaker optical absorption, resulting in deeper absorption of the light and longer characteristic time constants. A typical silicon solar cell was modeled, with a diffused (erfc profile) n type junction. The efficiency is 17.2% under AM0 (space) illumination, slightly better than cells used in space today, but well below the best efficiencies observed in the laboratory. Efficiency increases to 31.8% for monochromatic light at 900 nm at an intensity of 50 W/cm^2.

Figures 4 and 5 show the decay of short circuit current of the silicon cell compared with that of the GaAs cell. As expected, the silicon cell shows considerably slower response.

As in the GaAs cell, the decay has a rapid initial decay followed by a slower exponential decay. Figure 6 shows the fit of an exponential to the portion of the decay between 150 and 250 nS after the pulse. The characteristic time constant for this portion of the decay is 360 nS, which is intermediate between the base lifetime of 20 μS and the emitter surface lifetime of 11 nS.

Figure 7 shows the short circuit current at different wavelengths. Note that the currents have been normalized; the absolute response is best at 900 nm (peak of 31 A). The response at 1.06 μ is poor (peak 3.6 A). As with the GaAs cells, the most weakly absorbed light has the least rapid initial fall-off, and the most strongly absorbed light the most rapid initial fall-off. The response drops by a factor of e over a time scale on the order of 25 nS.

For such a cell, then, we can expect that the silicon cell will tend to integrate the pulsed input into nearly CW output only if the time between pulses is short compared to 25 nS.

The capacitance of a Si cell at zero bias is typically about 100 nF. The series resistance of this 1 cm^2 cell was taken to be 4 mΩ. The RC time constant for the charge to be removed from the cell under short circuit is thus expected to be about 0.4 nS. This is much shorter than the time scale of the current decay. In actual operation, however, the cell would be connected to an external circuit with associated resistance, inductance, capacitance, and a battery-supplied bias voltage. This external circuit will considerably complicate the output characteristic (refs. 3 and 4).

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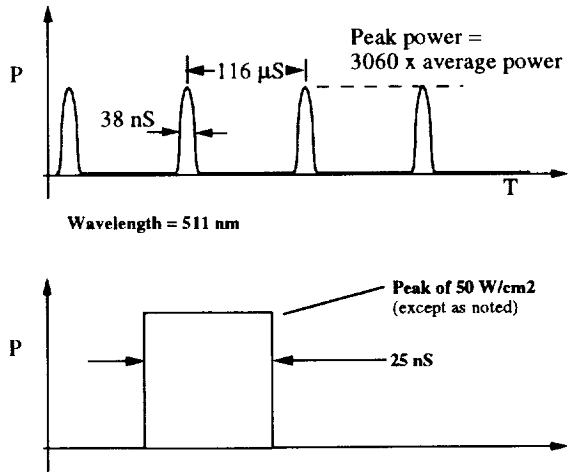

Figure 1A Pulse format of copper-vapor laser (top) and pulse used in computer model (bottom)

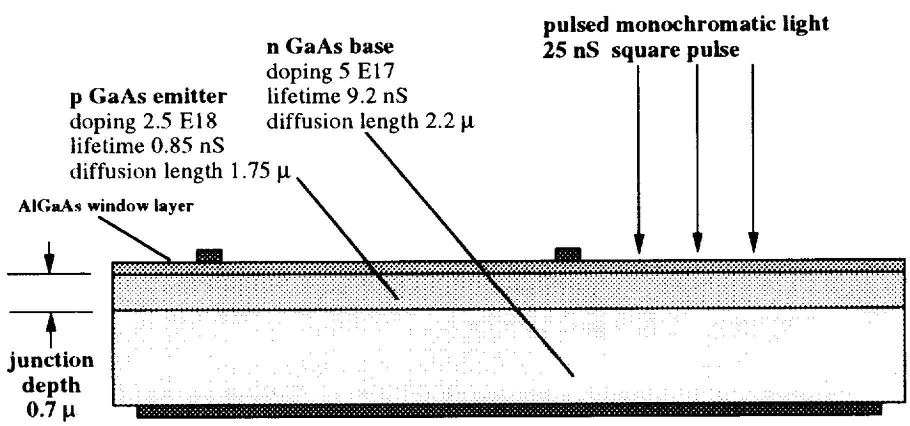

Figure 1B. GaAs solar cell model used for computer simulations.

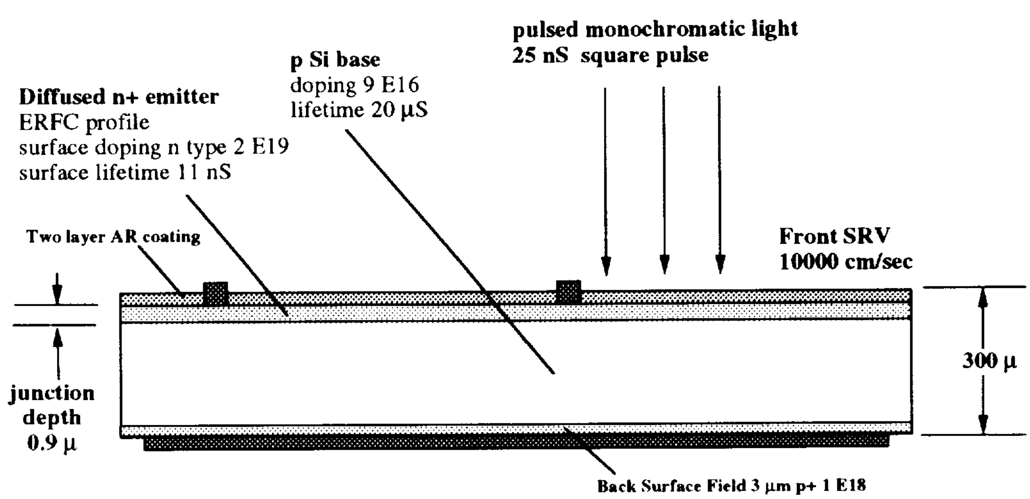

Figure 1C: Silicon solar cell model used for computer simulations.

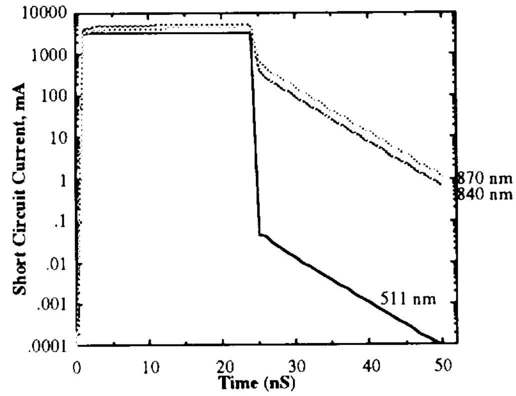

Figure 2. Short circuit current of GaAs cell during laser pulse with incident wavelength as parameter.

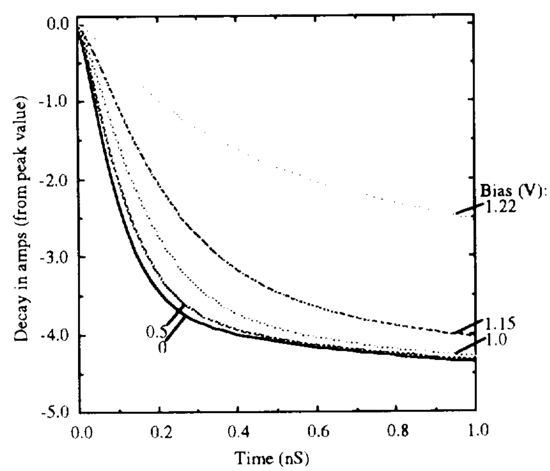

Figure 3. Current decay in first nanosecond of pulse as a function of bias (linear scale; current measured a decrease from illuminated value.) Wavelength 840 nm.

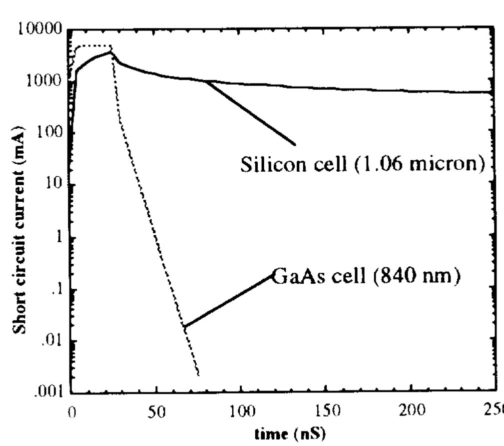

Figure 4: Comparison of Si and GaAs short-circuit current response to 25 nS pulse

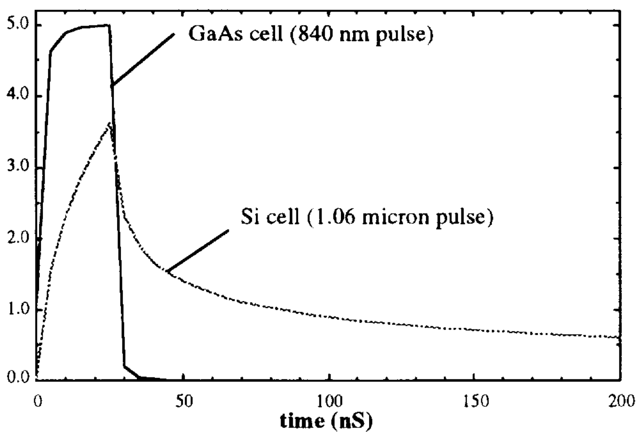

Figure 5: Comparison of Si and GaAs short-circuit current response to 25 nS pulse

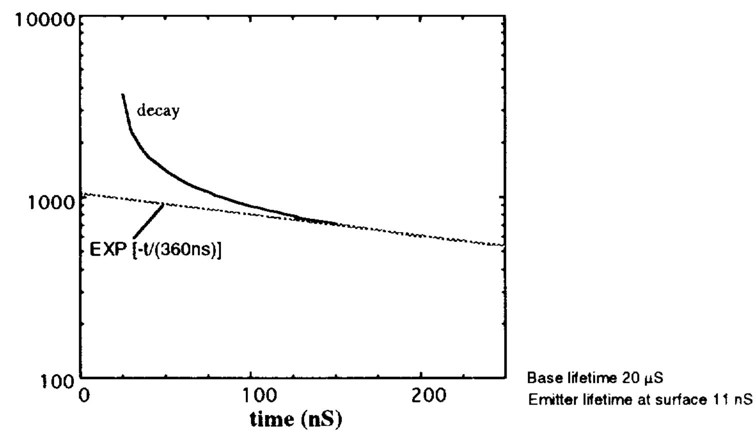

Figure 6: Exponential fit to decay of short circuit current for Si cell

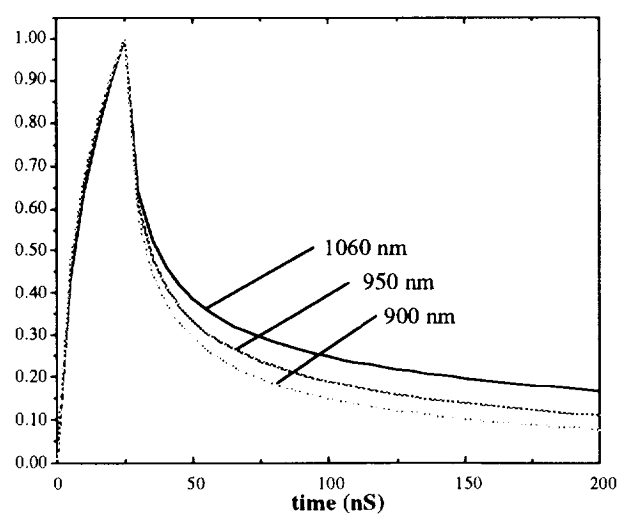

Figure 7: Decay of normalized short circuit current for Si cell at several wavelengths