

# Effect of ZnO:Al thickness on open circuit voltage of organic/ $\alpha$ -Si:H hybrid solar cells

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Hybrid solar cells are based on the concept of using both organic and inorganic materials to produce the devices. Hybrid solar cells based on a heterojunction between an inorganic electron acceptor layer and an organic donor layer have been produced. The effect of the electron transport layer on the open circuit voltage ( $V_{oc}$ ) of hybrid solar cells was investigated. Hybrid solar cells were fabricated using amorphous silicon as the main absorbing layer and electron-accepting layer, and copper phthalocyanine (CuPc) as the donor material. An Al-doped ZnO layer was used as a buffer layer between ITO and  $\alpha$ -Si:H to prevent ITO reaction with silane gas during plasma enhanced chemical deposition (PECVD). The ZnO:Al thin film also acts as an electron transport layer. The open circuit voltage of the hybrid solar cells was investigated by varying the thickness of the ZnO:Al layer.  $V_{oc}$  was increased from 0.30 volts to 0.52 volts by increasing the ZnO:Al layer thickness from 15 nm to 5 nm. The poor interface between the inorganic ( $\alpha$ -Si:H) and organic layers may be a possible reason for the low fill factor and low photocurrent of hybrid solar cells.

## 1. Introduction

In recent years solar energy has become the most plausible renewable energy technology to solve the demand of fuel based energy [1]. Because of cost and use of toxic polluting materials in inorganic solar cells, huge research has been focused on organic solar cells. As a renewable energy source, organic solar cells have been proved better than inorganic solar cells in terms of being cheap in production and environment friendly, low weight, flexibility, and simple fabrication process [2]. Amorphous silicon based solar cells process requires toxic gases for doping the p- and n-type layers. But the absorption coefficient of  $\alpha$ -Si:H films is higher than other semiconducting materials [3]. Organic solar cells have stability problem because of degradation of organic layer. There is a possible way to increase the absorption coefficient and stability of organic solar using amorphous silicon thin

film as absorbing layer. The high carrier mobility of the  $\alpha$ -Si:H is another factor which should improve the device efficiency. Amorphous silicon thin films absorb more light for wavelength range 300–500 nm. In polymer solar cells P3HT is used as absorbing layer while in small molecules based solar cells CuPc is used as absorbing layer. P3HT has same maxima of absorption range as  $\alpha$ -Si:H but lower absorption coefficient. CuPc films have a very high optical absorption coefficient in wavelength range 600–700 nm. So, combination of CuPc with  $\alpha$ -Si:H as active layer can be used in solar cells device structure. Sailor et al. [4] have used poly-(CH<sub>3</sub>)<sub>3</sub>Si-cyclooctatetracene as polymer and crystalline silicon to fabricate the hybrid solar cells. Photovoltaic properties of hybrid solar cells using amorphous silicon and polymer (P3HT, MEH-PPV) were investigated by Gowrishankar et al. [5]. It was reported that polymer plays main role in photo conversion in devices and  $\alpha$ -Si/P3HT showed higher

efficiency than a-Si/MEH-PPV devices. Hybrid solar cells using P3HT as organic electron donor layer and silicon as inorganic electron acceptor layer have been reported by Alet et al. [6]. They have investigated the photovoltaic properties of hybrid solar using both a-Si and  $\mu$ c-Si and P3HT as organic electron donor. It was concluded that the lower efficiency in hybrid solar cells was due to higher recombination at organic-inorganic interface. In another work, a-Si layer was replaced by crystalline silicon and improvement in photocurrent was observed [7].

In organic photovoltaic cells, n-type buffer layer is used to enhance electron transport towards cathode. ZnO:Al film as n-type buffer layer has been used in organic solar cells because of its high transparency and relatively high electron mobility [8–10].

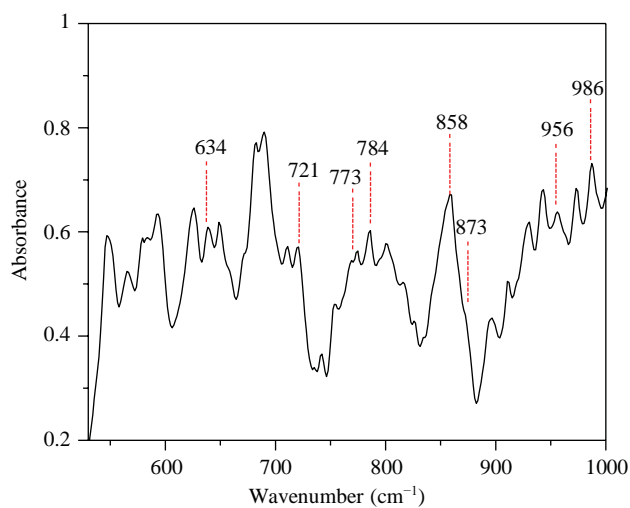
Here we report the design of hybrid organic/a-Si:H solar cells. ZnO:Al thin film as electron transport layer is used to modify the polarity of ITO. Thickness of electron transport layer (ZnO:Al) was optimized to increase the open circuit voltage.

## 2. Experimental Details

Hybrid solar cells have been fabricated on ITO coated glass substrates. In hybrid device structure first Al doped ZnO thin film is deposited using pulsed DC sputtering unit using 2% Al doped ZnO target. ZnO:Al films have been deposited using argon (Ar) as processing gas at deposition pressure of 0.05 mbar. Al films with varying deposition time are deposited at 200 watt power, 100 KHz frequency, 70% duty cycle, and 15 sccm Ar flow rate. After deposition of ZnO:Al film, amorphous silicon film is deposited using a RF-PECVD system (OXFORD, Plasma Lab System 100) operating at frequency 13.56 MHz. Process pressure, substrate temperature, and RF power have been kept at 1000 mT, 250°C, and 10 watt, respectively. Silane ( $\text{SiH}_4$ ) gas in Ar dilution has been used as process gas. Then CuPc (Sigma Aldrich) is thermally deposited on a-Si:H coated ZnO:Al/ITO/glass structure. In the same run without breaking the vacuum, 100 nm thick Al film is thermally deposited on CuPc film. The device structure of hybrid solar cell is shown in Figure 3.

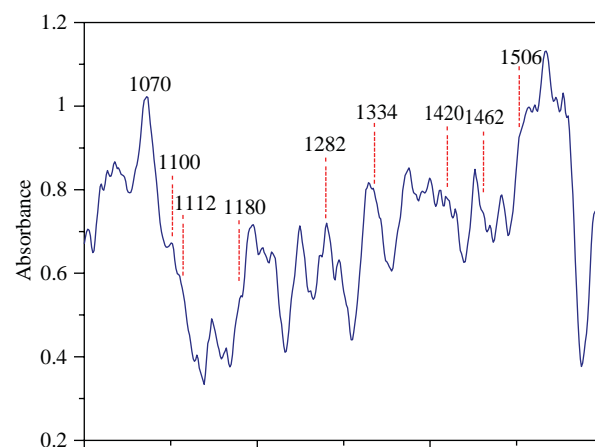
A current-density ( $\text{mA}/\text{cm}^2$ ) characteristic of the devices is measured using Keithley 2400 and solar simulator AM1.5 (Newport) with intensity of 1 sun. For measuring the absorption spectra of semiconducting layers used in hybrid solar cells, CuPc and  $\text{C}_{60}$  are thermally deposited on glass substrate. UV-Visible transmittance and absorption spectra of films have been measured using spectrometer (Perkin-Elmer UV/VIS Lambda 750) in wavelength range of 300–900 nm. FT-IR spectra of CuPc thin film have been taken in the wavenumber range 400 to 4000  $\text{cm}^{-1}$  in Transmission mode using Bruker Alpha-T System.

## 3. Results and Discussion



— FTIR spectra CuPc thin film

(a)



Infrared spectroscopy is used to study the bond nature of the CuPc thin films deposited on a-Si:H film. The chemical bonds in CuPc are detected by measuring the radiation absorption

FTIR spectra CuPc thin film

(  
b  
)

Figure 1: FTIR spectra of CuPc thin film deposited on a-Si:H film showing peaks for phases.

bands in the near infrared range. FTIR spectroscopy has been used to determine the nature of C-H, C-C, and C-N bonding in the film. The FTIR spectra of CuPc film are shown in Figures 1(a) and 1(b). Various band positions

around 700–800 cm<sup>-1</sup> range in IR spectra are used to study the phases of CuPc thin films. Standard peak of CuPc film at around 722 cm<sup>-1</sup> is absent which shows that molecules are parallel with the a-Si:H surface on which CuPc is deposited. A small peak at 715 cm<sup>-1</sup> is attributed to  $\alpha$ -phase of CuPc. This peak originates from C-H wagging motion. A small band at 782 cm<sup>-1</sup> suggests the presence of  $\beta$ -phase. This peak is attributed to C-H out-of-plane deformation. Medium

peak from 950 to 1120 cm<sup>-1</sup> is a signature of  $\beta$ -phase which corresponds to C-H in plane bending. Presence of  $\alpha$ -phase

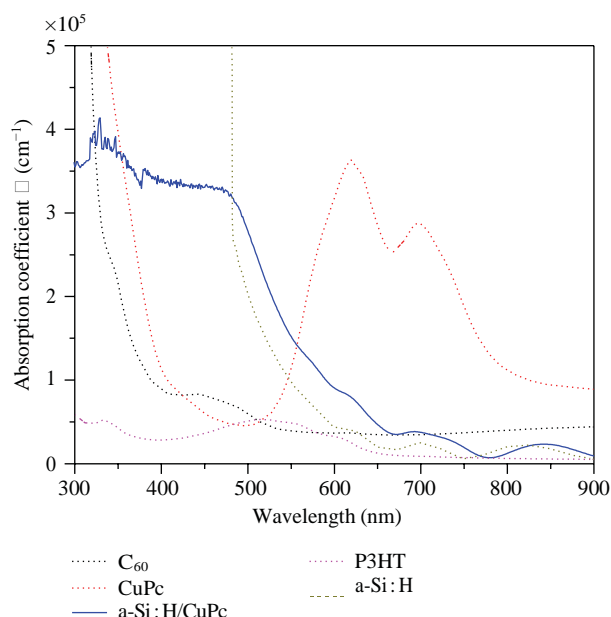


Figure 2: Optical absorbance spectra of various layers ( $C_{60}$ , CuPc, spin coated P3HT, PECVD deposited a-Si:H, and a-Si:H/CuPc double layer structure) incorporated in hybrid solar cell.

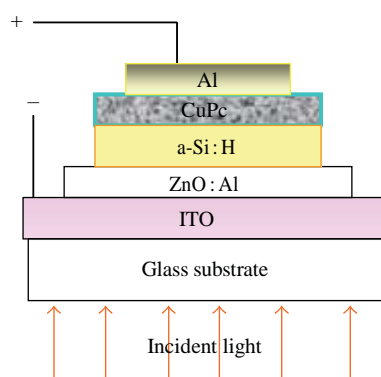
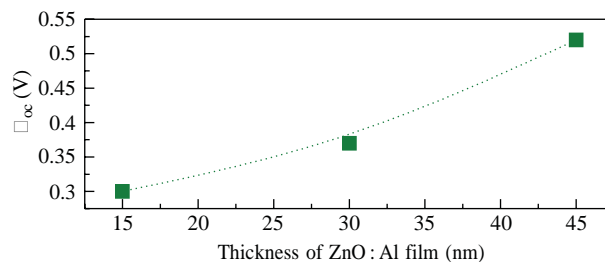


Figure 3: Schematic of the device structure of hybrid solar cell.

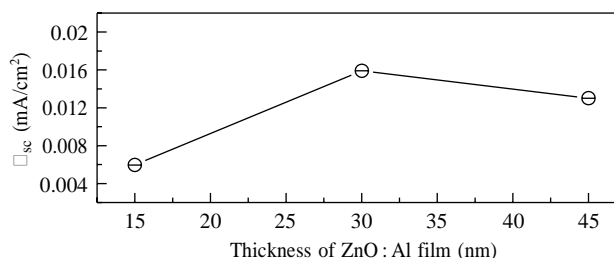
related peaks in IR Spectra of CuPc indicates the stability of CuPc films on a-Si:H surface [11].

Peak at  $1334\text{ cm}^{-1}$  and  $1420\text{ cm}^{-1}$  corresponds to C–C stretching in isoindole. Peak at  $1510\text{ cm}^{-1}$  corresponds to C=N stretching mode. From absorption spectra of a-Si:H and CuPc as shown in Figure 2, it is clear that both have maximum absorption in different range. From 300 to 500 nm wavelength range a-Si:H has high absorption, while from 600 to 800 nm CuPc has high absorption. P3HT film shows lower absorbance as compared to CuPc thin films.

The first set of organic/a-Si:H based solar cells are fabricated on glass substrates with device structure (ITO/ZnO:Al/a-Si:H/CuPc/Al). In these devices the ZnO:Al acts as electron transport layer (ETL).



■  $\square_{oc}$ , device: ITO/ZnO:Al/a-Si:H/CuPc/Al  
(a)



○  $\square_{sc}$ , device: ITO/ZnO:Al/a-Si:H/CuPc/Al  
(b)

Figure 4: Open circuit voltage ( $\square_{oc}$ ) and short circuit current density ( $\square_{sc}$ ) of the devices at different ZnO:Al film thicknesses.

thickness of ETL. It can be observed that  $\square_{oc}$  increased from 0.30 volt to 0.52 volt with increasing the thickness of ETL from 15 nm to 45 nm but current density is decreased for cells having 45 nm ETL. Hybrid solar cells having ETL 30 nm have showed higher photo current. Here ZnO:Al works as electron transport layer and it also blocks the hole transport to ITO, and thus photocurrent increased. ETL with thickness 45 nm causes series resistance at interface and thus lower photocurrent was observed.

The possible reason for lower photocurrent in hybrid solar cells, as compare to organic solar cell, may be due to poor interface between organic and inorganic layer.

#### 4. Conclusions

A systematic analysis for optimizing the ZnO:Al as electron transport layer for higher open circuit voltage in hybrid solar cells application is demonstrated. An improvement in

photocurrent is observed for hybrid solar cells having 30 nm thick ZnO:Al. The open circuit voltage increased from 0.3 to 0.52 after application of 30 nm ZnO:Al as electron transport layer.

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