SOLAR CELLS IN SPACE

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Devices and Materials

The increasing use of the photovoltaic solar cell as an energy conversion device for the utilization of solar energy, providing the electrical power for the orbital satellite, has resulted in several programs for improving the state of the art. Obviously, this solar energy being converted is provided for our use at the lowest imaginable price —free! Since this is the case, it becomes essential that means be developed for the greatest possible employment of this power. Hence, there has been considerable emphasis placed on the investigation of photovoltaic device improvement.

There are many avenues of approach that one can take to achieve the objective of increasing device capability for utilizing the solar spectrum. Even though there are several approaches, there are only two facets of the photovoltaic cell that can be investigated. They are device design and material exploitation. Neither of the facets are simple matters.

The Electronic Technology Laboratory designed a program for the advancement in the state of the art of solar cells and interesting results were obtained. The following paragraphs will explain the seven areas investigated.

At the initiation of the original program (1959), the most obvious investigation was to improve the much used silicon cell. One of the objectives of the program was to achieve a 15 percent conversion efficiency in the "standard" 1 x 2 cm unit. Having accomplished this objective, the program continued the research on dendritic materials. In this research a 15 percent conversion efficiency was to be maintained, but, only 13.5 percent conversion efficiency was produced. Concurrent with exploiting dendritic materials, the formation of epitaxial layers of material was investigated. Epitaxial cells are behind the state of the art of the "standard" 1 x 2 cm unit and the dendritic cells. The highest efficiency reported in the epitaxial cells was 8+percent.

The next item to be considered in device improvement is the material employed as the active element of photovoltaic cells. A survey was made of the various materials and the technology associated with each material was considered. Loferski, et al, showed that the "ideal" material for solar energy conversion would have a band gap greater than that of silicon, but would probably be close to 1.6 ev. However, very few materials satisfy this criteria, therefore, one must seek a material which would approach this value and still show promise of surpassing silicon cell capability. It would also be necessary that the basic material parameters, such as resistivity, mobility, carrier concentration, band gap, and similar properties must be known to a reasonable degree of accuracy to form a firm foundation for material selection. With these considerations in mind, the material offering the greatest potential was gallium arsenide (GaAs). The Electronic Technology Laboratory sponsoring a large effort in GaAs, found that the material technology was in an excellent state of perfection. Having a band gap greater than that of silicon, higher operational temperatures are to be expected. Figure 1 identifies the rate of degradation of both silicon and GaAs cells as a function of temperature. These rates of degradation were established as a result of the experiment.

In order that advancement in device capability could be made, the same parameters governing improvements in silicon cells would require investigation in GaAs. At the initiation of the program, GaAs cells were 5 to 6 percent efficient. As one reviews the progress of the program, it becomes apparent that a steady, month-by-month improvement was obtained, although material parameters are considerably more stringent in GaAs than they are in silicon and excellent results were reported. Not only was the objective nearly reached, but reproducibility between units was obtained. The program objective was set at achieving a 15 percent conversion efficiency. The highest value reported thus far was 14.7 percent. However, since gallium arsenide cells are in very short supply, the use of silicon cells must be continued to fulfill the quantity requirements.

Since many ideas have evolved whereby a greater utilization could be made of the solar spectrum through unusual device design, it was necessary that such structures be exploited for a determination of their capabilities as energy converters. Composite cells, stacked cells, variable band gap units, and polycrystalline films were among the unique units investigated. The result showed that although very definite gains could be made in greater spectrum utilization, the cost was too high and the project somewhat impractical to continue. The polycrystalline structure does hold promise for obtaining very large areas at reasonably low cost. The material presently being studied under this portion of the overall program is Cadmium-Telluride (CdTe). However, there has not been sufficient time or effort expended on the material to form any sound conclusions as to the capability of the material as a polycrystalline photovoltaic cell.

Now that we are attempting to maximize utilization of the solar spectrum outside the atmosphere, one seeks the answer to the question of: What is the best material for cell use? This is another part of the Electronic Technology Laboratory's program. The objective of this part of the program is to search for an "ideal" material to utilize the spectrum from 0.2 to 2.0 micron wavelength. Following a comprehensive literature survey, it was decided to study aluminum antimonide (AlSb) as the photovoltaic material. Obviously AlSb is not the "ideal" material, since it does not respond to the longer wavelengths of the spectrum, therefore other materials are being considered from a theoretical standpoint. Certain ternary compounds are presently being considered.

Device Capability

To determine the actual solar cell capability when operating under space conditions, it is necessary that the evaluation of cells be accomplished by either placing them aboard a satellite and receiving telemetered data concerning their operation, or within a simulated environment, or both. Unfortunately, space aboard various orbital vehicles is at a premium and therefore the evaluation is usually done with simulation techniques. However, simulation of the solar spectrum is not done easily. The light sources employed for evaluation range are color, temperature controlled tungsten bulbs to photoflood bulbs, and high pressure arc systems. Water filters are used to reduce the IR content of sources; liquid and gelatin filters are used to obtain a close approximation to a blackbody radiator; and multiple light sources are used to "fill in the gaps" in a given desired spectral distribution.

Evaluation techniques are nearly as varied as are the light sources. Black boxes are used to cut down reflections, monochrometers are used to determine light source spectral characteristics, thermopiles and phyrheliometers are used for intensity checks, and often the sunlight is employed for measurement correlation depending upon time of day, year, humidity conditions, and geographic location.

Under these conditions, it becomes very difficult for an applications engineer to design a solar cell panel having a particular set of characteristics, because the data on cell operation which is supplied to the designer leads to considerable confusion. If gallium arsenide, cadmium sulfide or some other compound semiconductor is employed in the cells to be used, then the design engineer has an entirely different set of conditions to work with, in comparison to silicon cells; the reason is simply that no two materials have the same spectral response, therefore do not respond to the same light source in the same manner. The only true method of determining cell operation would be to employ a sun simulator having the same spectrum as the sun.

Now let us combine the whole problem by adding temperature control problems, plus radiation and micrometeorite damage!

To better evaluate cells, and to stir the general thinking of all concerned with devices and their operation, the Electronic Technology Laboratory had a solar simulator designed and built, with emphasis on the light source. The simulator was intended to reproduce the solar spectrum from 0.2 to 2.0 microns or as near as possible. Not only must the solar spectrum be reproduced, but the intensity should fluctuate from a fairly low value, to well above that of space near the earth. Further, the system would employ a cooled vacuum chamber to determine cell operation under specific vacuum and thermal conditions. The simulator shown in figure 2 has been installed at the Electronic Technology Laboratory.

The light source employed is a plasma jet ionizing argon gas. The source simulates the spectrum as defined by Stair and Johnston to a fairly good approximation. Figure 3 depicts the spectral distribution taken of the sun under "one sun" intensity. One sun intensity is defined as 143.0 mw/cm_2 as found outside the atmosphere. The spectrum, as noted in figure 3, has been determined from 0.2 to 0.7 microns. The remainder of the spectrum from 0.7 to 2.0 microns is yet to be determined.

Using the solar simulator at ETL, the devices resulting from all of the applied research efforts, manufacturing methods programs, and cells supplied from commercial organizations were subjected to evaluation. It was found that the electrical characteristics of nearly all silicon units were somewhat optimistically stated by each supplier. Reproducibility between units of the same manufacturer also left something to be desired. Silicon units from commercial suppliers are generally 1 to 2 percent lower in efficiency than identified in data sheets. The evaluation of silicon dendritic cells manufactured by Westinghouse and evaluated in the ETL simulator often show good correlation between data taken at Westinghouse and ETL. Identical values have been obtained, but data are generally about 0.5 to 1.0 percent lower when taken with the ETL simulator.

The data on GaAs cells as evaluated at RCA and at ETL show the greatest degree of correlation and are generally within 0.5 percent of each other. Unfortunately, quantities of gallium arsenide cells are not available at this time, and until this problem is alleviated, system demands will have to be supplied from silicon units.

According to the most recent published data sheets, the value of solar intensity to which cells are being supplied by the various manufacturers is in accord with the value that has been determined to exist outside the earth's atmosphere. The solar spectrum is specified in most instances to a close approximation of that found outside the atmosphere. With cells supplied by these two factors the design engineer can more realistically establish a panel construction without over-design.

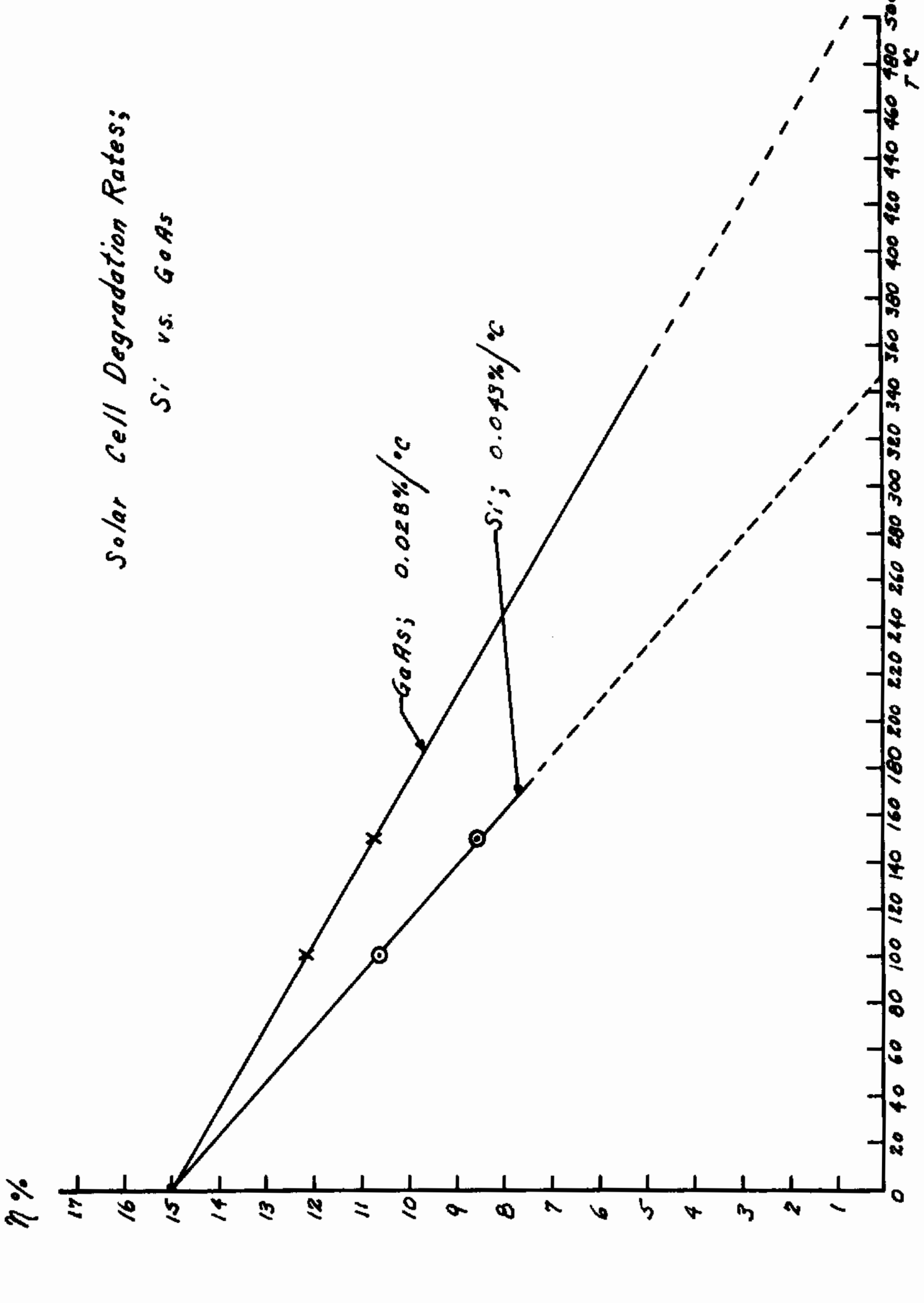
Solar Cell Degradation Rates;
Si vs. GaAs
GaAs; 0.028%/°C
Si; 0.045%/°C
η %
T °C

Figure 1.

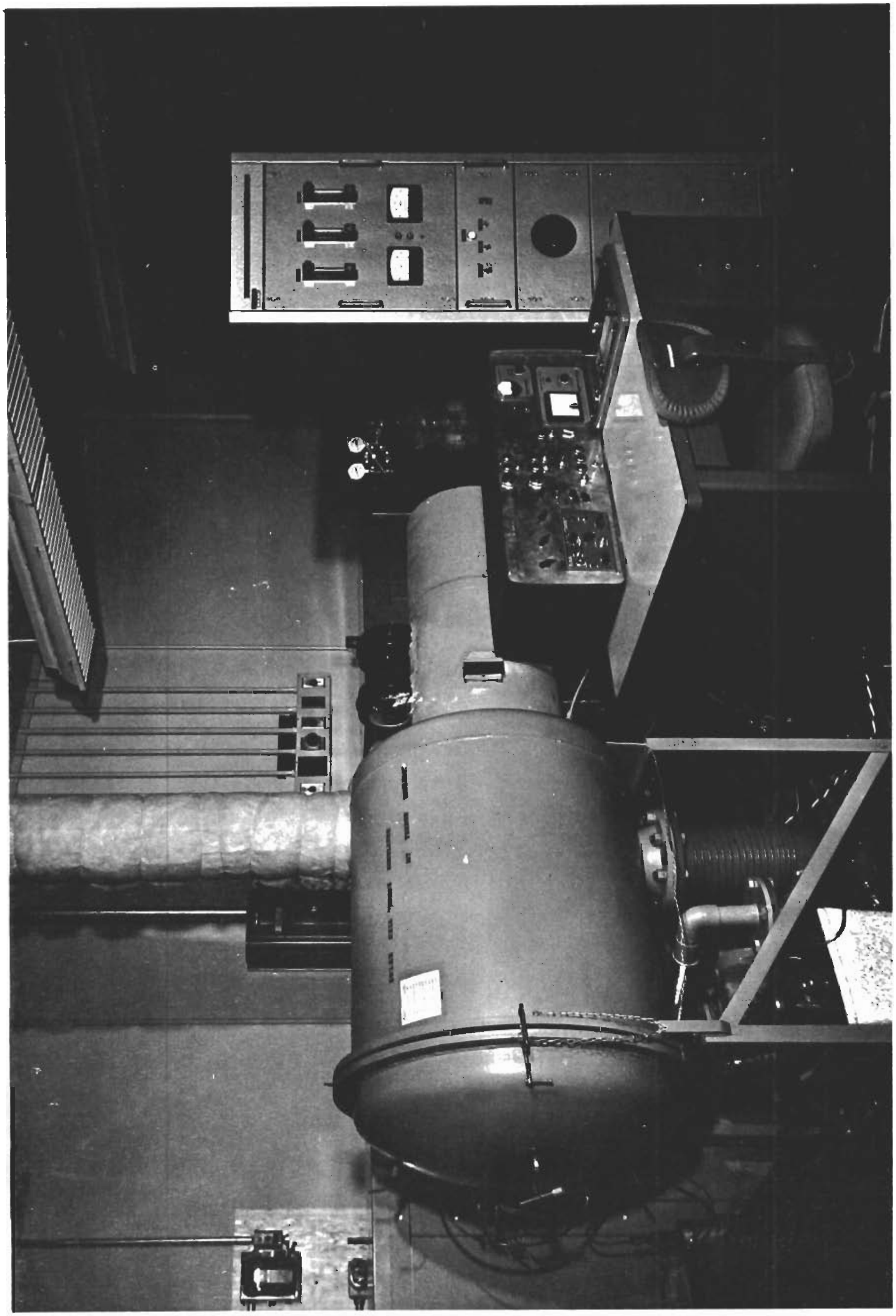

Figure 2.

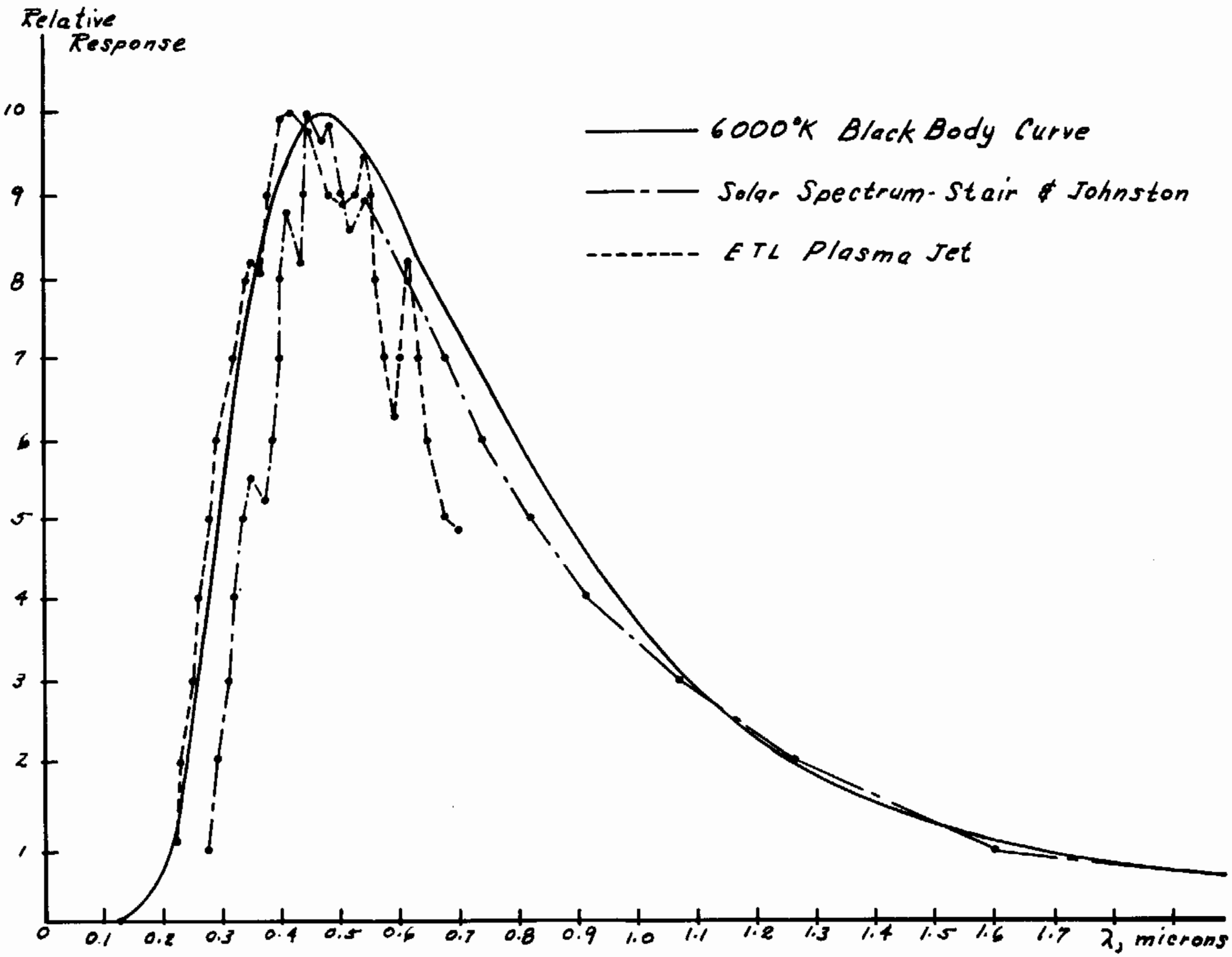
Relative Response
10
9
8
7
6
5
4
3
2
1
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
λ, microns
6000°K Black Body Curve
Solar Spectrum - Stair & Johnston
ETL Plasma Jet

Figure 3.