R&D in Amorphous Silicon Solar Cells at Chulalongkorn University, Thailand

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Abstract

A plasma enhanced CVD equipment was installed for the deposition of a-Si:H solar cells. The optical absorption coefficient spectra at the regions of low and high photon energies were measured by the Constant Photocurrent Method (CPM) and transmission method, respectively. The results revealed that the a-Si:H prepared at the substrate temperature of 200° C contained less density of gap states than that prepared at the substrate temperature of 300 °c. Using the optimal substrate temperature condition, the a-Si:H solar cell of the efficiency of 7% has been obtained. The results of the fabrication of various types of a-Si:H solar cells, i.e., tandem and integrated types are presented. A new application of a-Si:H solar cells deposited on flexible metal sheets to a battery charger for a mobile personal telephone is demonstrated.

1. Introduction

In 1988 the project of the fabrication of hydrogenated amorphous silicon (a-Si:H) solar cells started at the Semiconductor Device Research laboratory (SDRL) [1]. The a-Si:H solar cells have attractive features of possibility of low cost and large areas. The project was supported by the National Research Council of Thailand (NRCT) and National Electronic and Computer Technology Center (NECTEC). The study has been done on the characterization of a-Si:H films, physics and technology of the a-Si:H solar cells. In this paper, the results of the measurement of the optical absorption coefficient in the low absorption region reflecting the gap states by the Constant Photocurrent Method (CPM) is described. Results of the (fabrication of different structures of a-Si:H solar cells are reported. Finally, a new idea of the application of flexible a-Si:H solar cell to the battery charger for a mobile personal telephone is also proposed.

2. Preparation of a-Si:H

The a-Si:H was prepared by the plasma enhanced CVD (PE-CVD) method. The gases for doping a. Si:H into p- and n-type semiconductors were B2H6 and PHJ, respectively. The substrate temperature was 200-300°C and the gas pressure was I torr. The RF power frequency was 13.56 MHz with the power output of about 3 watt. The diameter of the substrate holder was 9 cm. Coming glasses #7059 were used as the substrates.

3. Measurement of Low Optical Absorption Coefficient By CPM Method

The optical absorption in a-Si:H arises from various optical transition processes as shown in figure, The process A is the optical transition from the valence band to the conduction band. The process B is the optical transition between the tail states and the extended states. The process C is the optical transitic between the extended states and the deep gap states. The deep gap states make bad affect in tt photoconductivity and the photoluminescent efficiency of a-Si:H. Amorphous devices prefer less density (the gap states. In this section the result of the measurement of the optical absorption coefficient due to tI process C is described and discussed. The optical absorption coefficient of the process C is too low that can not be measured by the conventional methods, e.g., transmittance. Recently the "Constant Photocurrent Method (CPM)" has been widely accepted as a simple and relatively reasonable method for the measurement of the low optical absorption efficient [2]. The basic principle of the CPM is that one has to control the photon flux that incident on the a-Si:H surface so that the photocurrent out put is constant. Figure 2 shows the schematic illustration of the CPM measurement technique. The photocurrent is generally described as follows [2];

$$I_{ph} \approx eN(1-R)\left[1-\exp\{-\alpha d\}\right]\eta\mu_0\tau F \quad (1)$$

where *e:* electronic charge, *N:* photon flux incident on a-Si:H, *R:* reflectivity of a-Si:H, *F:* applied electric field to a-Si:H, *a:* optical absorption coefficient of a-Si:H, *d:* thickness of a-Si:H, 1]:quantumefficiency of photoconductivity, JIor. mobility and carrier lifetime products.

The absorption coefficient in the range of photon energy below 1.3 eV in equation (I) is so small that

$$\alpha d << 1 \quad (2)$$

Therefore equation (1) has a simple form as

$$I_{ph} \approx eN(1-R)\alpha\eta\mu_0\tau F \quad (3)$$

The photon energy of the interesting range is 0.8-1.3 eV where it can be assumed that the parameters: R. 11,JIor-do not depend on the photon energy. Therefore, equation (3) is simplified to

$$I_{ph}(h\nu) \approx N(h\nu)\alpha(h\nu) \quad (4)$$

Therefore, in the measurement if we keep the photocurrent constant, we will get the next equation:

$$\alpha(h\nu) \approx \text{CONSTANT}/N(h\nu) \quad (5)$$

Therefore, in the CPM method, the optical absorption coefficient is inversely proportional to the photon flux.

Figure 3 shows the results of the measurements of the optical absorption spectrum of a-Si:H obtained trom the CPM method. The optical absorption coefficient in the process C is in the order of $10^{.3}$ I/cm. The absolute value of the CPM absorption coefficient is determined by the extrapolation of the conventional band edge spectrum. Highly photoconductive a-Si:H should have small absorption coefficient in this region. In the figure it is seen that the a-Si:H prepared at the substrate temperature of 200°C has the absorption coefficient lower than that prepared at the substrate temperature of 300°C. This result is consistent with the result of the measurement of the spin density by Electron Spin Resonance (ESR) [3]. The a-Si:H prepared at the substrate temperature of 200°C has the spin density (defect density) least than that prepared at the substrate temperature of 300°C. Therefore, it is concluded that the optimal substrate temperature for a-Si:H should be approximately 200°C.

4. Results of Fabrications of a-Si:H Solar Cells

The basic structure of the a-Si:H homojunction solar cell is glass/ITO/p-i-n a-Si:H/AI. The efficiency obtained in the homojunction a-Si:H solar cell is 5-6%. Using a-SiC:H as a wide band .gap window for a-SiC:Wa-Si:H heterojunction solar cells (figure 4) the conversion efficiency has been improved to about 7% as shown in figure 5. An integrated type a-Si:H solar cell with a new and simple configuration was proposed and fabricated as shown in figure 6.[4]. The integrated type a-Si:H solar ce1ts can be used as a battery charger. The tandem type a-Si:H solar cell consisting of a-Si:H solar cells deposited in the multilayer structure was fabricated as shown in figure 7 and the result showed that the output voltage is proportional to the number of the solar cell (5). The tandem type has an advantage of high efficient optical absorption of the solar radiation. Figure 8 shows the structure of the n-type microcrystalline Si:Wp-type polycrystalline Si stacked type solar cell. Its efficiency is «)01[[6].

S. Application of Flexible a-Si:H Solar Cells to Battery Charger for Mobile Personal Telephone

Mobile telephones are personal telecommunication equipment that are very popular and increasing their markets rapidly. The total number of the mobile telephones used in Thailand is about 1.5 million sets and the total number for world-wide in 1996 is estimated to be 85 million sets. The users of the mobile telephones are for example, business men, salesmen, politicians, travelers, trekkers, policemen, etc. Some mobile telephones are used in the oceans, deserts, mountains [7]. The battery in a general mobile telephone has a specification of the voltage of about 6.7 V with the capacity of 600 mAhr - 1200 mAhr. Although the solar cells have been already used in telecommunication, e.g., repeater stations (big capacity), walky-talky for military (small capacity). There has been no report on the application of a solar cell to a personal mobile telephone so far.

The purpose of this work is to point out that solar cells are very important energy source for personal mobile telephones and the personal mobile telephones are big markets for solar cells, especially amorphous silicon flexible solar cells. Moreover, when the project of low-orbital satellites (e.g., Iridium satellite project) is realized, solar cells will play more important rolls in mobile telephones which can be directly linked to the sate11ites.

The battery charging set used in the experiment for a mobile telephone consisted of amorphous Si foldable and flexible solar cells, a blocking diode, a charging box, Ni-Cd batteries (6 V, 700 mAhr) , plugs, selectors and cables. The amorphous Si solar cells were a double junction type and deposited on flexible stainless steel substrates [7]. Figure 9 shows the basic configuration of the charging set. A user can connect amorphous silicon solar cells either to a mobile telephone or a charging box. It is intere.sting to emphasize that the solar cells to be used for mobile telephones should have the following basic conditions: no glass to break or fragile, portable, light weight, rugged, tough, easy to transport. They are tough enough to be dropped and stepped on, packed and re-deployed, and they can produce enough electricity, etc. The amorphous Si flexible solar cells employed in the work satisfies all of these requirements.

The mobile telephone consumed the electric current of about 70-80 mA in a stand-by mode (waiting for r,alling) and about 200 mA in a talking mode. The amorphous Si solar cells used in the experiment consisted of 4 small sheets of double junction amorphous Si solar cells [7] connected in series, giving a total short circuit current (Isc) of about 400 mA, and open circuit voltage (Voc) of about 13 V [7]. Tough nylon fabric a1towed the solar cells to be rapidly folded to an A5 book size. Tefzel (by Dupont) served as a durable, long-lasting front cover. If one wants to charge a larger current into the battery in order to shorten the charging-time, one can do by connecting several sets of the solar cells in parallel. This will result in a longer time use of the mobile telephone. The study has been done on the relation between the period of using a mobile telephone in a stand-by mode and the charging time by the actual sun light. The data were colle:::ted for one month in February 1996. The period of battery charging was 1 hour for each experiment and the measurement in each day started from 9.00 am to 18.00 pm. The results showed that after charging the battery by the sun light for one hour, the battery could be used in the stand-by mode for about half an hour to about three hours depending on the time of charging. Since the consumption current in the talking-mode is about 2.5 times of that of the stand-by mode, the battery could be used in the talking-mode for about a quarter hour to about one hour and a half. In the actual application, an appropriate design of the size and the number of solar cells can be determined so that a user control the period'of the charging time and also the period of use of the mobile telephone.

It was shown that the battery charger using amorphous silicon flexible solar cells for a mobile telephone was very simple. The business of this equipment is only to prepare the amorphous silicon solar cells, since users of mobile telephones have already charging box accessories which are definitely provided with mobile telephones. The authors believe that mobile telephones are a new and big market for amorphous silicon flexible solar cells in the near future. The impact of the study in this work should contribute to the expansion of the PV market.

6. Conclusions and Future Plans

In Thailand the hydrogenated amorphous silicon solar cell is gathering interesting as a candidate for a low cost solar cell. It has been shown that the a-Si:H solar cells with the conversion efficiency of about 7% could be fabricated by a simple plasma enhanced CVD system. The areas of the solar cells have been limited to about 4 cm by 8 cm due to the size of the CVD system. The SDRL is planning to fabricate tandem type solar cells consisting of a-Si:H (Eg = 1.7 eV) cell and a-SiGe:H (Eg = 1.5.-1.6 eV) cell so that the solar radiation can be more efficiently absorbed and higher efficiency can be expected.

7. Acknowledgment

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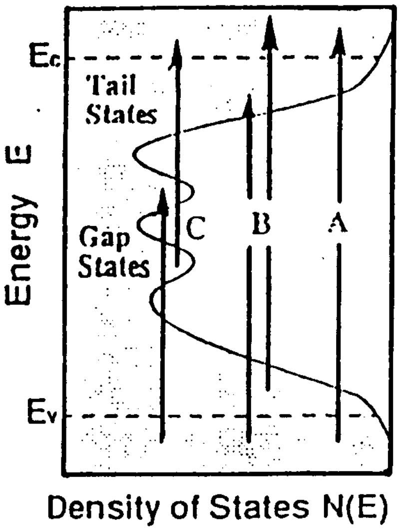

Figure 1 Three types of the optical transitions in a-Si:H

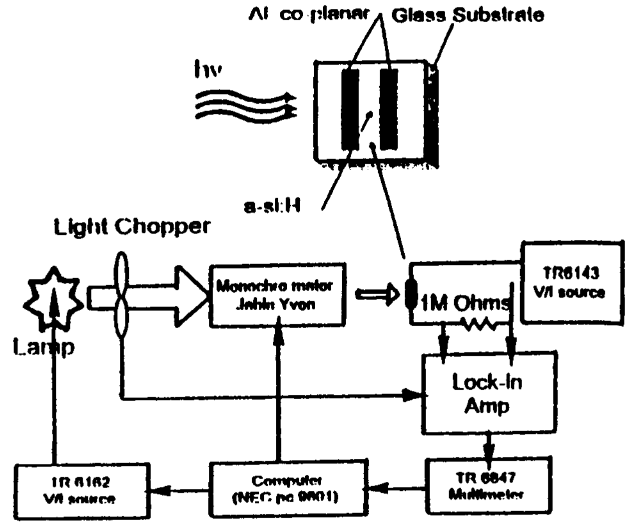

Figure 2 Principle of the measurement of Constant Photocurrent Method (CPM).

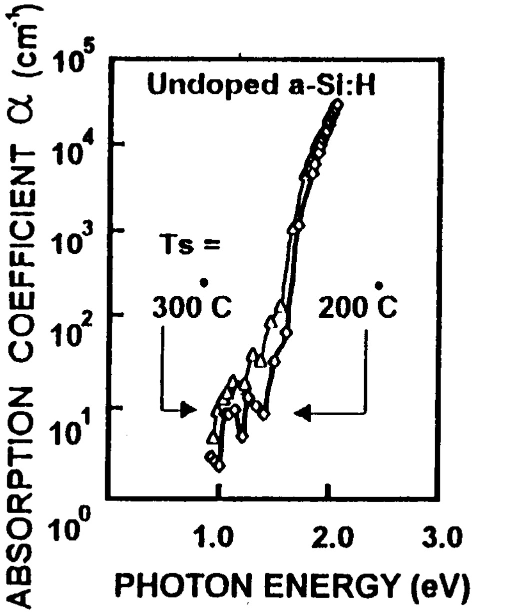

Figure 3 Optical absorption coefficient spectra for a-Si:H prepared at the substrate temperatures of 200 and 300°C.

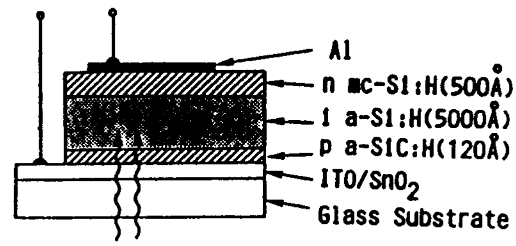

Figure 4 Structure of a-SiC:H/a-Si:H heterojunction solar cell.

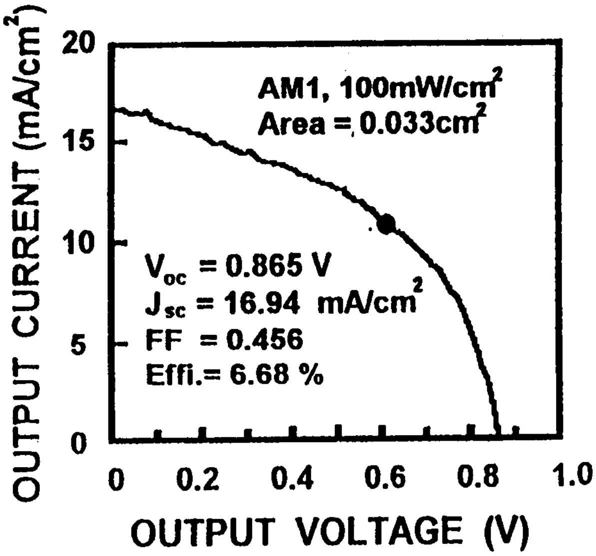

Figure 5 Example of output characteristic of a-SiC:H/a-Si :H heterojunction solar cell.

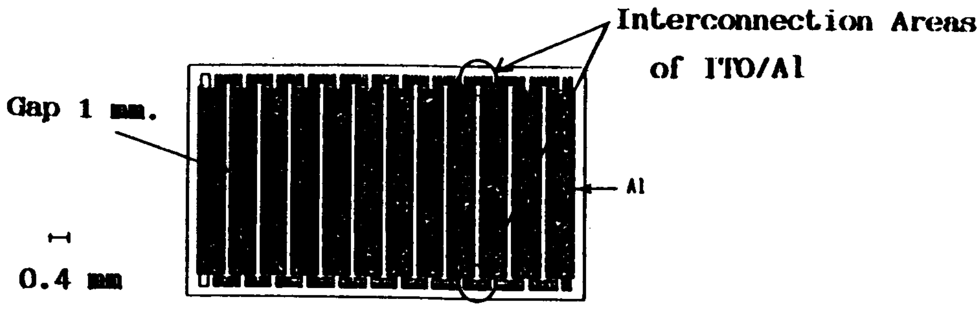

Figure 6 Structure of integrated type a-Si:H solar cell.

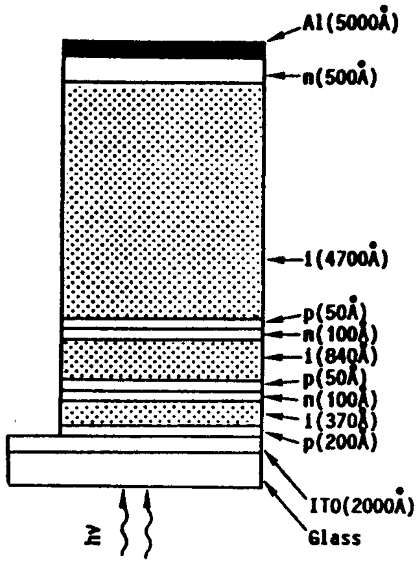

Figure 7 Structure of tandem a-Si:H solar cell.

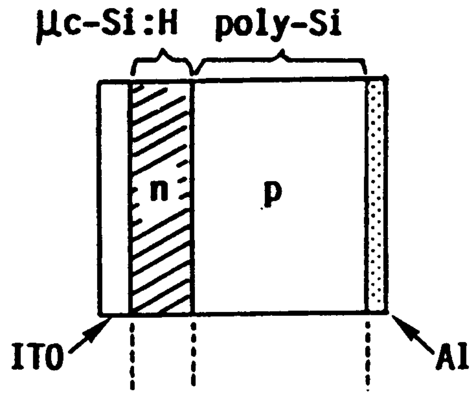

Figure 8 Structure of stacked microcrystalline Si:H/poly Si solar cell.

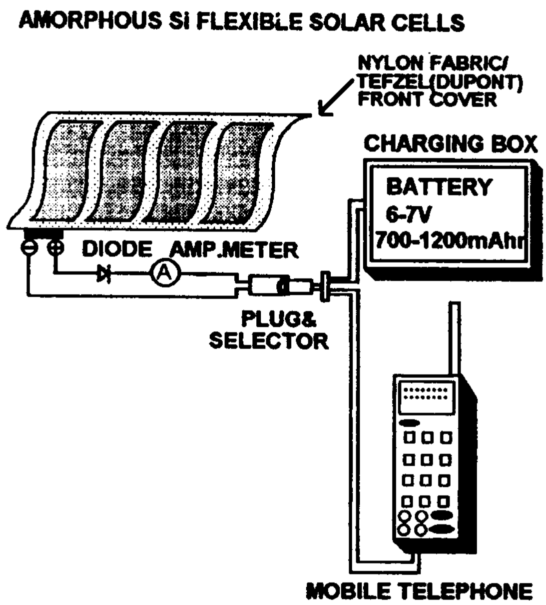

Figure 9 Basic configuration of the battery charger having a-Si:H solar cells.