Chapter 1
Introduction

1.1 Historical Background

Display devices are optoelectronic components that can produce the ultimate output of an information system. They are interfaces between men and machines [1]. Cathode Ray Tube (CRT) is one of the well-known displays. However, in the highly informationalized community, the potential needs of flat-panel and wide area displays are increased day by day. The flat-panel displays widely used at present are, for example, Liquid Crystal Display (LCD), Light Emitting Diode (LED) and Electroluminescence (EL). Table 1.1 compares the characteristics of various flat-panel display devices [2]. These flat-panel displays have both advantages and disadvantages. For example, the LCD strenght in low power consumption, but the main drawbacks are that the viewing angle is limited. In addition, the contrast is poor, and LCD needs an external back-light-source. EL can be produced in a large area display, but each EL pixel needs an operation voltage higher than 100 V. Therefore, EL requires a special high voltage output integrated circuit (IC). LED seems to be suitable with a flat panel display, since the brightness is very high and it can be operated at a low voltage (less than 10 V). However, currently the LEDs are made out of expensive and single crystalline semiconductors e.g., GaAlAs and InP, and the LED packaged in a chip have to be cut into a very small size (e.g. 0.1 x 0.1 mm^2). Which a wide area LED display must be constructed by gathering a large number of LED chips and put in arrays or matrix.

The raw materials used in LEDs have been restricted to single crystalline semiconductors. Therefore, the price of LEDs is expensive. It is also difficult to produce LEDs in large areas.

One approach to obtain low cost and large area LEDs is to use amorphous semiconductor materials. The first success of the fabrication of visible-light

Table 1.1 Comparison of different types of flat panel display devices.

(□ : very good, O : good, Δ : available, × : bad)

	EL	*LCD*	*c-LED*	*amorphous TFLED*
Substrate	glass	glass	crystal	any substrate
Possibility of Large Area	O	O	Δ	□
Fabricating Temperature	< 500 °C	-	> 800 °C	< 300 °C
Driving Voltage	ac, dc 160-250 V	dc < 5 V	dc 2-10 V	dc 5-15 V
Current Consumption	mA/cm^2	$\mu A/cm^2$	A/cm^2	mA/cm^2
Brightness (cd/m^2)	60-1000	-	> 150	5-20
How to Change Color	rare earth	filter	Crystal, Impurity	Material Content
Possibility of Full Color	O	O	O	O
Possibility of Tunable Color	O	×	Δ	O
Cost	middle	cheap	expensive	very cheap

amorphous semiconductor based LEDs can be traced back to the year of 1985. When D. Kruangam observed visible-light emission from the p-i-n junctions of hydrogenated amorphous silicon carbide (a-SiC:H) deposited on glass substrates [3-4]. The device was particularly named "Thin Film Light Emitting Diode" (TFLED) according to the unique thin film material system. The important motivation of the development of the amorphous TFLED is to use the unique feature of amorphous semiconductors that a lack of long range ordering in the atomic network relaxes the k-selection rules for the optical transitions. This will give rise to a large optical absorption coefficient and presumably a high luminescent efficiency, which can be used in the light emitting devices (TFLEDs).

The TFLED gathered much attention as a new candidate for a new type of low cost and large area of flat panel display [5-7]. Although, there were several efforts to improve the brightness of the amorphous TFLED [8-15], so far the brightness obtained in the TFLED was still of the level of several cd/m^2 which was too low for any application as a flat panel display. Therefore, it is necessary to improve more the brightness of the devices.

The aim of this thesis is to explore new amorphous semiconductor materials that can be applied to low cost and high efficiency TFLEDs. In this work, the author succeeded in the fabrication of thin film light emitting diode (TFLED) from various hydrogenated amorphous silicon alloys, i.e., hydrogenated amorphous silicon nitride (a-SiN:H), hydrogenated amorphous silicon oxide (a-SiO:H) and hydrogenated amorphous silicon carbide (a-SiC:H). Efforts have been made to improve the brightness by utilizing a metal substrate and highly conductive wide band gap microcrystalline SiO:H as the hole injection layer. Large area matrix TFLED displays have also been proposed and fabricated for the first time. Moreover, the amorphous TFLED has been applied as a light emitting device in a new amorphous optoelectronic device so-called amorphous photocoupler for the first time.

1.2 Significance of This Work

In this work the author succeeded in the fabrication of visible-light amorphous TFLEDs from several kinds of amorphous silicon alloys, i.e, a-SiN:H, a-SiC:H and a-SiO:H [2,14-22]. The amorphous TFLEDs have several advantages over conventional crystalline LEDs as follows:

1. The optical energy gap of amorphous silicon based alloys, e.g., a-SiN:H, a-SiC:H and a-SiO:H can widely be varied from 1.7 eV up to more than 4.0 eV by changing the composition of Si/N, Si/C and Si/O in the film as shown in Figure 1.1. So far, the optical energy gap of crystalline semiconductors is mostly constant.

2. The color of luminescence of a-SiN:H, a-SiC:H and a-SiO:H can be varied from red to white-blue by adjusting the optical energy gap of these materials.

3. Because of the feature of amorphous network, a-SiN:H, a-SiC:H and a-SiO:H films can be deposited in large areas on various kinds of foreign substrates, e.g., glass, stainless steel, ceramic and polymer sheets, etc.

4. The fabrication process of a TFLED does not require a high temperature condition. This process leads to a low cost LED and possibility of mass production.

5. The TFLED can emit the light having a desired pattern by designing the pattern of the internal conductive electrodes, e.g., Indium Tin Oxide (ITO) and Aluminum (Al) electrodes. The pattern of the electrodes can be easily performed by either a wet process (chemical etching) or a dry process (laser scribing).

6. The TFLED can be operated at a low voltage (5 - 15 V). By utilizing thin film technology, the TFLED and its driving circuits can be fabricated on the same substrate. It can lead to new and smart three-dimensional optoelectronic devices.

In this work, a large area dot matrix TFLED display has been developed for the first time [21,23-24]. The dot matrix TFLED consists of a large number of grid ITO and Al electrodes. A dot matrix TFLED with the screen area of 8 x 8 cm^2 has been demonstrated. It is shown that the display can be operated in a scanning mode at the modulation frequency as high as several hundred kHz.

The author succeeded in the improvement of the brightness of the TFLED by utilizing a metal sheet as a substrate and p-type μc-SiO:H as a p-layer [15]. The

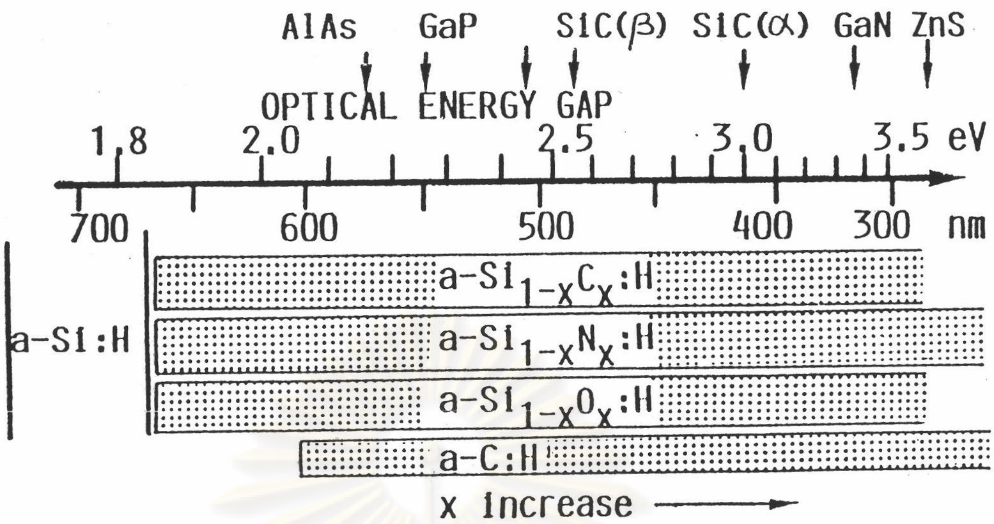

Figure 1.1 Optical energy gaps of various amorphous silicon alloys and crystalline semiconductors.

Table 1.2 Outline of the contribution of the thesis.

Materials	R&D on applications in past time	Contribution of the thesis
a-SiC:H	• a-SiC:H/a-Si:H solar cell • Passivation layer • Heterojunction bipolar transistor • a-SiC:H TFLED - Small area - Glass substrate	• Large area a-SiC:H TFLED • Dot matrix large area a-SiC:H TFLED • a-SiC:H TFLED on metal substrate • Improvement of brightness • Development of amorphous photocoupler
a-SiN:H	• Passivation layer • Gate layer in TFT	• a-SiN:H TFLED - Various patterns
a-SiO:H	• Gate layer in TFT • Passivation layer • Anti-reflection layer in solar cell	• a-SiO:H TFLED
p-μc-SiO:H or p-a-SiO:H	• Wide-gap window in solar cell	• p-μc-SiO:H/i-a-SiC:H/n-a-SiC:H TFLED • Improvement of brightness of TFLED

brightness was increased from 0.1-1 cd/m^2 to the level of 10 cd/m^2. The emission was bright enough to be observed in a room with low light.

Another significant success in this work is the development of a new kind of optoelectronic device so-called amorphous photocoupler [25-27]. The amorphous photocoupler consists of an amorphous TFLED and an amorphous photodiode sealed in a single package. It is useful, for example, in providing optical signal transmission, interfaces between logic circuits, position & size detection of moving objects, tape end detection, I/O interfaces for computers, etc. So far the conventional photocouplers have been made of crystalline semiconductors, such as GaAs, InP, Si, CdS, etc. The disadvantages of the crystalline photocouplers are that they are made out of expensive materials, small devices, hybrid devices, needs of different manufacturing technologies, such as Liquid Phase Epitaxy (LPE) technology for GaAs and Czochralski (CZ) technology for Si, etc. The advantages of the amorphous photocouplers can be described as follows:

1. Ease of fabrication of both small and large area and low cost.
2. Ease of fabrication of arrays or matrix type photocoupler.
3. Use only amorphous silicon alloys in both light emitting diode and photodiode both of which can be fabricated by a glow discharge plasma CVD method.
4. Possibility of deposition of the amorphous TFLED and the amorphous photodiode on the dual surfaces of the common glass substrate. Therefore, it will not need any position alignment during operation.
5. The amorphous photocouplers can be produced both in the photointerrupter type and in the photoisolator type.

Table 1.2 summarizes the outline of the contribution of this thesis work.

1.3 Purposes and Contents of This Work

The purposes of this work are to develop amorphous silicon alloy Thin Film Light Emitting Diodes (TFLEDs), as well as to improve their brightness and to explore the new applications in optoelectronics, such as amorphous photocouplers.

In this thesis, the results of a systematic study on the fabrication and characteristics of hydrogenated amorphous silicon alloys, i.e., hydrogenated amorphous silicon nitride (a-SiN:H), hydrogenated amorphous silicon carbide (a-SiC:H) and hydrogenated amorphous silicon oxide (a-SiO:H) are presented. A series of technical data on the fabrication of p-i-n junction thin film light emitting diode (TFLED) and basic characteristics and performances of the TFLEDs are presented and discussed. Results of the improvements of the brightness by using several attempts are described . In this work, a large area dot matrix TFLED has been fabricated for the first time. Finally, utilizing advantage features of amorphous TFLED, a new optoelectronic device so-called amorphous photocoupler is proposed and discussed.

In chapter 2, the preparation methods of wide band gap amorphous silicon alloys, i.e., a-SiN:H, a-SiC:H and a-SiO:H by the glow discharge plasma CVD system from the mixtures of SiH_4 and NH_3, C_2H_4, CO_2, respectively are described. The optical energy gaps of these materials can be varied from 1.8 eV to more than 3.0 eV by increasing the gas fraction of N, C and O sources. It is shown that the effective diameter of the area of the deposition is 8 cm and a good uniformity of the thickness can be obtained.

In chapter 3, the development of an amorphous p-i-n junction TFLED having a-SiN:H as a luminescent layer is described. The a-SiN:H is prepared by the glow discharge plasma CVD system from the mixture of SiH_4+NH_3. The structural and optical properties of undopded a-SiN:H have been studied by using IR absorption, ESR, optical absorption and photoluminescence techniques. It is indicated that the undoped a-SiN:H possessing a wide range of optical energy gap from 1.8 eV to 3.1 eV can be prepared by adjusting the ratio of the ammonia gas to the silane gas. The PL emission color changes from red to white-blue along with the increasing in the optical energy gap. A series of technical data on the fabrication technology, basic characteristics of a-SiN:H TFLEDs including carrier injection mechanism and the optimization of the thickness of the i-a-SiN:H layer are presented and discussed. The structure of the TFLED employed in this chapter is glass/ITO/p-type a-SiC:H/i-type a-SiN:H/n-type a-SiC:H/Al. The emission color can be varied from red to yellow by adjusting the optical energy gap of the i-a-SiN:H layer. The typical bias voltage and injection current are 5-15 volt, 100-1000 mA/cm^2, respectively. The brightness of the a-SiN:H TFLED is about 0.7-0.8 cd/m^2. An investigation on the frequency modulation characteristic reveals that the brightness of the a-SiN:H TFLED dose not decrease even the frequency of the input pulse current is as high as 1 MHz. This condition matches very well with the requirement for the operation in a scanning mode. The yellowish-orange and white-blue a-SiN:H TFLED displays with emission areas of several cm^2 are demonstrated.

In chapter 4, an amorphous p-i-n junction TFLED having a-SiC:H as a luminescent layer is fabricated. The results of a systematic study on the fabrication and characterizations of a-SiC:H are presented. The brightness of the a-SiC:H TFLED is 1-2 cd/m^2 which is bright enough to be observed in a bright room. It is revealed that the a-SiC:H TFLED can be operated by a pulse current mode with the modulation frequency as high as 500 kHz. The yellow and orange color a-SiC:H TFLEDs with various emission patterns are demonstrated.

In chapter 5, a series of the technical data on the fabrication technology and basic characteristics of undoped a-SiO:H is described. An amorphous p-i-n junction TFLED having a-SiO:H as a luminescent layer is fabricated. A series of the technical data on the device fabrication technology and basic characteristics of the a-SiO:H TFLEDs including carrier injection mechanism and the relation between brightness and current injection density are presented and discussed. The brightness of the a-SiO:H TFLED is 0.3-0.5 cd/m^2. By comparing the brightness of the TFLEDs with different materials in the i-layers, the result indicates that the TFLED with a-SiC:H as the i-layer gives the highest brightness, while the a-SiN:H shows the brightness higher than a-SiO:H. Although the a-SiO:H TFLED gives the lowest brightness, it is the first time to report that a-SiO:H can be applied as a luminescent layer in an amorphous visible-light TFLED.

In chapter 6, some efforts have been carried out in order to improve the brightness of the a-SiC:H TFLED. The first approach is done by using a highly thermal conductive metal sheet as a substrate instead of a conventional glass substrate. The metal substrate has a good thermal conductivity coefficient so that the heat generated in the TFLED can be quickly dissipated to the ambient. By this technique, the brightness is increased by a factor of 2-5 to the level of 5 cd/m^2. The second approach to improve the brightness of the a-SiC:H TFLED is done by increasing the hole injection efficiency and by using wide band gap and highly conductive boron doped μc-SiO:H as the p-layer in the TFLED. The result shows that the brightness is increased to the level of 10 cd/m^2. This value is the best record reported so far.

In chapter 7, a large area dot matrix amorphous TFLED display is proposed. Any moving emitting pattern can be obtained in this type of display. The dot matrix TFLED display consists of a number of grid ITO electrodes deposited perpendicularly to a number of grid Al electrodes. Several versions of the dot matrix yellowish-orange displays with the screen size ranging from 4 x 4 cm^2 to 8 x 8 cm^2 have been fabricated and demonstrated. It is clarified that there is no cross talk in the display, and the theoretical minimum spacing distance between the adjacent two ITO or Al electrodes can be as small as the order of micron.

In chapter 8, it is demonstrated that the amorphous TFLED is useful not only as a display, but also as a light source in a new optoelectronic application. As a result, a new optoelectronic device so called amorphous photocoupler (optocoupler) is developed. In this device, the light emitting device is made of an amorphous TFLED and the light detecting device is made of an amorphous thin film photodiode (TFPD). The amorphous 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.

In the final chapter, the results obtained through this thesis work are summarized.

Figure 1.2 summarizes the structure of the thesis.

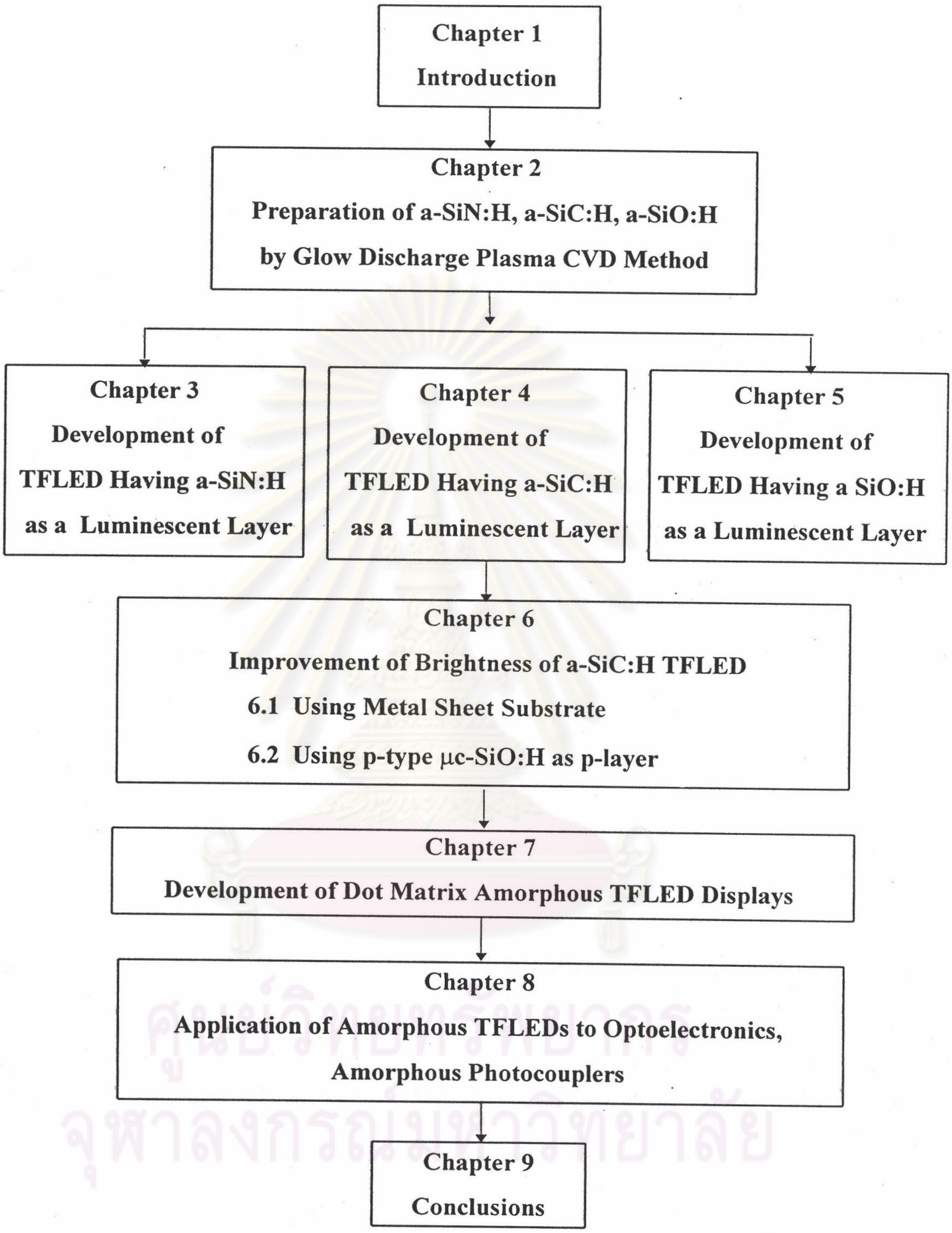

Figure 1.2 Structure of the thesis

This thesis is contributed not only to the development of a new flat panel display, but also to the expansion of application fields of amorphous semiconductors, which have been restricted so far to solar cells and TFTs, to Thin Film Light Emitting Diodes and to the possibility of the fabrication of amorphous photocoupler and amorphous OE-IC. There are several significant results obtained in the thesis as follows:

1) Amorphous TFLEDs with a structure of p-i-n junctions of amorphous silicon alloys have been developed. The result of the comparison of the brightness of the TFLEDs that the i-layers were prepared from three different materials, i.e., a-SiC:H, a-SiN:H and a-SiO:H showed that the best brightness of 2-5 cd/m^2 was obtained in the a-SiC:H, then less brightness in a-SiN:H and a-SiO:H, respectively.

2) By using a metal sheet as a substrate for the TFLED, the brightness of the TFLED was improved 5 cd/m^2.

3) By using p-type microcrystalline SiO:H as the hole injection p-layer in the TFLED, the brightness was improved to 10 cd/m^2.

4) Novel dot matrix amorphous TFLED displays have been developed. The dot matrix design is the basic structure for a practical large area display.

5) Novel amorphous photocouplers have been developed. The amorphous photocouplers are also divided into a photo-isolator type and a photo-interrupter type.

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