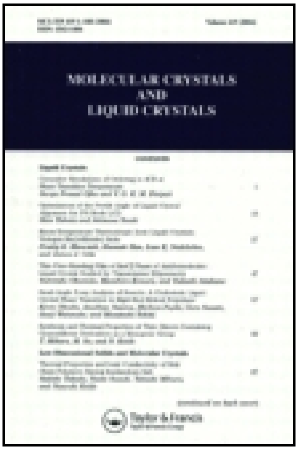

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Analysis on the Photocurrent in a-Si:H Thin Film Transistor in terms of Spectral Characteristics of CCFL Backlight

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For an analysis on the relationship between the photoelectric properties of a hydrogenated amorphous silicon (a-Si:H) thin film transistor (TFT) and the spectral characteristics of cold cathode fluorescent lamp (CCFL) backlight, a few spectrum filters were used in the electrical measurement of the photocurrents in a-Si:H TFT and the results were investigated and analyzed. When the backlights were transmitted through the various white spectrum filers and illuminated to the a-Si:H layers of TFT, the obtained photocurrents showed that the off state currents are related to the transmittance at the lower wavelength because the absorption coefficient of a-Si:H layer is reversely proportional to the wavelength of incident light and almost all the absorptions of light are carried out at lower wavelength than about 500∼600 nm.

Keywords: absorption coefficient; amorphous silicon thin film transistor (a-Si TFT); cold cathode fluorescent lamp (CCFL); spectrum filter; transmittance

INTRODUCTION

In the structure of thin film transistor liquid crystal display (TFT-LCD), a-Si:H TFT has been mostly used as a active matrix device to drive data signals from the external driving circuit and data electrode to each pixel of the display panel. Since TFT-LCD panels were applied to TV system, it has been expected to obtain the high

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luminous backlight system because of the demand of high contrast and brightness. However, a-Si:H TFT has a high photo conductivity and leads a high photo leakage current as a result of the high luminous illumination from backlight [1]. The photo leakage current may degrade some parameters such as contrast ratio and causes the leakage power of the whole TFT-LCD panel system. In particular, the recent TFT-LCD panels have relatively larger photo leakage currents because active photo mask and source-drain photo mask are merged into one photo mask step by using a slit mask for the reduction of the fabrication cost. Therefore, a-Si:H layer is inevitably directly exposed to the illumination from backlight of TFT-LCD as a result of the isotropic wet etch of source-drain electrode in the reduced mask process (4 mask process) [2,3]. It is necessary to reduce the photo leakage current of a-Si:H TFT for the improvement in the driving of the TFT-LCD panel.

There have been a lot of reports about the improvements on the process to reduce the photo leakage current of a-Si:H TFT [4–7]. However, the photocurrent of a-Si:H TFT has not been much fundamentally investigated in terms of spectral characteristics of backlight sources. Because the industry of backlight is continuously increased with the expansion of TFT-LCD market and new advanced light sources such as light emitting diode (LED) are used as backlight systems [8], it is important to investigate the effect of the illuminated light on the photoelectric properties of a-Si:H TFT.

In this article, a spectrum filter was used in the measurement of photocurrent in a-Si:H TFT when a-Si:H layer was directly exposed to the backside illumination from a CCFL backlight. When a backside illuminated light goes through the spectrum filter, the transmittance of the light is controlled in a specific range of wavelength. Therefore, it is possible to investigate the effect of the specific wavelength of illuminated light on the photocurrent of a-Si:H TFT from a comparison of various spectrum filters. From the photocurrents and the optical properties of spectrum filters, the mechanism of photocurrent of a-Si:H TFT will be analyzed.

EXPERIMENTAL

To obtain the same effect as the investigation of the photocurrent in a-Si:TFT fabricated with a 4 mask process, an a-Si:H TFT with an exposed active pattern was fabricated on glass substrate by using a conventional fabrication process (5 mask process) [9,10]. The fabricated TFT has a structure of a conventional back channel etched (BCE) inverted staggered type.

As a gate electrode and a source-drain electrode, Cr was sputtered with a thickness of 200 nm and was patterned. Silicon nitride (SiN_x), a-Si:H and phosphorus doped hydrogenated amorphous silicon (n^+ a-Si:H) layers were sequentially deposited with the thicknesses of 350 nm, 200 nm, and 30 nm, respectively. After a-Si:H and n^+ a-Si:H layers were dry etched by using reactive ion etch (RIE) in condition of SF_6 gas, the active patterns were protruded outside gate pattern to be directly exposed to the illumination from the backside of glass as shown in Figure 1. The designed area of the exposed active area was $2 \times 30\,\mu m \times 10\,\mu m$. The width and the length of TFT were designed and patterned as $20\,\mu m$ and $4\,\mu m$, respectively. The n^+ a-Si:H layer in the TFT channel and the SiN_x layer on the gate contact pad were etched at the same process condition as the active etch and only the etch times were adjusted.

Figure 2(a) shows the structure of CCFL backlight. When a high voltage is applied to CCFL, Hg atoms are ionized in CCFL located at the edge of the whole backlight system and an infrared light is radiated. The radiated light is emitted through the fluorescent materials covered inside the CCFL and is uniformly distributed to the whole area of backlight system by the reflection on the reflect sheet and the distribution on the Light Guide Plate (LGP). As the distributed light passes through the diffuser sheet and the prism sheets, the luminance of the light is uniformly obtained in a wide viewing angle and the

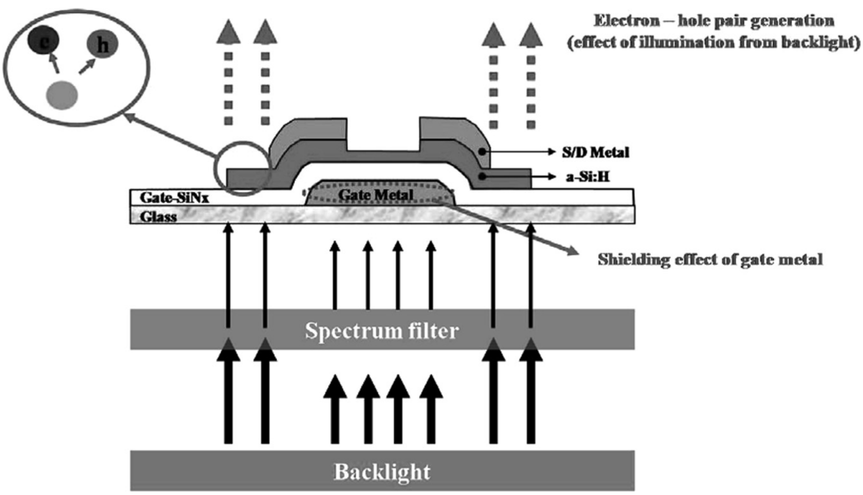
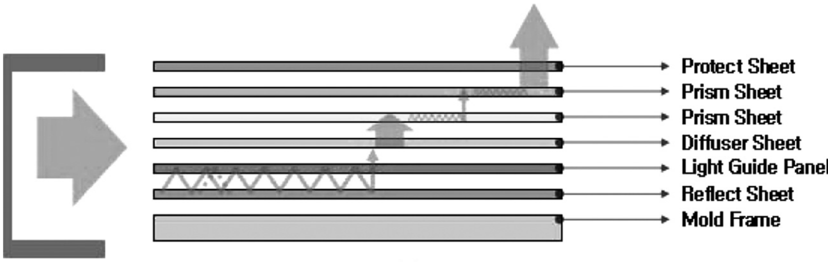
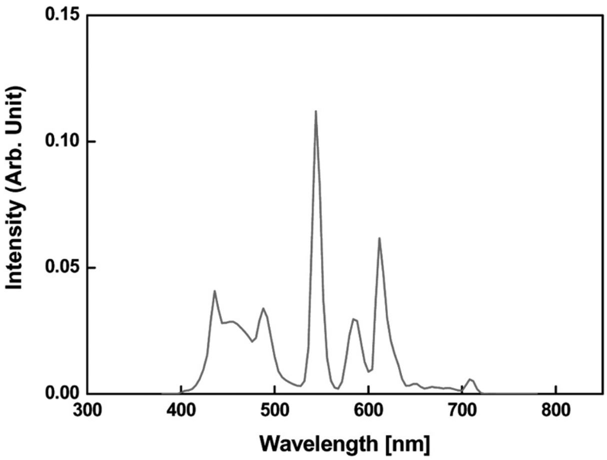


FIGURE 1 A configuration of the generation of electron-hole pairs in a-Si:H layer caused by transmitted backside illumination through the spectrum filter.



(a)



(b)

FIGURE 2 (a) Schematic diagram of CCFL backlight and the distributed route of light. (b) Spectral characteristics of CCFL backlight.

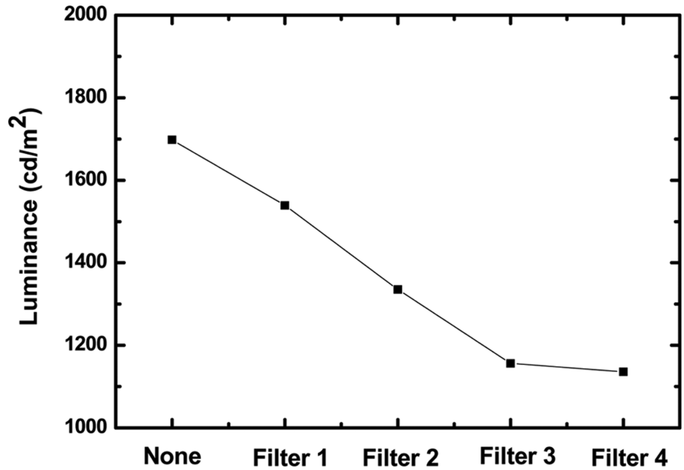
luminance of the front side view is improved. The protect sheet is used to protect the prism sheets and other optical sheets in the backlight system.

Figure 2(b) shows the spectral characteristics of the CCFL backlight of Figure 2(a). Photo Research 670 Spectrascan Colorimeter was used in the measurement and the three apparent peaks were investigated at 436 nm (blue), 544 nm (green), and red (612 nm). Two small peaks were also investigated at about 490 nm and 580 nm. Transfer characteristics of the fabricated T FT were obtained by using Agilent 4156C and four different white spectrum filters were inserted between backlight system and TFT glass substrate during the measurement as shown in Figure 1.

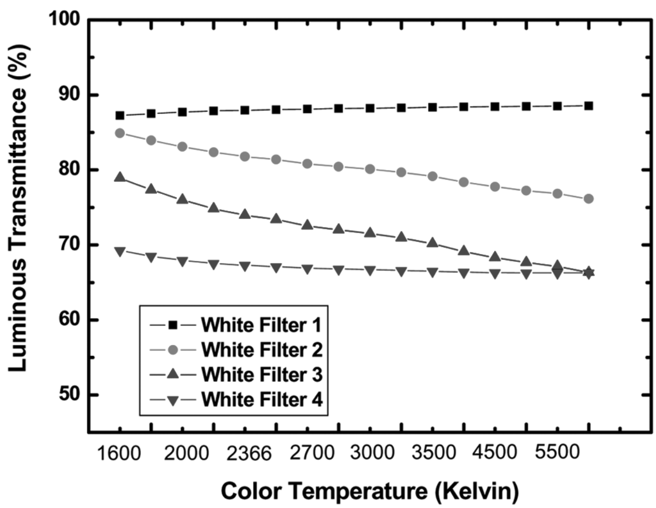
RESULTS AND DISCUSSION

Without the illumination from the CCFL backlight, the fabricated TFT exhibited a threshold voltage of 5 V and an on/off current ratio of 4.14×10^5 when the on-current and off-current were defined as the currents at the gate voltage of 20 V and −8 V, respectively. The CCFL backlight was operated by an inverter system and showed the luminance values of 1698 cd/m^2 measured by MINOLTA CS-100A. Figure 3(a) shows the luminance values of the transmitted lights through the white filters used in the experiment from CCFL backlight. For the white filter 1, 2, 3, and 4, the luminance value of the light was 1539, 1335, 1156, and 1136 cd/m^2, respectively. From Figure 3(b), it is possible to conclude that the differences in transmittance of the filters cause the difference in luminance values. The color temperature of the CCFL backlight was measured about 6000 K and the luminous transmittance of the white filters was 88.53, 76.16, 66.35, 66.26% at 6000 K for white filter 1, 2, 3, and 4, respectively. The ratios of the luminance of the transmitted light through the filters to that of the CCFL backlight are 90.6, 78.6, 68.0, and 66.9 for white filter 1, 2, 3, and 4, respectively. The ratios were almost equivalent to the transmittances of the filters.

Figure 4 shows the transfer characteristics when the TFT is illuminated through the white filters from the CCFL backlight. The photocurrents were higher than dark current by about a factor of 10^1 or more. For the illumination without any white filter, the photocurrent was higher than any other photocurrent through a white filter. In case of white filter 1, the photocurrent was also higher than the other photocurrents through the other white filters. However, although the filter 2, 3, and 4 have the different transmittance and show the different luminance values, the measured results showed almost the same photocurrents. For the more elaborate analysis of the results, the off currents were defined at the gate voltages of − 9 V, −8 V, and −7 V and they were compared about different white filters as shown in Figure 5. For the illumination without any filter, the off currents were 1.38×10^{-11}, 1.5×10^{-11}, and 1.49×10^{-11} A for −9, −8, and −7 V, respectively. With the white filter 1, the off currents were 9.64×10^{-12}, 1.03×10^{-11}, and 1.09×10^{-11} A and they were a little smaller than those of the illumination without filtering. For the white filter 3 and 4, the off currents were distributed between 7.92×10^{-12} and 8.79×10^{-12} A and they were a little larger than those in case of white filter 2. Considering the luminance values of the transmitted lights of Figure 3(a), it is not easy to describe the photocurrents of Figures 4 and 5 in the off state gate voltage. It is necessary to explain



(a)



(b)

FIGURE 3 (a) The luminance of the backlight when the white spectrum filters were used in the experiments. (b) The luminous transmittances of the white filters of (a).

the reason of the same photocurrents and the mechanism of the light-induced photoelectric properties in the a-Si:H TFT.

Figure 6 shows the spectral characteristics of the transmitted lights through the filters used in the Figures 4 and 5. For the transmitted

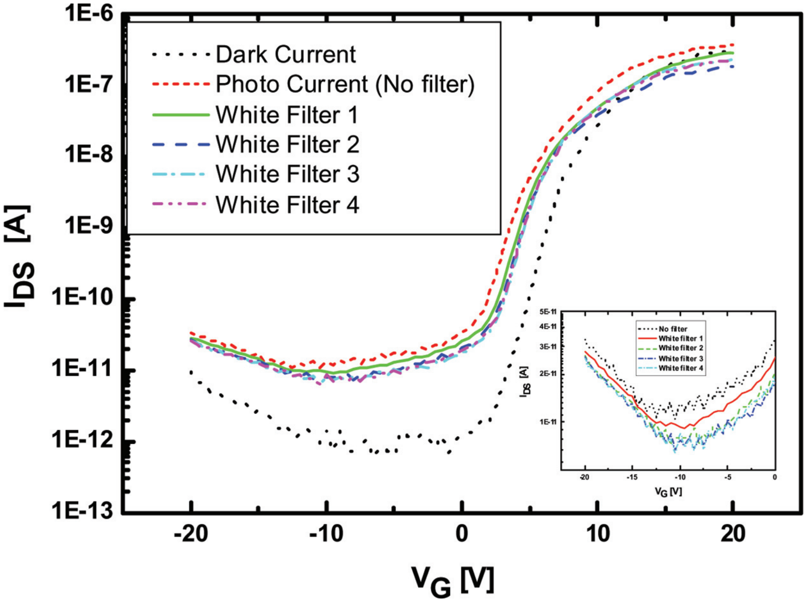


FIGURE 4 The transfer characteristics of a-Si:H TFT under backside illuminations through the white spectrum filters of Figure 3(a). The width and the length of TFT are 20 μm and 4 μm, respectively. The area of the a-Si:H layer which is exposed to the backside illumination was $2 \times 30\,\mu m \times 10\,\mu m$.

light through the white filter 1, the spectral properties have almost the same intensity peaks as those of the backlight without any filtering. Only the intensity peaks had a little smaller magnitude than those of the backlight without any filtering. However, in case of white filter 2, the spectral properties of transmitted light had much lower values of intensities than those of other cases at the wavelength of about 400∼500 nm. The intensity peak at 436 nm was degraded and the small intensity peak at 488 nm was also much smaller than those of other cases. It is possible to conclude that the transmittance of the backlight through the white filter 2 was restricted in a range of the wavelength of blue color. In case of white filter 3, the intensity peak of the transmitted light was relatively apparent at 436 nm. But, the intensity showed a smaller values at the wavelength about 450∼500 nm than those of any other cases. The intensity of the transmitted light through the white filter 4 had a lower peak than those of the other cases about 600∼650 nm of red color. However, the intensity peak at the 436 nm was higher than those of any other white filters.

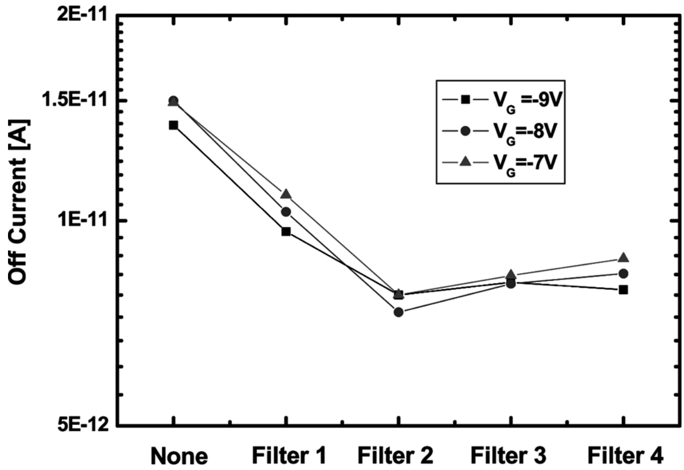


FIGURE 5 The off currents at the gate voltage of −9 V, −8 V, and −7 V of Figure 4 in case of transmitted illuminations through white spectrum filters of Figure 3(a).

Figure 7 shows the intensities peaks of blue color at 436 nm for all the cases of Figure 6. It is apparent that the white filter 2 has the lowest intensity peak than any other case at 436 nm.

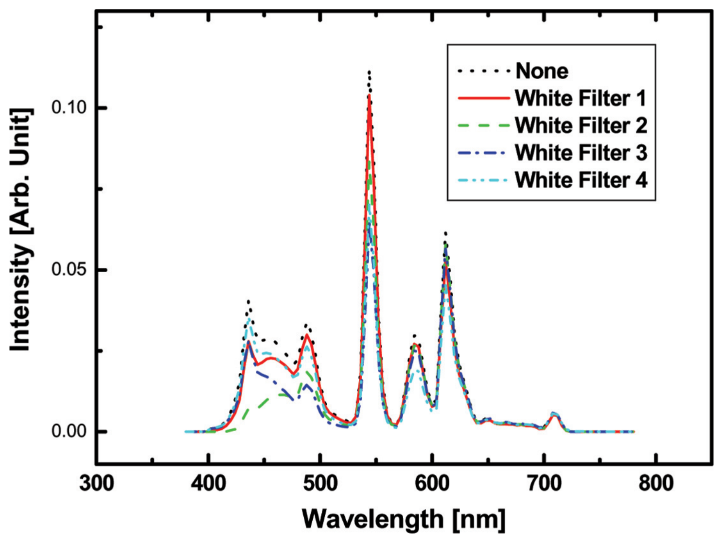


FIGURE 6 The spectral characteristics of the transmitted lights through the white spectrum filters of Figure 3(a).

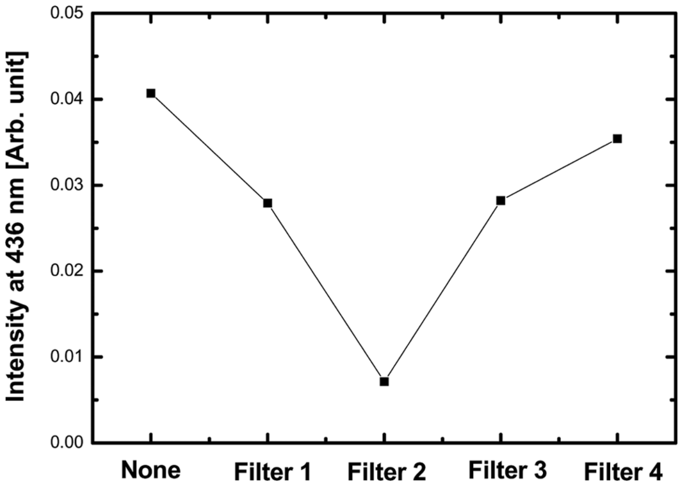


FIGURE 7 The intensities at the 436 nm for the spectral characteristics of Figure 6.

From the photocurrents and the spectral characteristics for the transmitted lights, the generation of photocurrent in the a-Si:H layer of TFT is related to the spectral characteristics of light. When a semiconductor or a amorphous solid layer is illuminated, the photon energy is reversely proportional to the wavelength of the illuminated light. The illuminated light, photons are absorbed to a-Si:H layer and electron-holes pairs are generated. The absorption coefficient of a-Si:H is dominant (more than $10^5\,cm^{-1}$) at the wavelength of about 400∼500 nm. The absorption drops off abruptly from about 550 nm [11]. At the wavelengths of intensity peaks, more electron-holes are expected to be generated and to consist of the carriers of currents. Therefore, the number of the generated electrons and holes are related to the spectrum region of blue color (400∼500 nm) and the effect of the photo generation is thought to be restricted for the case of white filter 2. Considering the difference in the luminance values of the filters and the difference in the spectral properties of the transmitted lights, it is possible to obtain the reason of the similar photocurrents. The results are expected to be helpful to the research for the reduction of the photo leakage current of TFT and the relationship between the optical characteristics of the backlight system in the TFT-LCD module and the photo leakage current of TFT is expected to be continually discussed for the visual improvement of the TFT-LCD in terms of backlight systems and color filers.

CONCLUSIONS

The photocurrents of a-Si:H TFT were investigated by using spectrum filters with various filtering wavelengths and the relationships between the photocurrents and spectral properties of CCFL backlight were analyzed. For a spectrum filter, the backside illuminated light could be controlled for the selected range of wavelength. In spite of the higher luminance of the transmitted light, it was possible to obtain lower or similar photo leakage current and it was concluded that the photocurrent is related to the intensities at the lower wavelength of the transmitted light. The intensity peaks at the wavelength of about 400∼500 nm (blue color) are thought to bring about mainly the absorption of light in a-Si:H layer of TFT and the generation of electron-hole pairs. The results are expected to be applied to the adjustment of color characteristics of backlight and the driving method of TFT-LCD panel.

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