LIGHT-INDUCED CHANGES IN HYDROGENATED AMORPHOUS SILICON: ANOMALOUS RECOMBINATION BEHAVIOUR AT LOW TEMPERATURES

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ABSTRACT

The open circuit voltage decay (OCVD) method has been used to characterise a-Si:H, p-i-n photovoltaic cells over a range of temperatures from 228 K to 291 K.

We have found that the form of the OCVD voltage-time curves is sensitive to light soaking: the curves at different temperatures for as-deposited samples are nested inside each other with similar overall decay times, whereas, for the light soaked samples, as the temperature is decreased the decay time increases markedly and successive curves overlap.

Our preliminary results indicate that the phenomena observed may be related to the overshoot in the transient photocurrent observed by other researchers under similar conditions.

INTRODUCTION

In a semiconductor, excess carriers produced by transient illumination or forward bias, decay as a result of recombination with a characteristic time; the recombination lifetime. This is the average time of the existence of an excess electron-hole pair. It is normally referred to as the minority carrier lifetime when the minority carriers dominate the recombination process [1]. When electron-hole pairs are created in the intrinsic region of a p-i-n cell, the carriers diffuse to the p and n regions respectively, where they contribute to the photocurrent if the cell is connected to an external circuit, or produce the photovoltage if the cell is open-circuit. Some of the carriers are lost before this happens by the processes of bulk or surface recombination.

Recombination takes place preferentially at trap sites such as dangling bonds. The number of dangling bonds is a measure of the quality of the photovoltaic material. The greater the concentration of dangling bonds, the faster the rate of recombination and the shorter the minority carrier lifetime. Thus the minority carrier lifetime is an important parameter used in characterising photovoltaic materials and predicting photovoltaic performance. There are a number of methods used for the determination of the minority carrier lifetime, but the most popular appears to be the open circuit voltage decay (OCVD) technique [2,3,4].

This present study is an extension of a project carried out for an honours thesis [5] and not previously published and is, to our knowledge the first report of temperature dependence of minority carrier lifetime in a-Si:H.

Berry and Longrigg [3] have described the form of the OCVD response of an a-Si:H cell as shown in Fig. 1.

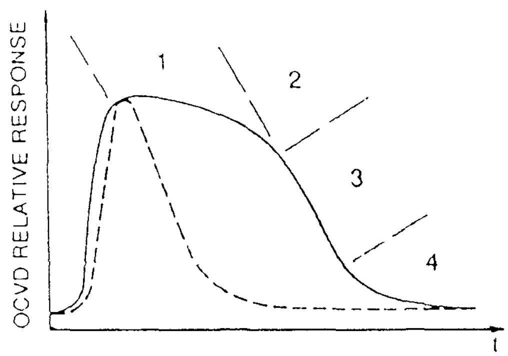

Fig. 1. A comparison of a typical OCVD response for an amorphous silicon module to the excitation pulse showing the four decay modes: 1, intrinsic; 2, trap activation; 3, trap-assisted intrinsic decay; 4, final non-linear exponential decay.

There is some dispute over the magnitudes of the minority carrier lifetime values obtained from such responses curves [6], but the form of the curve, particularly the voltage at which the break-point (2) occurs, is a useful measure of the quality of the cell [3].

EXPERIMENTAL

The samples measured consisted of single homojunction p-i-n a-Si:H cells produced by plasma enhanced CVD on ITO coated glass substrates, with substrate temperatures

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of 225°C. The i-layer was approximately 400 nm thick. Back contacts were aluminium dots 0.049 cm² in area. The cells were produced without any efficiency enhancement modifications and gave efficiencies up to 7%.

Open circuit voltage decay measurements, were made using the experimental arrangement shown in Fig. 2.

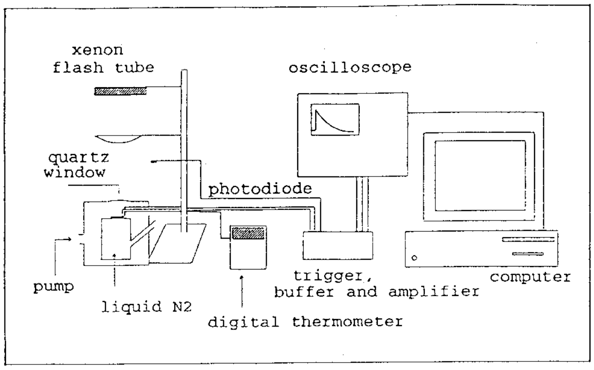

Fig. 2. Experimental arrangement for the measurement of the open-circuit-voltage-decay

A Xenon flash lamp with a repetition rate of 12 Hz and a total pulse length of 80 μs was used as the excitation source. A fast photodiode sensed the stray light from the lamp and was used to trigger the Phillips PM 3323 500MS/s digital storage oscilloscope. The open circuit voltage was fed via a high impedance buffer/amplifier to the oscilloscope. The oscilloscope was interfaced with a PC.

The sample was cooled using either a thermoelectric device or by the use of liquid nitrogen. Electrical contact to the sample was made using gold wire probes. The sample temperature was measured with a thermocouple. Heating and temperature control could be performed using either the thermoelectric device or a resistive heater.

RESULTS

The typical form of the measured OCVD curves is shown in Fig. 3. The curves at low temperature display all four regions, band-to-band decay (1), trap activation (2), linear decay (3) and exponential decay (4), described by Berry and Longrigg [3]. At the highest temperatures the intrinsic region (1) is absent or very much attenuated, due to the comparatively low intensity of the flash lamp; the V_{oc} signal at room temperature is about 0.4 volt which is smaller than the V_{oc} obtained under AM1 illumination and decreases with decreasing temperature as shown in Fig. 4. At lower temperatures, the intrinsic region is clearly evident. At temperatures below room temperature, the decay curves neatly nest inside the room temperature curve. Region 1, attributed to band-to-band decay is enhanced at low temperatures, while the overall decay time is slightly reduced.

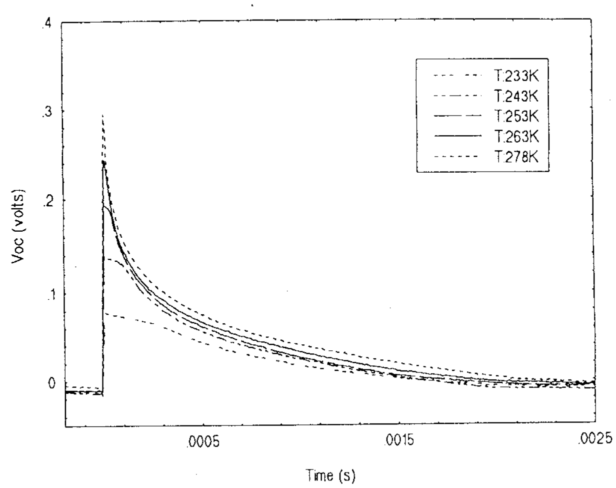

Fig. 3. V_{oc} decay curves for an a-Si:H p-i-n cell at various temperatures.

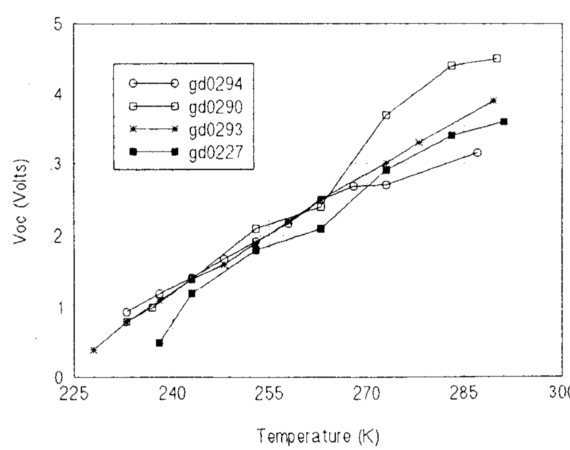

Fig. 4. V_{oc} vs. temperature for a-Si:H, p-i-n cells.

A set of curves for a sample following 24 hours of light soaking is shown in Fig. 5. In this series of curves the low temperature band to band region is enhanced and occurs over sufficiently long periods of time that the decay curves at successively lower temperatures cross over the higher temperature curves and the overall decay times increase with decreasing temperature. This is in complete contrast to the form of the as-deposited curves.

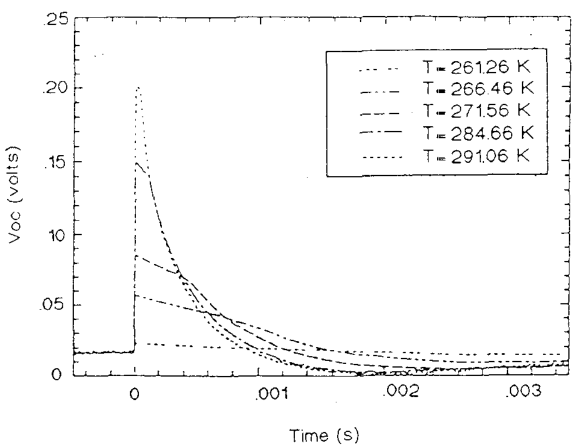

Fig. 5. V_{oc} decay curves for an a-Si:H p-i-n cell following light soaking.

It appears in this case that similar numbers of charge carriers are excited at each temperature but that these take much longer to recombine as the temperature is reduced.

OCVD behaviour intermediate between the two forms shown in figures 3 and 5 occurred for a sample following exposure to light during a number of IV measurements but with no explicit light soaking, this is shown in Fig. 6.

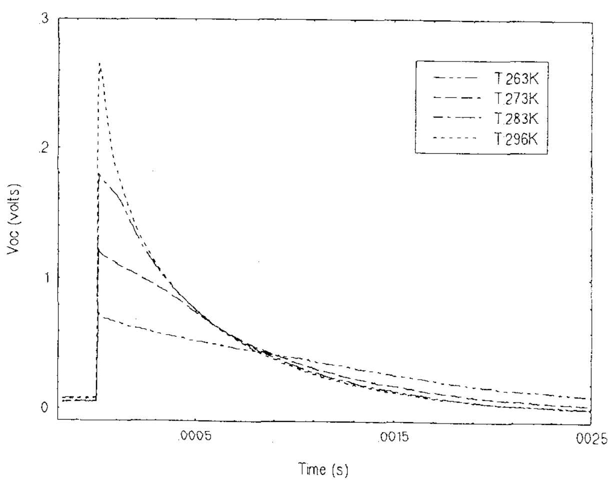

Fig. 6. V_{oc} decay curves for an a-Si:H, p-i-n cell after exposure to AM1 illumination.

For this sample the number of dangling bonds is expected to be somewhere between those for the previous two samples.

DISCUSSION

The different regions in the decay curves shown above can be related to different decay mechanisms. Berry and Longrigg [3] describe the response in terms of decay in the intrinsic layer of the cell, and in the p-i and i-n barrier layers. Intrinsic band-to-band decay occurs when all the traps within the mobility gap are saturated. Illumination of the a-Si:H creates excess carriers (electrons and holes) which populate the extended and localised states at the band edges. At room temperature the light intensity used in this investigation was not adequate to fulfil this condition and the band-to-band region is not seen on the curve. However, at lower temperatures, region 1 does appear and becomes more significant as the temperature is decreased. The onset of decay via trap states is increasingly delayed as lower temperatures are reached and intrinsic band-to-band like decay is observed.

It is expected that both the number of traps and the number of carriers generated should be independent of temperature. Thus saturation of the traps and intrinsic band-to-band transitions should not occur at any temperature.

If the trap filling process is thermally activated, then at low temperatures, the production rate of free carriers may exceed their loss rate to traps resulting in a quasi-saturation and band-to-band decay takes place which persists until the traps are activated. Evidence for this process is seen in transient photocurrent data, where at low temperatures an initial overshoot in the current has been observed [7]. This is explained as due to the rate of deep trapping of the current carriers being less than their generation rate. Ulrich, Eickhoff and Wagner [7] have observed such overshoots persisting up to several hundreds of milliseconds after the onset of illumination, adequately covering the band-to band decay times observed in the OCVD results for as-deposited samples.

In the OCVD results for light soaked material, the band-to-band transitions are significant for even a small reduction in temperature. This effect increases as the temperature is further reduced. Since light soaking produces an increased number of dangling bonds, these should give rise to more trap states, and hence saturation of such material should be less likely and band-to-band transitions are unlikely to be observed. This is clearly not so.

Ulrich, Eickhoff and Wagner have investigated the effect of light soaking on the transient photocurrent, and have shown that the overshoot is considerably reduced [8]. Since their carrier generation rate is much less than that used in the present OCVD measurements, an effect may be present but onobserved, it would have to tke place in the first 100 ms or so. Fig. 5. shows the region 1 decay extending up to about 100 ms. Wieczorek and Fuhs [9] have demonstrated overshoot in the hole current generated in a n-i-p diode even at room temperature. In this case the time for the overshoot to decay was over 100 ms. It is expected that this effect would be enhanced at lower temperature and could adequately describe the curves of Fig. 5.

CONCLUSIONS

Our preliminary investigations have revealed a distinctive effect which may have considerable value in determining the quality of a-Si:H material and in monitoring the degradation of solar cells and modules. Systematic investigations have commenced to obtain quantitative data suitable for a basis on which to model the processes responsible for the observations. In addition simultaneous transient photocurrent measurements will be made, using a pulsed laser source with a rapid rise time to provide further information on the initial processes involved.

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