SOME ASPECTS OF SILICON SOLAR CELLS
IN TERRESTRIAL ENVIRONMENT

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PREFACE

In this thesis, the results of an investigation on some aspects of a silicon solar cell (SSC) in terrestrial environment are presented. SSC is basically a p-n junction 0.3 - 0.5 micron below the active surface of a single crystal silicon slice. It is the best amongst the direct energy conversion devices known at present, with a conversion efficiency of 14-16% at room temperature. Since the SSC is first prepared in 1954-55, it has undergone many improvements in its design, fabrication and technique of mounting.

In the past solar cell parameters have been optimized for solar intensity outside the earth's atmosphere i.e., 130 mw/cm^2. But solar radiation on the surface of the earth lies somewhere between 0-100 mw/cm^2 depending upon the latitude, zenith angle of the sun and local weather conditions. The optimization criteria of an SSC in terrestrial environment might be different. This aspect is investigated in the present thesis.

In chapter-I the need for direct energy conversion devices and various types of devices are discussed briefly. We see that solar cells have maximum conversion efficiency amongst the solar energy converters. The physics and elementary theory of the solar cells is given here. The losses which account for the difference in theoretical and practical efficiency of solar cells are discussed. The reasons for selecting silicon as solar cell material are discussed.

The effects of particle radiation and temperature on the performance of a solar cell are also presented.

In chapter-II, important steps in the fabrication of silicon solar cell starting from the material selection to applying antireflection coating are discussed in detail. The measurement of important characteristics of solar cells (i.e.) spectral response and Electrical characteristics are given here. Solar cells from materials other than silicon and various other types of solar cells including thin film solar cells are given in brief.

In chapter-III, the effect of angle of incidence on the performance of a solar cell and the method of estimating optimum load resistance of a solar cell in terrestrial environment are given. Solar cell performance deteriorates with increase in angle of incidence and any such power penalty gets magnified in large area solar cell arrays or high intensity environment. Solar cell performance is studied as a function of angle of incidence. The results show that the theoretical and experimental curves do not coincide with each other. The difference increases as the angle of incidence increases. The power output falls at larger angles of incidence from the expected value. This decrease in the power output is mainly attributed to the increased reflection losses at larger angles of incidence. A study of its spectral response as a function of angle of incidence shows a small and systematic shift of the peak of the spectral response towards the red wavelength region. It is suggested that this shift in spectral response may be responsible for a fraction of the fall in the power output observed. Experimentally observed shift in the position of the peak is compared with the theoretically expected value.

Solar intensity undergoes significant changes from dawn to dusk. Further, the power output of SSC is a strong function of the load resistance. A load resistance giving maximum conversion efficiency at mid-day intensity becomes less efficient at other times of the day under reduced intensity levels. The load resistance is to be optimized to derive maximum over-all power output for the whole day after taking the intensity variations into account. A method of estimating the optimum load resistance is presented here. It is also shown that considerable improvement in the power output of a terrestrial power system could be achieved at solar intensity ≤ 100 mw/cm^2 by using this optimum load resistance.

In chapter-IV, the effect of X-rays and electrical discharge on the performance of silicon solar cells are discussed.

The surface of a solar cell is very delicate in view of the shallow junction ($\sim$ 1 micron) involved. A study of the influence of X-ray irradiation on such a highly sensitive surface is interesting. The effect of X-ray irradiation at room temperature on spectral response of bare and SiO coated cells is investigated. SiO coated cells do not exhibit any change. But the bare cells show a small and reversible change in their spectral response, which is attributed to the increased surface recombination. The possibility of using a calibrated cell as a device to measure the intensity of an x-ray beam is pointed out.

It is the general belief that there is no known possibility of deterioration occurring in SSC on the surface of the earth. As one of the tests for their environmental capabilities, the effect of electrical discharge on the cell characteristics is investigated. The cells are found to exhibit unexpectedly large and permanent deterioration. The efficiency decreases to 20% of the initial value after 60 minutes of electrical discharge. Some of the phenomena which might be responsible for this degradation are pointed out and discussed.

In chapter-V, the series resistance and its effect at low intensities on the performance of SSC is investigated. Since the load resistance corresponding to the maximum power point was found to be a function of intensity below 100 mw/cm^2, it was suspected that the series resistance of the cell might be a function of intensity for intensities below 100 mw/cm^2. A simple method is suggested to find out the series resistance of a solar cell using a single I-V curve. From a set of experimental I-V curves of the SSC at various intensities at room temperature for intensities ≤ 100 mw/cm^2, the series resistance values are computed using the single I-V curve method. A theoretical calculation also shows how series resistance varies with temperature and junction parameter 'n'. The results show that the series resistance is a sensitive function of the intensity for intensities < 100 mw/cm^2. The series resistance is low $\sim$ one ohm and constant for higher intensities. The results suggest that if the value of series resistance is to be measured at low intensities, the intensity value must also be specified.

The effect of series resistance on the maximum power output at low intensities is investigated here. The experimental results presented in the thesis show that the sensitivity of the maximum power output with series resistance decreases with decreasing intensity for intensities 100 mw/cm^2. The consequences of this result are discussed.

Part of the work presented in the thesis is reported in the following papers.

1. The effect of angle of incidence on the performance of a silicon solar cell. Phys. Stat. Sol. (a) 1, K.29, 1970.

2. Effect of electrical discharge on silicon solar cell characteristics.

   Accepted for publication in Bri. J. Appl. Phy. 1970.

3. A method of estimating the optimum load resistance of a silicon solar cell used in terrestrial power applications

   ~~(Communicated for publication)~~.
   Accepted for publication in "SOLAR ENERGY"

4. Silicon Solar Cell as a device to measure X-ray intensity. (Communicated for publication).

5. The series resistance of a solar cell at low intensities

   (Communicated for publication).

6. The effect of the series resistance on the maximum power output of a solar cell in terrestrial environment.

   (Communicated for publication).

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