Chapter 8

Development of Amorphous Photocoupler Consisting of Amorphous TFLED as a Light Emitting Device

8.1 Introduction

A photocoupler (optocoupler) is a functional optoelectronic device which consists of a light emitting device and a light detecting device in a single sealed package to provide optical signal transmission. Electrical isolation is provided between input and output, and induction from external electro-magnetic fields is eliminated between circuits of different impedance levels. As interface elements for signal transmission, photocouplers are widely used in office and factory automation equipment, as well as in all kinds of household appliances. Examples of the applications are interfaces between logic circuits, position & size detection of moving objects, tape end detection, I/O interfaces for computers, etc. [1]. Table 8.1 shows some examples of the applications of photocoupler.

The conventional photocouplers have been made of crystalline semiconductors, such as GaAs, InP, Si, CdS, etc. so far. The disadvantages of these crystalline photocouplers are that they are made of expensive materials, small devices, hybrid devices, needs of different manufacturing technologies, such as Liquid Phase Epitaxy (LPE) for GaAs and Czochralski (CZ) for Si, etc.

Meanwhile, it has been described in chapters 2-7 that visible-light a-SiC:H, a-SiN:H, a-SiO:H thin film LEDs (TFLEDs) have been developed [2-8]. Eventhough various efforts have been made to improve the brightness of TFLEDs, the brightness is still low (<10 cd/m^2, efficiency = 10^{-3} %). The author has an idea that the amorphous TFLED may have a possibility to be used as a light source in a photocoupler.

The purpose of the work in this chapter is to explore and check the possibility of utilization of amorphous silicon alloy TFLEDs in photocouplers. In the preliminary experiments, amorphous silicon carbide (a-SiC:H) thin film light emitting diode (TFLED) and amorphous silicon (a-Si:H) thin film solar cell (thin film photodetector : TFPD) have been used as the light emitting device and the light detecting device, respectively, in the photocouplers. Since both the light emitting device and the light detecting device were made of amorphous devices, we named the "amorphous photocoupler". The amorphuos photocoupler has several advantages as compared with the conventional crystalline photocouplers, e.g. low cost, large area, ease of fabrication as line and/or matrix arrays, etc.. It is shown that the amorphous photocoupler can be produced both in a photointerrupter type and in a photoisolator type. One example of the unique structure of the photoisolar type is TFLED/glass/TFPD, where the TFLED and the TFPD are deposited on the dual surfaces of a common glass substrate. The amorphous photocoupler can be operated at the modulation frequency as high as about 500 kHz.

Table 8.1 Examples of Applications of Photocoupler

Interface between circuits with different voltages
Video signal transmission
High speed optical switch
Controlling speed of motor
Relay
Detection of telephone signal
Detection of rotation speed (video, laser disc, etc)
Detection of rotation direction of material
Encorder
Detection of position in mouse
Measurement of size of materials
Optical communication system
Counting number of materials
Electrography copy machine

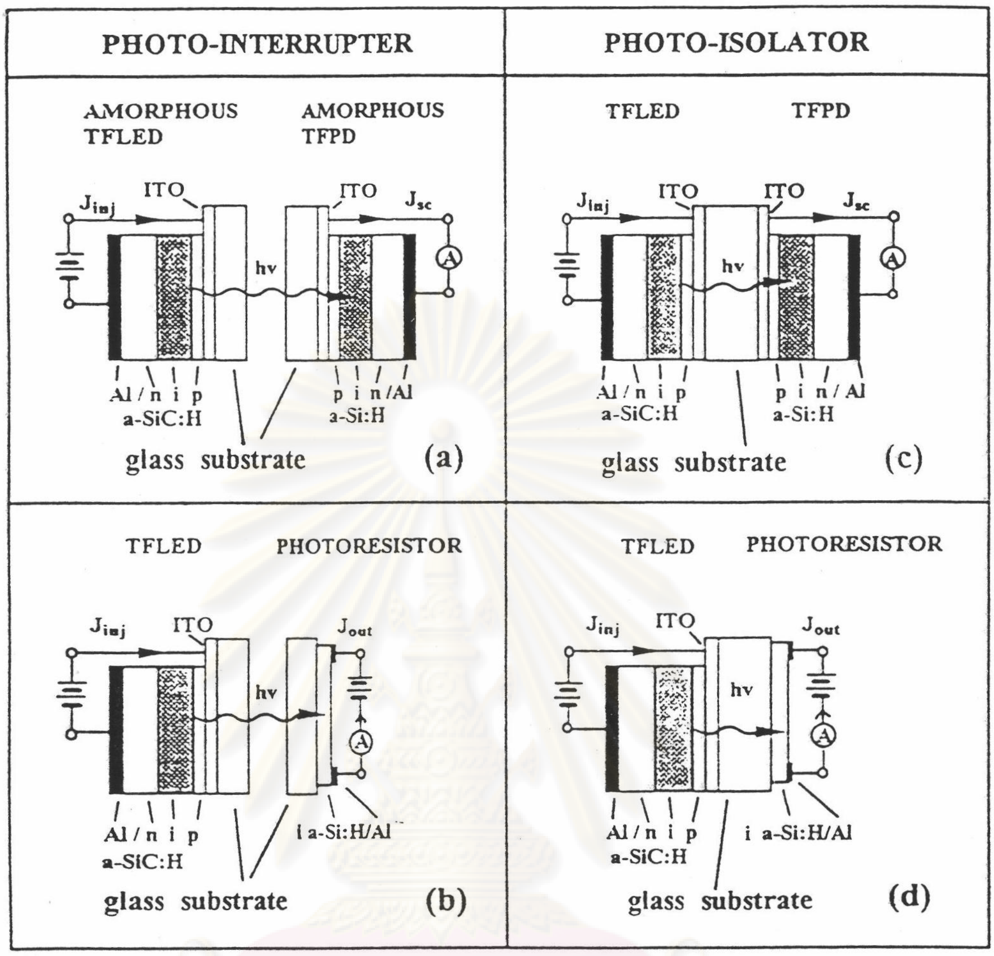

Figure 8.1 Structures of novel amorphous silicon alloy photocouplers,
(a) photo-interrupter type having a-Si:H photodiode as a detector,
(b) photo-interrupter type having an a-Si:H photoresistor as a detector,
(c) photo-isolator type having a-Si:H photodiode as a detector and
(d) photo-isolator type having an a-Si:H photoresistor as a detector.

8.2 Development of Amorphous Photocouplers Consisting of Amorphous TFLED as a Light Emitting Device

Possibilities of simple configurations of amorphous photocouplers considered in the work are illustrated as in Fig. 8.1 (a)-(d). The selection for utilization from these types might be based upon the purpose of work as can be pointed as follows:

Type (a) can work as a photointerrupter. It comprises an amorphous TFLED and a-Si:H solar cell (photodiode). The output response time is better than types (c) and (d). But the magnitude of output signal is low due to internal quantum efficiency of the solar cell [9].

Type (b) can work as a photoisolator. The unique point of this type is to use dual surfaces of a common glass substrate. Therefore, one can get rid of a hybrid process and may reduce cost.

Type (c) is also a photointerrupter. A photoresistor consisting of undoped a-Si:H with a couple of coplanar electrode arrangement is used as a light detecting device. The advantage of the photoresistor is that it is capable of high gain and therefore high signal strengths, because of the secondary photocurrent resulting from their ohmic contacts. But the output response time is worse than type (a) [10-11].

Type (d) is a photoresisting type photoisolator. The TFLED and photoresistor are deposited on dual surfaces of a common glass substrate, similarly to type (b).

Some examples of encapsulation of these devices are schematically illustrated in Fig. 8.2.

8.3 Preparation and Device Properties of Amorphous Photocouplers

The a-SiC:H TFLED and the a-Si:H solar cell (thin film photodiode : TFPD) were fabricated by a glow discharge plasma CVD method. The details of preparation conditions have been reported in chapters 2-7 [7,12-13]. Typical device parameters are summarized in Table 8.2. The typical structure of a-SiC:H TFLED is the p-i-n junctions of a-SiC:H in which the optical energy gaps are 2.0, 3.0 and 2.0 eV, respectively. The color of light output is yellowish-orange. The TFPD has a-SiC:H/a-Si:H p-i-n heterojunction as the same used in general a-Si:H solar cells

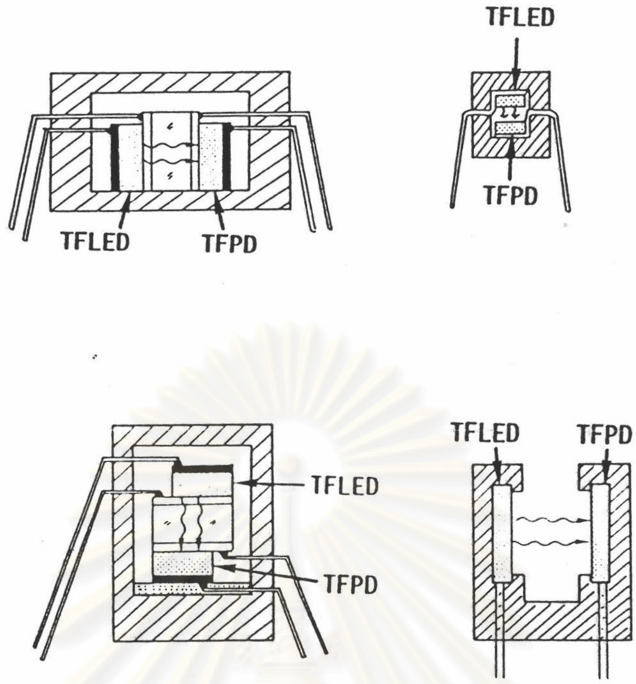

Figure 8.2 Examples of encapsulations of amorphous photocouplers.

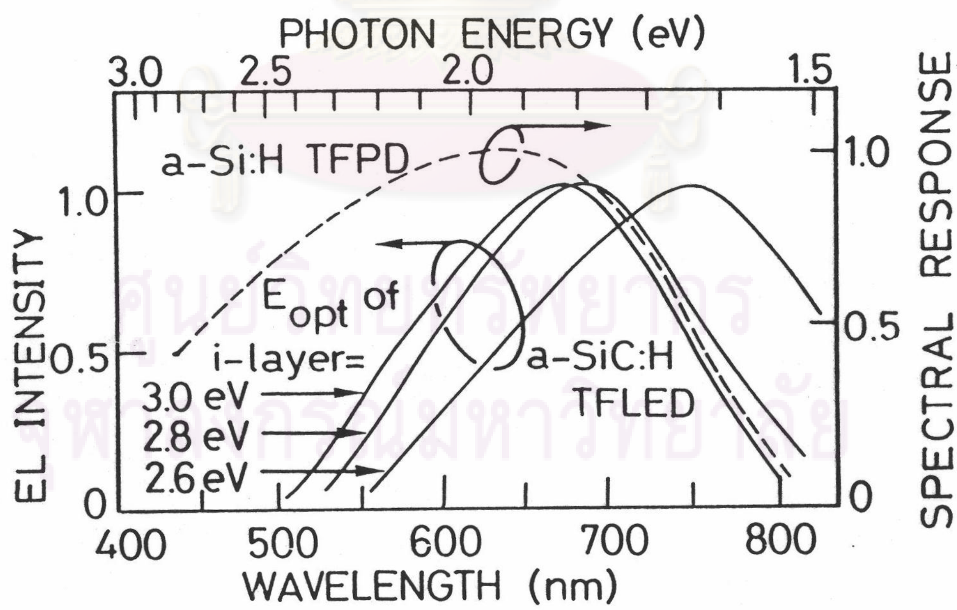

Figure 8.3 Comparison of a spectral response of an a-Si:H solar cell and emitting spectra of three a-SiC:H TFLEDs in which the optical energy gaps of the i-a-SiC:H layers are 2.6, 2.8 and 3.0 eV, respectively.

[14]. The average conversion efficiency measured under AM1 (100 mA/cm^2) of the a-Si:H solar cell fabricated in the work was about 6 %. The areas of TFLED & solar cell were 15 mm^2.

Table 8.2 Device parameters in amorphous TFLED and amorphous photodiode (TFPD) for the amorphous photocoupler.

	TFLED		TFPD	
p	a-SiC:H	E_{opt} = 2.0 eV d = 150 Å σ_D = 10^{-7} S/cm	a-SiC:H	E_{opt} = 2.0 eV d = 150 Å σ_D = 10^{-7} S/cm
i	a-SiC:H	E_{opt} = 3.0 eV d = 500 Å	a-Si:H	E_{opt} = 1.8 eV d = 5000 Å
n	a-SiC:H	E_{opt} = 2.0 eV d = 500 Å σ_D = 10^{-7} S/cm	μC-Si:H	E_{opt} = 2.0 eV d = 500 Å σ_D = 10^{-1} S/cm
		Efficiency = 10^{-3} %	Efficiency = 6 %	

8.3.1 Selection of a-SiC:H TFLEDs

One important principle in a photocoupler is that the light emitted from the light source must be efficiently absorbed by the light detecting device. The spectral response of a-Si:H solar cell (including a-Si:H photoresistor) generally lies in a visible region peaking near 600 - 800 nm. Figure 8.3 shows the comparison of a spectral response of an a-Si:H solar cell and emitting spectra of three a-SiC:H TFLEDs in which the optical energy gaps of the i-a-SiC:H layers are 2.6, 2.8 and 3.0 eV, respectively. It was found that the optimal optical energy gap of the i-layer in the TFLED was about 2.8 to 3.0 eV so that the light output should be best absorbed by the TFPD. The color of the light output from these large optical energy gap TFLEDs was orange-yellow. The peaks of the emission spectra of a-SiC:H TFLEDs always lie in the photon energy regions below the optical energy gaps because the radiative

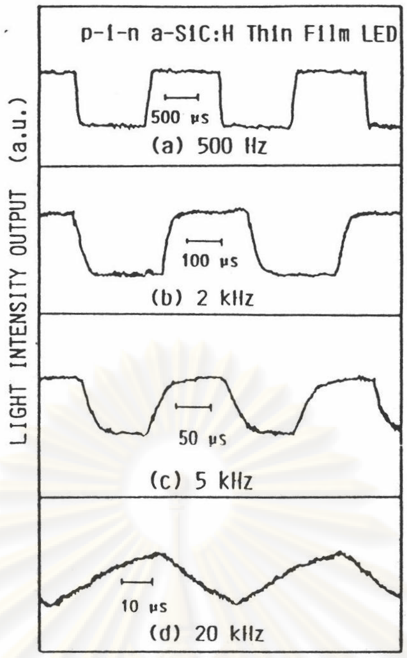

Figure 8.4 Output waveforms of a yellow a-SiC:H TFLED driven by pulse current of the frequency from 500 Hz to 20 kHz (duty cycle = 50 %).

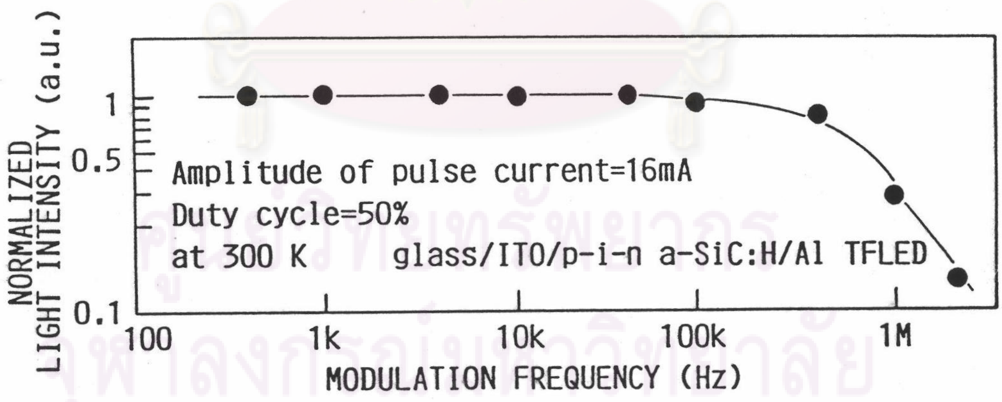

Figure 8.5 Dependence of the integral intensity of the light emission from an a-SiC:H TFLED on the frequency of the pulse current source.

recombination of the doubly-injected electrons and holes occurs in the deep localized states in the i-a-SiC:H layer.

Figure 8.4 shows output waveforms of a yellow a-SiC:H TFLED driven by pulse current having frequency from 500 Hz to 20 kHz (duty cycle = 50 %). The rise time & fall time of the waveform of the light output from an a-SiC:H TFLED range from several microseconds .

Figure 8.5 shows the dependence of the integral intensity of the light emission from an a-SiC:H TFLED on the frequency of the pulse current source. The intensity of the light emission was constant at the frequency below 100 kHz and started to decrease at the frequency higher than 100 kHz. The cut-off frequency defined as the frequency of which the intensity of light was about 70% of the value at low frequency was about 500 kHz.

On the other hand, the rise time & fall time of output waveform of a-Si:H solar cell (in this work & in general) responding to light pulse was of the order of several microseconds. Therefore, it was considered that the amorphous photocoupler consisting of the a-SiC:H TFLED and the a-Si:H solar cell was able to be operated up to several hundred kHz.

8.3.2 Characteristics of Amorphous Photocouplers

Figure 8.6 shows the relationship between the injection current density (J_{inj}) of the a-SiC:H TFLED (area = 3 x 5 mm^2) and the short circuit output current (J_{sc}) of a-Si:H solar cell (area = 3 x 5 mm^2) constructed in the photo-interrupter type (a). The parameter *d* is the distance (including thicknesses of glass substrates) isolated between the two devices.

The J_{sc} increased linearly from 1 - 10 nA/cm^2 with J_{inj} in the range of J_{inj} = 10 -100 mA/cm^2. This was because the brightness (0.01 -1 cd/m^2 or 0.01 -1.1 lux) of the a-SiC:H TFLED changed linearly with J_{inj} in this region.

In general photocouplers, a current transfer ratio (CTR) or coupling efficiency is an important parameter defined as the ratio of the output photocurrent J_{sc} to the input forward current J_{inj}. That is CTR = J_{sc} / J_{inj} x 100 %. Therefore, from Fig. 8.6

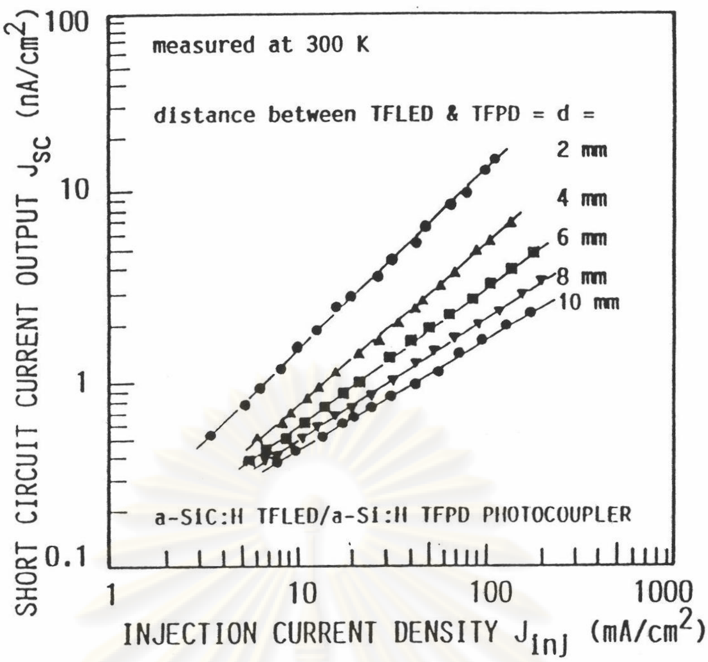

Figure 8.6 Relationship between the injection current density (J_{inj}) of an a-SiC:H TFLED (area = 3 x 5 mm^2) and the short circuit current output (J_{sc}) of an a-Si:H solar cell (area = 3 x 5 mm^2) constructed in the photo-interrupter type (a).

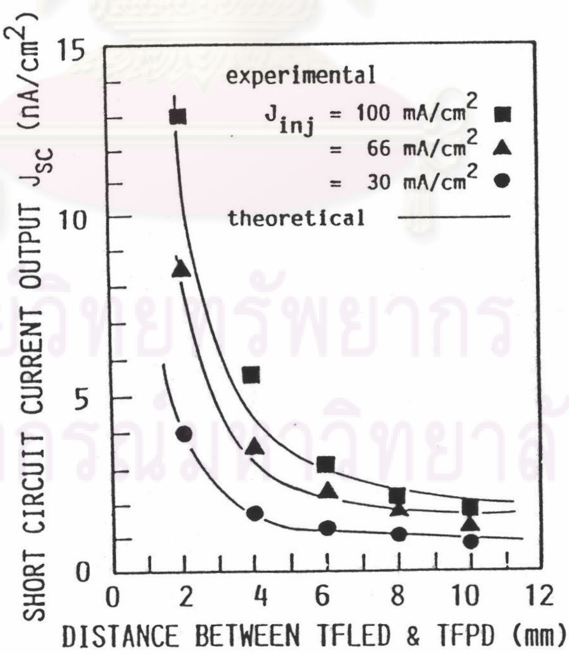

Figure 8.7 Dependence of the J_{sc} of an a-Si:H solar cell (photodiode) on the distance between the a-SiC:H TFLED and the solar cell. The solid line is a calculated result from the relation of light intensity $\propto 1/(\text{distance})^2$.

the CTR in the amorphous photocoupler obtained in this work was of the order of 10^{-5} %. In Fig. 8.6, as the distance increases, the J_{sc} decreases. Figure 8.7 shows the dependence of the J_{sc} of a-Si:H solar cell (photodiode) on the distance between an a-SiC:H TFLED and solar cell. The solid line was a calculated result from the relation of light intensity $\propto$ 1/ $(\text{distance})^2$. It is seen in Fig. 8.6 and 8.7 that the maximum distance between the TFLED and solar cell could be as long as 10 mm.

Figure 8.8 shows the relationship between the input and output signals of the phot-isolator type (c). The distance *d* between the two devices was 1 mm., which was mostly equal to the thickness of the glass substrate. Despite the distance *d* in type (c) was 1 mm., the current output of type (c) in Fig. 8.8 was lower than that of type (a) in Fig. 8.6. One reason might be because the TFLED was degraded due to the heat annealing effect during the fabrication of the TFPD (or vice visa) on the opposite side of the glass substrate.

Figure 8.9 shows the relatioship between the applied voltage and photocurrent output of the photoresistor in the photo-interrupter type (b). The a-Si:H photoresistor which works by a photoconductive effect consists of an intrinsic a-Si:H film (about 5000 Å thickness) deposited on a glass substrate, followed by a coupler of co-planar type Al electrodes. The data in Fig. 8.9 was obtained when the injection current density of TFLED was 50 mA/cm^2 and the distance d was 4 mm. The advantage of the photoresistor as a light detector is that it is capable of high gain and therefore high signal strengths, because of the secondary photocurrent resulting from their ohmic contacts. But the drawback is that its output response time is slower than that of a-Si:H p-i-n TFPD.

Figure 8.10 demonstrates the photograph of the amorphous photocouplers in which the TFLED and the TFPD were deposited on the separated glass substrates.

Figure 8.11 demonstrates the photograph of the amorphous photoisolator in which the TFLED and the TFPD were deposited on the dual surfaces of a common glass substrate.

Figure 8.12 shows the examples of the packages of the amorphous photointerrupter and the amorphous photoisolator produced in the work.

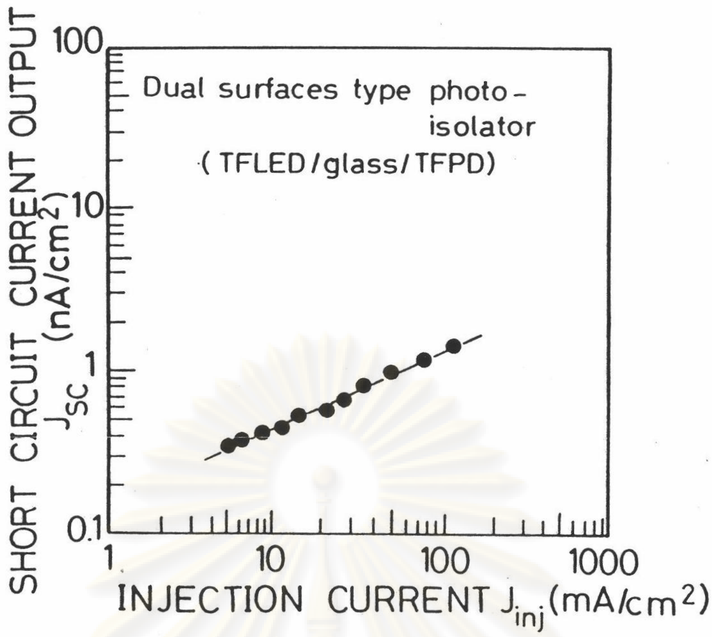

Figure 8.8 Relationship between the input and output signals of the photo-isolator type (c).

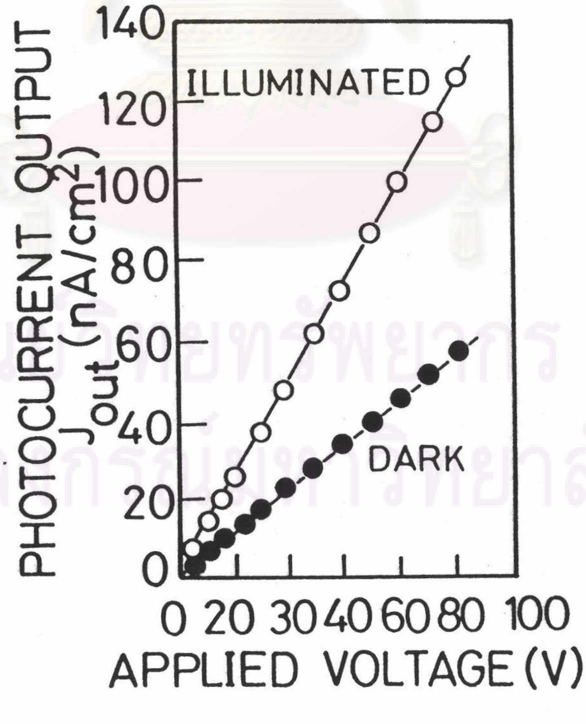

Figure 8.9 Relationship between the applied voltage and photocurrent output of the photoresistor in the photo-interrupter type (b).

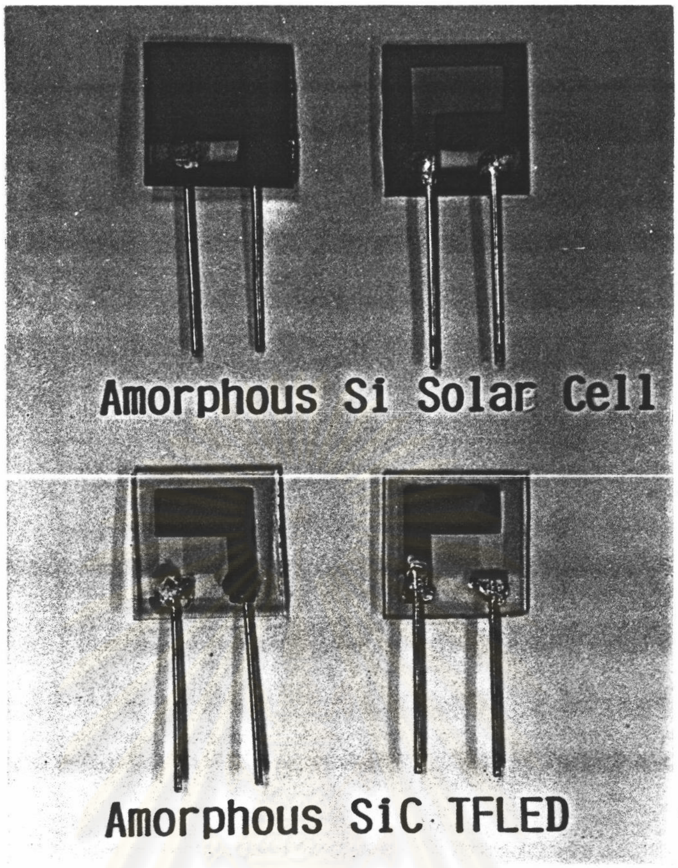

Figure 8.10 Photograph of the amorphous photocouplers in which the TFLED and the TFPD were deposited on the separated glass substrates.

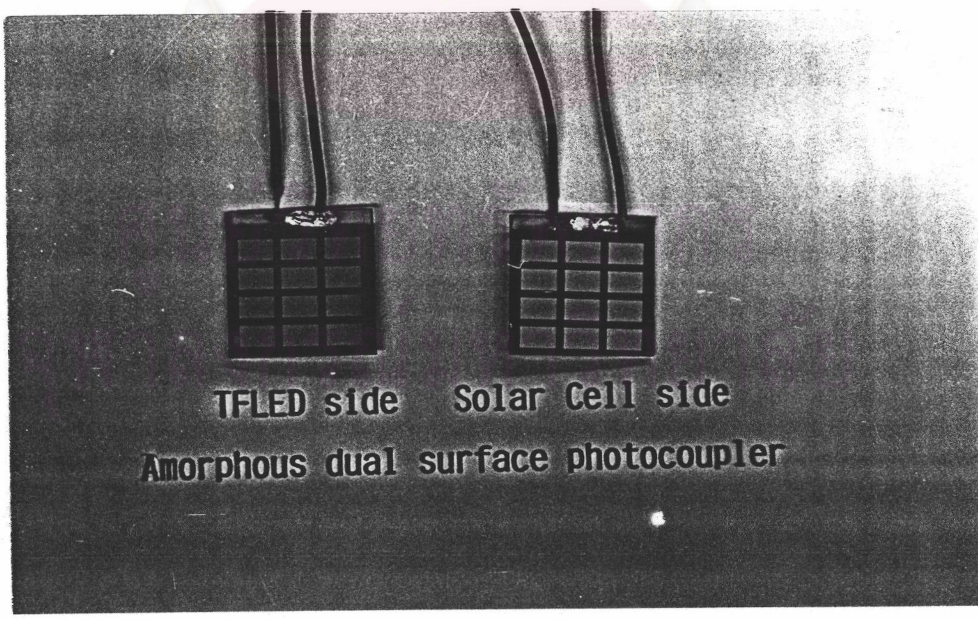

Figure 8.11 Photograph of the amorphous photoisolator in which the TFLED and the TFPD were deposited on the dual surfaces of a common glass substrate.

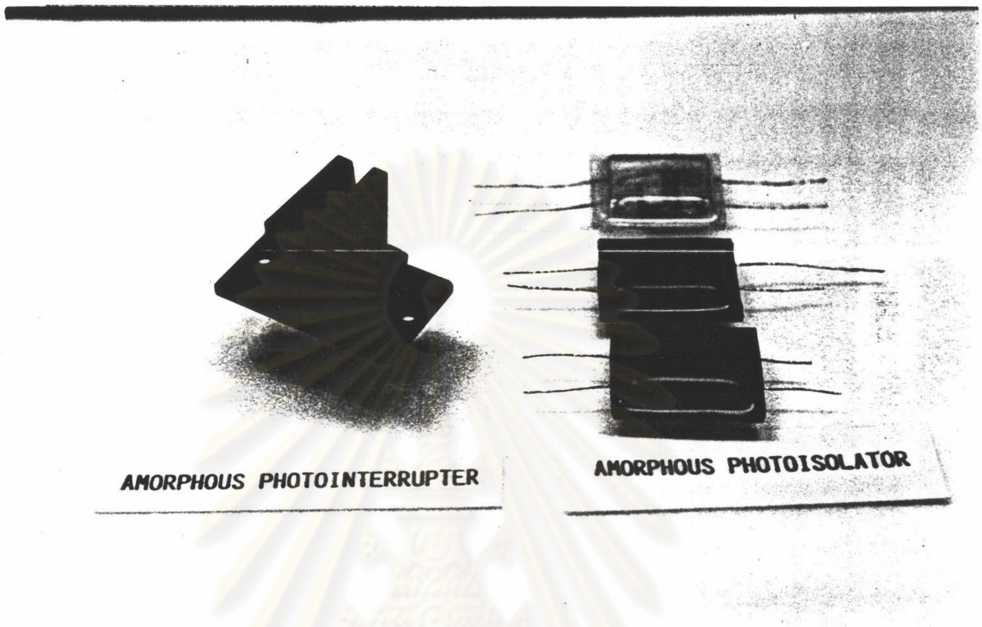

Figure 8.12 Examples of the packages of the amorphous photointerrupter and the amorphous photoisolator produced in the work.

8.4 Summary

Hydrogenated amorphous silicon alloy photocouplers have been developed for the first time. The light source was made of an a-SiC:H TFLED and the light detector was made of an a-Si:H TFPD (thin film photodiode). Two types of the photocouplers were fabricated. In type I, so-called photo-interrupter, a TFLED and a TFPD were fabricated on the two separating glass substrates. In type II, so-called photo-isolator, a TFLED and a TFPD were fabricated on the dual surfaces of a common glass substrate. The coupling efficiency of the photocouplers is approximately 10^{-5} %. The amorphous photocouplers can be operated up to the frequency of several hundred kHz. It was considered that the application of the amorphous TFLED to the amorphous photocoupler could be possible in a mass production industry.