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HIGH EFFICIENCY, LARGE-AREA PHOTOVOLTAIC DEVICES USING AMORPHOUS Si:F:H ALLOY

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Abstract.- Overall conversion efficiency of 6.6% has been obtained for a photovoltaic device over an active area 0.73 cm² using amorphous Si:F:H alloy in a MIS configuration.

Introduction.- The possibility of low-cost thin film photovoltaic cells using amorphous silicon (a-Si) based alloys has generated an intense amount of interest in the past few years. Previously, we have reported on the properties of a-Si:F:H alloy (1,2) as a useful photovoltaic material. We also reported an overall device conversion efficiency of 6.3% over an active area of 0.042 cm² (3). In this paper we consider the level of reproducibility that has been obtained and latest data on MIS (metal-insulator-semiconductor) devices which have yielded conversion efficiencies of 6.6% over a much larger active area.

Photovoltaic Properties of a-Si:F:H Alloy.- In previous publications we have reported that an a-Si:F:H alloy with a low density of states and a high photoconductivity can be fabricated using the radio frequency glow discharge of mixed SiF₄ and H₂ gases (1,2). We have also shown that this type of material can be doped easily by introducing small amounts of PH₃ or AsH₃ in the gas phase to obtain conductivities (for the n+ layer) ~ 10⁻³ (Ω cm)⁻¹.

Typical MIS device structures were fabricated as follows: a thin, highly conductive n+ layer (~ 200-500 Å) was deposited onto a reflecting bottom contact such as Mo, Cr, etc.; next, ~ 5000 Å of active photoconductive a-Si:F:H layer was deposited using a volume gas ratio of SiF₄/H₂ = 5/1. (The photoconductivity under AM-1 excitation of this component is typically in the range 10⁻⁴ - 10⁻³ (Ω cm)⁻¹, which provides for a low series resistance in operation.) Then a 20 Å thick layer of oxide such as Nb₂O₅ was thermally evaporated and contact was made to the device using 70 Å of high work function Au:Pd (90:10) or Pt metal. Finally, a layer of 350 Å thick ZnS served as an antireflection coating.

Fig. 1: Forward and reverse J-V characteristics of a typical MIS device.
Figure 1 shows a typical dark current density-voltage (J-V) characteristics for forward and reverse bias. We note that the rectification ratio at 0.5V bias is about 10^5. The dark diode ideality factor for the device is $n = 1.2$. We have previously shown (4) that the value of $n$ is dependent on the oxide layer thickness (i.e., for $\delta = 0$ (corresponding to a native oxide) $n = 1.05$ and for $\delta = 30 \, \text{Å}$, $n = 1.2$) and can be interpreted in terms of a low surface state density.

The cell response under simulated AM-1 illumination exhibits the following characteristics: $V_{OC} = 0.8\, \text{V}$, $J_{SC} = 12.9 \, \text{mA cm}^{-2}$, $FF = 0.61$, yielding an overall conversion efficiency of 6.3% over an active area of 0.042 cm².

The presence of the insulator enhances the open circuit voltage, $V_{OC}$, due to the suppression of the majority carrier (electron) current without any effect on the minority carrier (holes) density which constitutes the short-circuit current. This is shown in Figure 2(a) and (b) where $J_{SC}$ and $\Delta V_{OC}$, the enhancement in $V_{OC}$, are plotted against the insulator thickness, $\delta$. We should note that for $\delta = 30 \, \text{Å}$, $\Delta V_{OC} = 250 \, \text{mV}$.

Since performing the above work (3), Gutkowicz-Krusin et al. (5) have suggested that the introduction of the insulator could also enhance the $J_{SC}$, primarily at the blue end of the spectrum, due to the reduction in the thermal diffusion of electrons against the electric field. The above data, shown in Figure 2(b), indicates that $J_{SC}$ is possibly enhanced. Figure 3 shows the spectral response of a cell with and without the insulator. We note that the spectral response of the cell is improved toward the blue end of the spectrum when an insulator is introduced in agreement with Gutkowicz-Krusin et al's suggestion.

Fig. 2: (a) Short-circuit current density as a function of oxide thickness ($\delta$). (b): Open-circuit voltage enhancement as a function of oxide thickness ($\delta$).
Reproducibility.- In Figure 4(a), we show the data from numerous devices of active area 0.042 cm\(^2\) ostensibly fabricated from identical conditions. We note that the fill factor is typically 0.55 - 0.6, \(V_{oc} = 0.78 - 0.88\), \(J_{sc} = 12 - 14\) mA cm\(^{-2}\) with A.R. coating; the device efficiency, as shown in Figure 4(b), is between 3-4\% without A.R. coating, and 5.5\% - 6.6\% with A.R. coating.

![Fig. 3: Relative collection efficiency for devices with and without the insertion of an insulating layer.](image1)

![Fig. 4: (a) Device parameters such as open-circuit voltage, \(V_{oc}\), fill factor, FF, and short-circuit current density, \(J_{sc}\), as a function of run number for devices fabricated under ostensibly identical conditions.](image2)

In Figure 5, we show the overall conversion efficiency for larger area devices. The total area of the device is 0.81 cm\(^2\) and has utilized a grid pattern (Ag), and the active area is 0.73 cm\(^2\), which was used in the calculation to obtain the overall conversion efficiency. We note that the efficiencies, with antireflection coating,
for these large-area devices is the same as for the small areas. The best efficiency obtained is 6.6% with the following characteristics, $V_{oc} = 0.88V$, $J_{sc} = 13.1$ mA cm$^{-2}$, $FF = 0.57$. Recently, Hamakawa (6) has reported that a conversion efficiency of 7.1% over an area 0.033 cm$^2$ has been obtained, using glass/ITO/Si:C/a-Si:H/n+/Al structure in which the fill factor was 0.65. It is therefore interesting to note that with a similar fill factor, the active area efficiency for our best device would be 7.5%. Indeed, when the illumination intensity is decreased, the fill factor in our devices does improve which suggests a sheet resistance effect coming into play. Therefore, the lower fill factor in our devices is not a materials problem, but a simple technological problem which should be easily remedied.

Conclusion.- In summary, we have shown that high efficiency, large-area cells can be reproducibly made using a-Si:F:H alloy.

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