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RECEIVERS FOR LASER POWER BEAMING

Summary of the Workshop at SPRAT-XII

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Abstract

At the Space Photovoltaics Research and Technology [SPRAT] conference at NASA Lewis Research Center, a workshop session was held to discuss issues involved in using photovoltaic arrays ("solar cells") to convert laser power into electrical power for use as receiving elements for beamed power.

Introduction

Photovoltaic cells could potentially be used as power receivers for several laser sources. At NASA Langley, Conway and Walker has investigated use of space-based lasers, both direct solar-pumped [1] and diode lasers [2], for power transmission. Coomes, Bamberger, and co-workers at DOE have proposed a space-based nuclear reactor to power diode lasers which beam power to photovoltaic receivers [3]. Use of diode lasers to transmit power down optical fibers to remote GaAs receivers [4] for use on airplanes wingtips and other fiber-linked remote applications is a technology with many near-term applications. Finally, recent suggestions that adaptive optics technology could be used in conjunction with ground-based lasers to beam power to photovoltaic receivers in space [5,6] has resulted in the NASA SELENE (Space Laser Energy) project [7]. SELENE has concentrated on the use of 100-kW to MW-class free-electron lasers (FELs) for transmission to geosynchronous orbit satellites, electric-propulsion orbital transfer vehicles, and (in the long term) to a photovoltaic array powering a lunar base. The consensus of the workshop was that the technology for space-based lasers would not be available until well past the year 2000, and thus the workshop focussed mainly on PV receivers for ground-based laser transmitters, which were felt to have the possibility of a near-term payoff.

Near-term Applications

The most-discussed applications were to geosynchronous orbit satellites. The remark was made that many organizations have satellites that could possibly benefit from laser power beaming, and that the options should not be restricted only to communications satellites, or even only to U.S. satellites. A difficulty in near-term demonstrations is that only satellites in range of U.S. laser sites such as the White Sands testing range can be considered.

The need to make a near-term demonstration of the feasibility of the system, even if only at a low power level, was emphasized. It was suggested that operation of a single transponder on a communication satellite by laser power through a full eclipse would be a convincing demonstration. A typical satellite has 24 transponders drawing roughly 17 watts, and requires 62 watts of housekeeping power [12]. Thus, operation of a single transponder would require only 9% of full power. At 532 nm (doubled YAG wavelength), 9% of full power would require 14 kW of laser power if a 2.5 meter mirror is used [12], assuming perfect atmospheric compensation. Although many issues need to be resolved, perhaps this could be done with lasers now existing or under development in the laboratory, such as the AVLIS copper-vapor laser or frequency-doubled YAG lasers, with existing beam-directors and adaptive optical systems used for the test.

Finally, during the discussion of radiation damage, another application was suggested, that of using a ground-based laser to heat up solar cells to anneal radiation damage. This could even use laser types which operate at wavelengths that are not good for power conversion but are now available in high power. It would, however, require high-temperature design of the arrays, which is possible, but has not been currently implemented on existing satellites.

Experiments Needed

The next workshop question was, what experiments needed to be done now in order to verify key assumptions about laser receivers? All high-powered lasers available now or in the near future at the wavelength range of interest are pulsed. Investigation of the effect of the pulse format on the cell response is a major concern. The AVLIS copper vapor laser, currently the highest continuous average-power laser in operation at wavelengths below 1 micron, has a pulse format with a pulse width of ~50 nS and a repetition rate up to 26 kHz. The wavelength can be varied somewhat by pumping a dye with the copper-vapor light at 511 and 578 nm. Of the free-electron lasers under consideration, the RF FEL will typically have a pulse width of 10 pS, with a repetition rate on the order of a GHz, while the induction FEL would have a pulse width on the order of 20 nS, with a repetition rate of twenty kHz. A frequency-doubled Nd:YAG laser would require a pulsed output in order to achieve high efficiency on the doubling crystal without thermal distortion, since the efficiency of frequency doubling is directly proportional to the intensity. Various pulse formats would be possible for this laser, as long as the peak-to-average ratio is sufficiently high to reach good doubling efficiency.

If cell operation at 1.06 microns is possible, it may be possible to use a Nd:YAG laser without frequency doubling in CW operation.

Experiments reported at this SPRAT showed the response of cells to pulsed lasers is significantly different than the response to CW laser illumination [8,9], and suggested that this response may be dependent on laser wavelength [10]. Thus, it was suggested that pulsed laser experiments in the wavelength range of 750-850 nm GaAs cells should be done, to learn as much as possible about GaAs cell response at the most efficient operating wavelength of GaAs cells. This could potentially be done using a Ti-sapphire laser or a dye laser.

Experiments done previously showed difficulties with lasers using the induction FEL or copper-vapor pulse formats, and suggested that novel cell and circuit design techniques, such as monolithically integrated cells, wide flat conductors, and integral capacitors, could ameliorate some of the difficulties. Experiments should be done to test some of these possibilities, as well as to gather further data on cell response at these pulse formats.

Few tests so far have been done using the RF laser format, and the tests done to date have not resolved the picosecond micropulse structure of the laser. Since this is an increasingly attractive laser format, further tests on RF lasers should be done.

Operating wavelengths were discussed later in the workshop. It was suggested that if cell operation at longer wavelengths is desirable, cell testing at the desired wavelength should begin immediately.

Cell Types and Operating Wavelength

Silicon cells showed better response than GaAs cells to the induction format pulses, and it was suggested that, in the near term, the pulse format problem should probably be solved by simply going to silicon cells. The feeling was, it works and it's available. Silicon was also desirable since it is already flying, although it was noted that cells now flying are relatively old designs which have been further radiation damaged, and thus will not have significant response to 1.06 micron radiation.

A wavelength of 1.06 micron has been suggested [11] as being considerably better (from the point of view of laser technology and atmospheric transparency and compensation) than the 840 nm chosen for the baseline SELENE system. The atmosphere is known to be extremely transparent at some specific wavelengths near 1.06 microns. It is important to start testing cells at this wavelength. Cell possibilities include both silicon and InGaAs cells. It is noteworthy that, while silicon has low optical absorption at 1.06 microns at room temperature, the absorption constant rapidly increases at elevated temperatures. For Si cells at 1.06 microns, it may be desirable to operate at high temperature.

It was agreed that it would be possible to operate photovoltaic cells that respond in the "eyesafe" wavelength range of 1.5 to 1.7 microns, but that this will result in a very large loss in performance due to the lower efficiency (figure 1), and that these cells would not be able to operate at high laser intensities due to the adverse temperature coefficient. It is important to know just how advantageous operation at this wavelength is. Operation in the eyesafe wavelength range may be required if a relay mirror is used, since an error in the mirror pointing would direct the beam back toward the ground.

On "exotic" cell types, production will be a big problem. For anything except silicon or conventional GaAs cells, the capability for production of large (square meters) arrays is nonexistent. In many cases technologies such as cell to cell interconnections have not been addressed. Cells that have only been produced on a laboratory scale will take considerable time and effort to bring to production readiness and space-qualify.

Conclusions

The possibilities for laser power beaming engendered a lively discussion, and it was agreed that there were likely to be many applications that have not yet been thought of. The idea of an early technology demonstration to stimulate interest in the technology, was particularly well received. It was cautioned that, despite the cutting-edge nature of the technology, mundane solar array considerations such space qualification and manufacturing readiness cannot be ignored.

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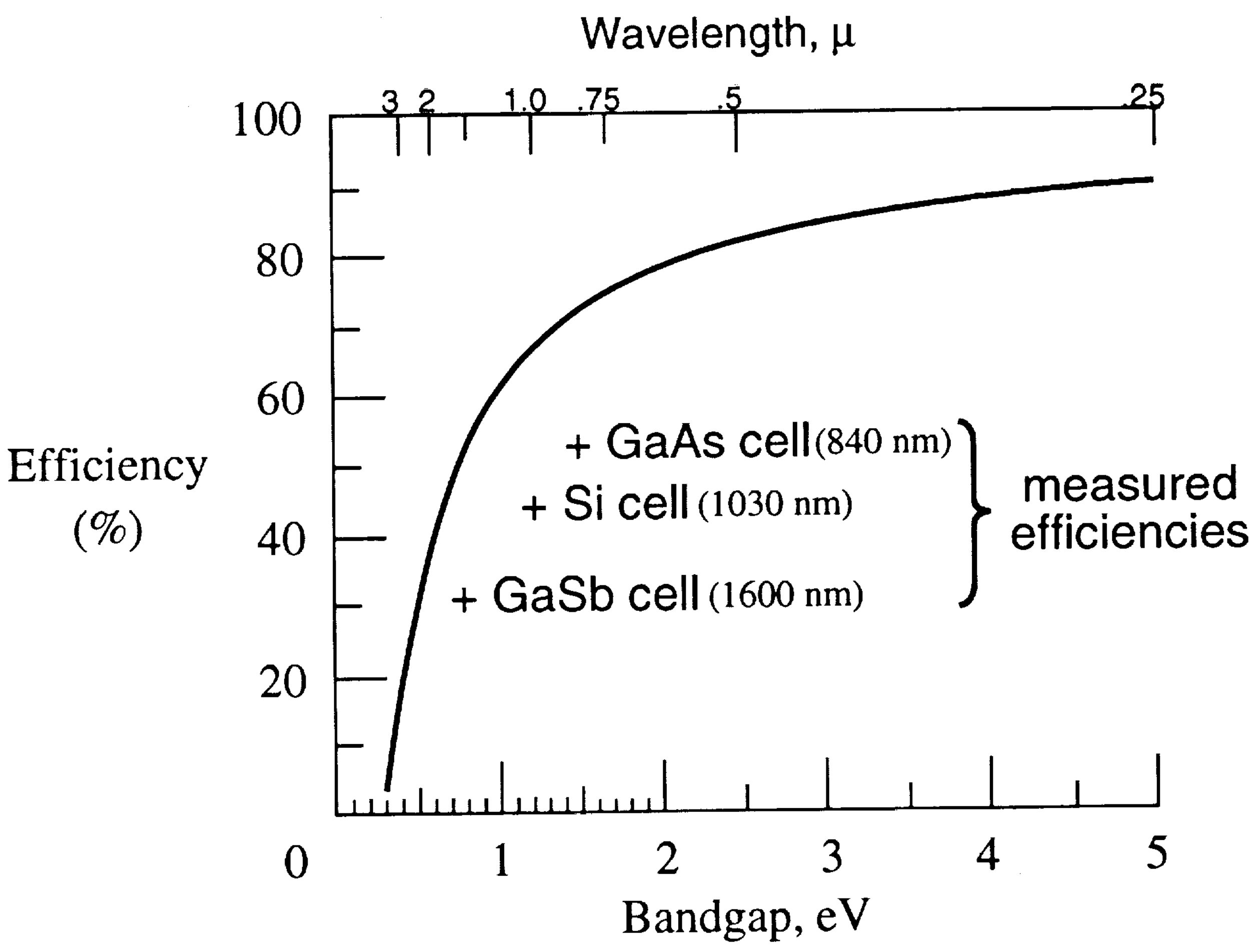
Figure 1: Theoretical and Measured Conversion Efficiency of Photovoltaic Cells for Monochromatic Light

Intensity = 500 mW/cm^2, temperature = 25 °C



Theoretical curve from Larry Olsen, *Space Photovoltaic Research and Technology 1991*

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