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CRUCIAL PARAMETERS AND DEVICE PHYSICS OF AMORPHOUS SILICON ALLOY TANDEM SOLAR CELLS

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We have previously shown that tandem solar cells exhibit higher efficiency and better long-term stability than single junction cells. We shall discuss crucial parameters for achieving high performance solar cells and certain aspects of device physics associated with the tandem structure. We will present data on what effect changes in intrinsic layer thicknesses, p+ and n+ layer thicknesses, back reflector quality, and solar spectral variation have on these multijunction devices.

1. INTRODUCTION

It has been well established that multijunction solar cells are superior to single junction solar cells in terms of conversion efficiency and long-term stability. The highest efficiency achieved to date for an amorphous silicon alloy device is 13% reported by our laboratory[1], using a dual band-gap triple-cell configuration. The J-V characteristic and quantum efficiency are shown in Fig. 1. This device has a structure of ITO/pin/pin/pin/back reflector/stainless steel. This device utilizes a 1.5 eV a-Si:Ge:F:H bottom cell, a 1.7 eV a-Si:F:H middle and top cell, microcrystalline p^+ layers[2] and a scattering back reflector. This device configuration exhibits excellent long-term stability, showing a stabilized output >90% of its initial value after 1500 hours of continuous indoor AM1 light exposure[3].

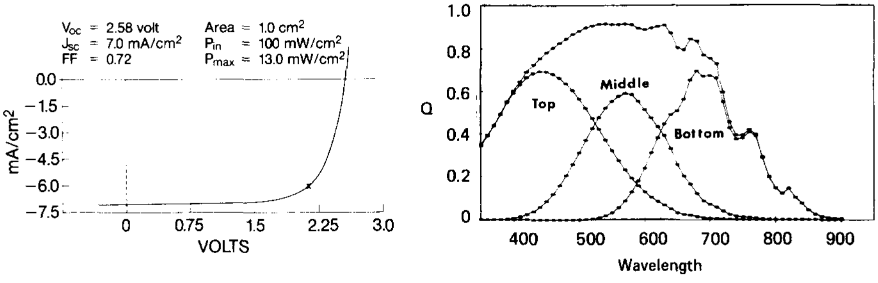

Figure 1. The J-V characteristic and quantum efficiency of a 13% amorphous silicon alloy dual-gap triple-junction device.

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In order to achieve these high efficiency devices,every layer of the device must be of the highest quality. We must have a clear understanding of how doping concentrations in the p^+ and n^+ layers as well as variations in thickness affect the output characteristics. We will also show that the role of the back reflector is not only to increase efficiency through increased absorption but may also improve the long-term stability of the device. In addition to material quality it is also very important to develop techniques to optimize the thicknesses and band gaps of each layer for various spectral conditions.

2. DISCUSSION

We have shown that the use of a transparent barrier layer in combination with a scattering back reflector may enhance the device current by as much as 15% over the standard scattering back reflector[4]. In Fig. 2 we show the effect of this barrier layer on the quantum efficiency of a single a-Si:Ge:F:H device. Note that the quantum efficiency at 800 nm increases by a factor of 2.5. This result will also enable us to decrease the thickness of the bottom cell of the multijunction device thereby increasing its carrier collection characteristics and reducing degradation effects.

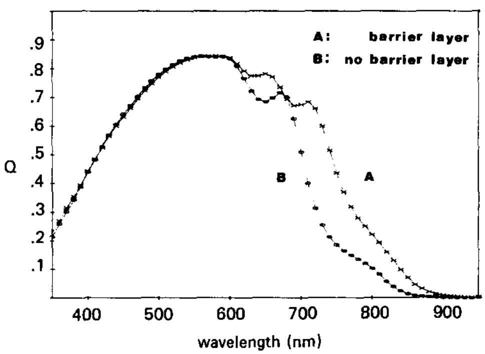

Figure 2. The quantum efficiency of a single junction a-Si:Ge:F:H device (A) with a barrier layer and (B) without a barrier layer.

We have also studied the effects of the doping and the thickness of the center p-n junction in same band-gap tandem devices[4]. It was observed that, for a given doping level, the open-circuit voltage increased rapidly from the single-cell value at zero p-n junction thickness to the full tandem value at several tens of angstroms. After that point the V_{OC} was quite independent of thickness. The same qualitative behavior was observed when the doping level was varied at constant layer thickness; the V_{OC} increased from a single-cell value to that of a tandem and became independent of dopant concentration.

Since spectrum-splitting multijunction devices are more sensitive to spectral distribution than are single junction cells,it is very important to quantify what effect changes in spectrum will have on these multijunction devices. Conversely, we also know that changes in layer thicknesses for a given spectrum will affect the multijunction device output more dramatically than similar changes in single junction devices. Therefore techniques to readily evaluate the effect of spectral and layer thickness variations on multijunction device performance are essential for further enhancement of efficiency, quality control, and long-term outdoor performance assessments.

We have recently reported on a procedure that allows us to measure the conversion efficiency of any multijunction device under any spectral distribution to a high degree of accuracy[5]. This method utilizes several reference cells, a multiple-source simulator, and spectral mismatch to duplicate current-matching conditions of the individual component cells within the multijunction device for the desired spectrum under the simulated conditions. This procedure may also be used to assess the outdoor performance of multijunction modules at various latitudes, or climatic, i.e. atmospheric, conditions.

With the use of either theoretical[6] or experimental outdoor spectral irradiance data sets we are able to simulate variable spectral conditions under our multiple-source simulator and evaluate and compare the performance of various single- and multiple-junction devices. In a previous study[7], for example, we concluded, on the basis of results utilizing the above technique, that multijunction devices actually outperform single junction devices in terms of total integrated power delivered over the course of a day. In Fig. 3 we show the power output of a single, tandem, and triple

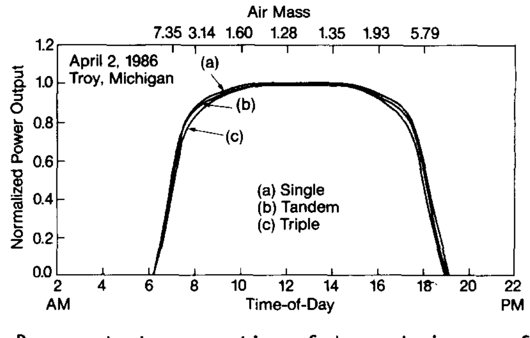

Figure 3. Power output versus time-of-day and air mass for (a) a single, (b) a tandem, and (c) a triple device.

device versus time-of-day. It is very important to note that the effect of initial efficiency has been normalized out of this curve to observe strictly the effect of air mass and time-of-day response. If we then take into account the effects of initial efficiency and stability the multijunction device would supply in excess of 30% more integrated power than the single junction device over the same period of time.

3. CONCLUSION

We have discussed some of the crucial parameters for developing stable high efficiency multijunction solar cells. These include the effect of layer thicknesses, p^+ and n^+ doping level, back reflector quality, and solar spectral variation on these multijunction devices.

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