STRATEGY FOR ASSESSING THE RELIABILITY OF III-V CONCENTRATOR SOLAR CELLS: WORKING PLAN REVIEW AND FIRST RESULTS

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ABSTRACT

The reliability of III-V concentrator solar cells is an essential task to be carried out before the commercialization of CPV systems based on this kind of solar cells. This paper presents a working plan for assessing the reliability of this kind of III-V concentrator solar cells consisting in accelerated ageing tests and real time tests. The difference between reliability and degradation tests is highlighted as an important issue to be considered. As an example results for a step-stress temperature ageing test are shown, with a Mean Time to Failure (MTTF) of up to 69 years with a bilateral confidence interval of 80%, a reliability value of 70% at 25 years and a failure rate that trends to a steady value after a burning period.

INTRODUCTION

Since the very early stages of photovoltaic research, the use of concentrated light has been considered as an interesting way for reducing the cost of photovoltaic electricity [i][ii][iii]. In recent years, there has been a significant advance in the field of III-V high-concentrator solar cells, achieving peak efficiencies of 32.6% at 1000 suns for a double junction solar cell [iv], and 40.8% at 326 suns for a triple junction solar cell [v].

These satisfactory results have crystallized into the first commercial ventures of concentration photovoltaic systems based on III-V solar cells. Some representative examples can be found around the world, such as Solar Systems (Australia), Solfocus (USA), Isofoton (Spain), Concentrix (Germany), Daido Steel (Japan), Entech (USA), Spectrolab (USA), Emcore (USA), Menova Energy (Canada), Pyron Solar (USA), Renovalia (Spain), Sol3G (Spain), Arima Eco Energy (Taiwan), among others, which are now being demonstrated and are expected to launch their first commercial products in short [vi].

In spite of all these good perspectives, there are still many open questions that should be answered before the commercialization of products based on III-V high concentration solar cells, such as: will the product perform its purpose adequately for the period of time intended? will it do it under the specified operation conditions? which warranty can be given to the customer? In summary, what happens with the reliability of these concentrator solar cells and modules?

In this paper, it will be shown that, even though there are some preliminary studies regarding the degradation of III-V high-concentrator solar cells, there is not yet enough experience to assess their reliability. The difference between degradation and reliability tests will be analyzed.

The working plan designed to assess the reliability of III-V concentrator solar cells will be presented. One of the tests of this plan will be described with some detail: the step-stress temperature ageing test.

DEGRADATION VS. RELIABILITY

A review of the related literature shows that, basically, degradation studies have been published up to now regarding the reliability of III-V concentrator solar cells [vii][viii][ix][x][xi][xii].

The study of degradation is of great importance but, it is important to keep in mind that reliability is a completely different issue. For instance, a set of solar cells is introduced in a climatic chamber. The temperature is increased and the cells are biased to a specific current level. The number of failures is registered and the Mean Time to Failure (*MTTF*) is calculated with the following expression:

(1)

Where t_{Fi} is the time of every failure and N_F is the number o failures. In this case, the test is just a degradation limited in time study. The problem is that this kind of tests does not establish a correlation between the test time and the lifetime of the device. The periods of the lifetime of the device are shown in the graph of Figure 1. In this graph three different periods can be identified: 1) a period of early failure or "infant mortality", with decreasing failure rate, in which weaker devices begin to fail; 2) a period of useful life, with constant failure rate and 3) a period of wear out in which devices begin to fail as they reach the end of their life. With degradation limited in time, it is not possible to determine in which one of these periods is the device working at.

In order to clarify how a reliability test should be carried out, it is important to consider the following points:

1. To define what reliability is: a good definition is that reliability is the probability that a component part, equipment, or system will satisfactorily perform its intended function under given circumstances, such as environmental conditions, limitations as to operating time, and frequency and thoroughness of maintenance for a specified period of time.
2. To establish a test procedure (see Figure 2) in which the following tasks should be taken into account:
    a. To define a failure criterion.
    b. To apply a stress factor.
    c. To carry out statistics, with the aim of getting:
        i. The activation energy.
        ii. The acceleration factor.
        iii. The main reliability functions (reliability (*R(t)*), failure rate ($\lambda(t)$) and *MTTF*).

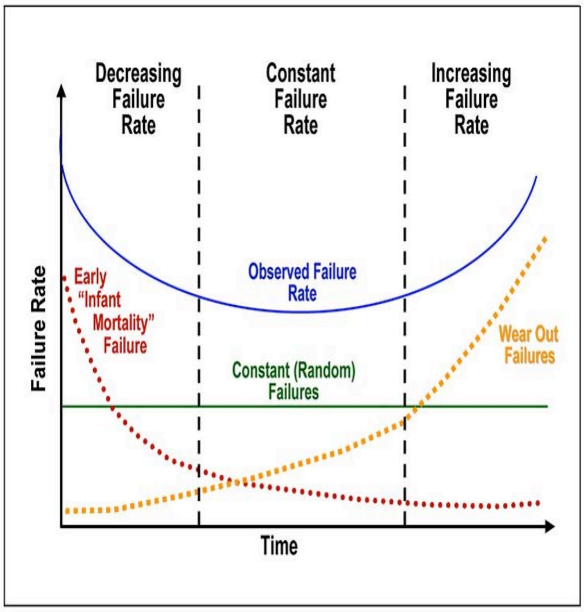

Figure 1: Periods of the life of a device.

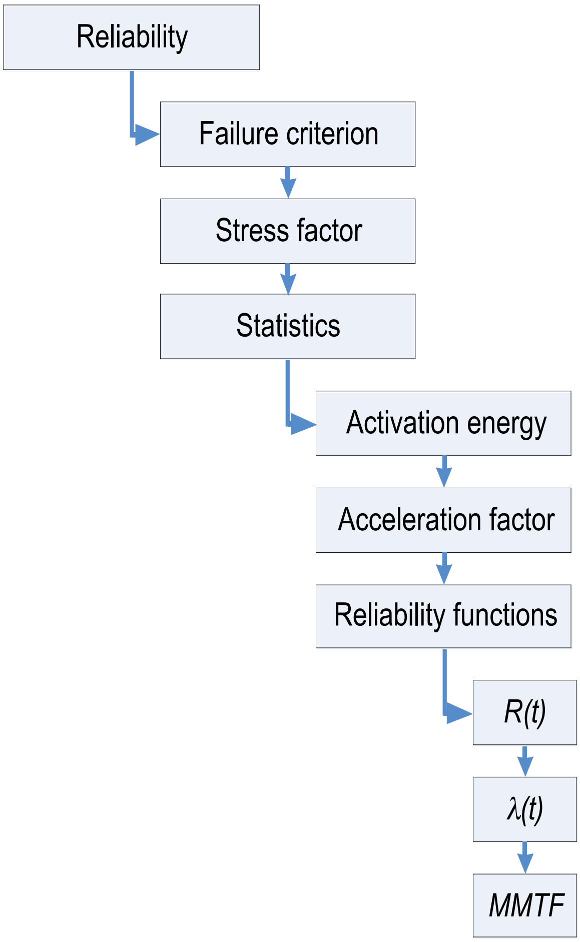

Figure 2: Procedure for assessing the reliability.

Summarizing, the reliability testing should be directed not only to determine how long devices are going to live, but the way in which these devices are going lo live. In other words, reliability is also interesting in knowing the probability distribution of failure in nominal conditions of operation.

WORKING PLAN

A working plan has been defined to carry out the reliability assessment on GaAs single junction solar cells as Figure 3 shows. This plan consists of real time tests and accelerated ageing tests The accelerated tests allow to shorten the time to evaluate the reliability of a device; the real time tests allow to determine if the stress factor introduces failure modes that would never happen in real operation.

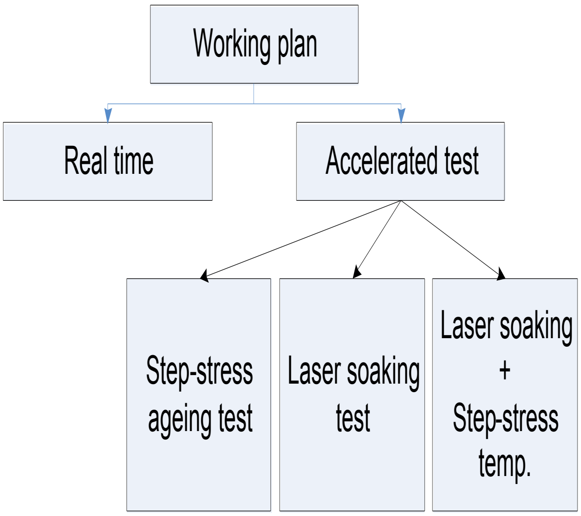

Figure 3: Working plan for assessing the reliability.

Considering the accelerated ageing test, the step-stress temperature ageing test and laser soaking (see Figure 4) have been already carried out on GaAs single junction cells. In a next step, we will combine both tests at the same time to evaluate the whole action of increasing light and temperature. In a short future these tests will be done on double and triple junction solar cells.

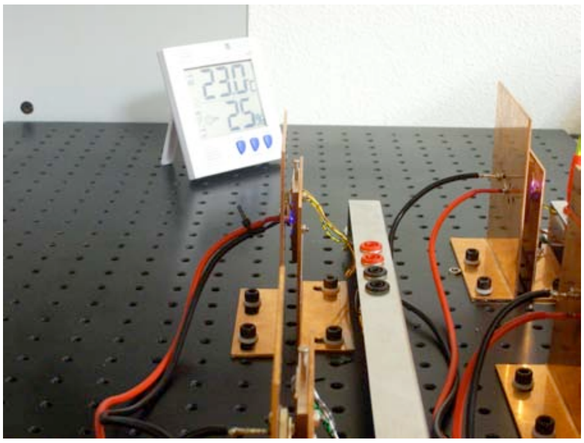

Figure 4: laser soaking test.

STEP-STRESS TEMPERATURE AGEING TEST

The step-stress temperature ageing test was carried out on GaAs single junction solar cells not covered with any epoxy or silicone, with temperatures ranging from 90 to 150ºC. This test was carried out in the facilities of a company specialized in reliability testing (Tecnologica S.A., see Figure 5) according to standards.

Figure 5: climatic chambers in Tecnológica.

A new failure criterion has been introduced reproducing the I-V curve under illumination from the dark I-V curve [xiii]. For determine the failure mode, a simulation of dark I-V curves has been carried out with a distributed 3D model, which description can be found elsewhere [xiv]. From this simulation, the failure was located in the solar cell perimeter.

The statistical analysis has been carried out with Weibull distribution which is a continuous probability distribution of common use in the reliability field, because of its flexibility, since it can reproduce the behaviour of other well known probability distributions such as the normal and the exponential. The following equation shows the probability density function:

(2)

This distribution depends on three parameters that have been calculated using a software tool for reliability testing. With them is possible to determine the Mean Time To Failure or MTTF, as well as the failure rate and reliability functions.

The results are summarized in the following points:

- MTTF of 69 years for the 90% lower limit confidence interval.
- *R(t):* the survival probability is of 70% at 25 years.
- The failure rate, after a burning period, reaches a steady value.

SUMMARY AND CONCLUSIONS

In this paper the main differences between degradation and reliability tests have been highlighted.

A working plan, considering real time and accelerated ageing tests has been presented. This plan is a powerful tool to evaluate the reliability of concentrator solar cells. The tests presented in this plan have been successfully applied to GaAs single junction solar cells and, in the short future, will be carried out on double and triple junction solar cells.

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