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than the optical energy and also showed a strong dependence on the excitation photon energy when the excitation energy was less than the optical energy gap. These results suggested that the radiative recombination process involves localized states which are widely distributed within the gap. This point gave an important insight in understanding the basic properties the a-SiN:H TFLEDs.

4) The quality of the a-SiN:H prepared in this work was good enough to be used as the luminescent active layer in the visible-light thin film light emitting diode (TFLED).

5) A visible-light TFLED with a-SiN:H active i-layer has been developed for the first time. The device structure was glass/ITO/p-a-SiC:H/i-a-SiN:H/n-a-SiN:H/Al. The emission color could be varied from red to yellow by adjusting the optical energy gap of the i-a-SiN:H layer. In order to obtain a visible light emission, the optical energy gap of the i-layer had to be larger than 2.5 eV, while the optical energy gaps of the p- and n-layer were kept constant around 2.0 eV to ensure the valency controllability.

6) A systematic study on the carrier injection mechanism and EL property in this kind of heterojunction TFLEDs has been done. The result has revealed that the carrier injection mechanism in the a-SiN:H TFLED is based upon the tunneling injections of holes and electrons from the small gap p- and n-layers into the wide gap i-layer through the notch barriers at the p/i and i/n heterointerfaces. Based upon this analysis, a simple optimization of the thickness of the i-a-SiN:H layer has been done.

7) At the present stage the brightness obtained in the a-SiN:H TFLED so far is about 0.7-0.8 cd/m^2. The external luminescence efficiency is estimated to be the order of 10^{-3} %.

8) An investigation on the frequency modulation characteristic revealed that the brightness of the a-SiN:H TFLED did not decrease even the frequency of the input pulse current was as high as 1 MHz. This performance of the a-SiN:H TFLED satisfied the requirement for the utilization as a display which was

generally operated in a pulse current scanning mode with the frequency of several kHz.

9) Some unique designs and fabrication of a-SiN:H TFLED as flat panel displays have been proposed and demonstrated. The yellowish orange and white-blue a-SiN:H TFLED displays with emission area of several cm^2 have been demonstrated.

10) Hydrogenated amorphous silicon carbide (a-SiC:H) with wide optical energy gap from 1.8 eV to 3.1 eV was prepared by the glow discharge plasma CVD method. The visible photoluminescence could be observed in the a-SiC:H with the optical energy gap wider than about 2.3 eV.

11) A visible-light a-SiC:H p-i-n junction thin film LED (a-SiC:H TFLED) has been developed. The brightness of the a-SiC:H TFLED was 1-2 cd/m^2 which is bright enough to be observed in a bright room. The brightness of the a-SiC:H TFLED was better than that of the a-SiN:H TFLED (0.7-0.8 cd/m^2) described in chapter 3.

12) It has also been shown for the first time that the a-SiC:H TFLED could be operated by a pulse current mode with the modulation frequency as high as 100 kHz. This frequency was high enough to use the a-SiC:H TFLED in a scanning mode as a new type of flat panel display.

13) The yellow and orange color a-SiC:H TFLED with various emitting patterns have been fabricated and demonstrated.

14) Hydrogenated amorphous silicon oxide (a-SiO:H) with wide optical energy gap from 1.8 eV to 3.1 eV was prepared by the glow discharge plasma CVD method form the mixture of SiH_4 and CO_2. The visible photoluminescence could be observed in the a-SiO:H with the optical energy gap wider than about 2.3 eV.

15) A novel visible-light amorphous p-i-n junction thin film LED (TFLED) having undoped a-SiO:H as the luminescent layer has been fabricated for the first time. The brightness of the a-SiO:H was approximately 0.3-0.5 cd/cm^2.

16) This was the first trial that uses the semiconductor property of the a-SiO:H to the light emitting device.

17) A comparison has been done on the brightness of TFLEDs that the i-layers were prepared from three different materials, i.e., a-SiC:H, a-SiN:H and a-SiO:H. The result shown that the best brightness was obtained in the a-SiC:H, a-SiN:H and a-SiO:H, respectively.
18) The improvements of the brightness of the amorphous TFLED have been successfully done.
19) The first effort was to improve the internal luminescent efficiency by controlling the temperature of the TFLED by using a metal substrate. The metal substrate had a better thermal conductivity coefficient so that heat generated in the TFLED could be quickly dissipated to the surrounded area. By this technique, the brightness was increased by a factor of 2-5 to the level of 5 cd/m^2. Moreover, metal substrates also have various advantages, e.g., flexible, conductive electrodes by themselves, rigid, not broken, heat sink by themselves, etc. A patent on this invention has been applied.
20) The second effort to improve the brightness had been done by improving the hole injection efficiency by using new materials, so called p-type amorphous silicon oxide (p-a-SiO:H) and p-type microcystalline silicon oxide (p-μc-SiO:H). The materials had wider optical energy gaps and higher conductivities than those of conventional p-a-SiC:H. The new device structure was glass/ITO/p-a-SiO:H (or p-μc-SiO:H)/i-a-SiC:H/n-a-SiC:H/Al. By using these excellent materials not only the EL spectrum shifts to higher energy but also the brightness was increased to the level of 10 cd/m^2. This was the best record reported so far.
21) Large area dot matrix amorphous TFLED displays have been proposed and fabricated for the first time. The dot matrix amorphous TFLED display consisted of a number of grid ITO electrodes deposited perpendicularly to a number of grid Al electrodes.
22) Two versions of the dot matrix displays; version No.1 with a screen area of 4 x 4 cm^2, pixel area of 2 x 2 mm^2; version No.2 with a screen area of 8 x 8 cm^2, a pixel area of 1 x 1 mm^2, have been demonstrated.

Appendix A

Miscellaneous Structures of Amorphous TFLEDs and Amorphous Optoelectronic Integrated Circuits (OE-ICs)

Some miscellaneous structures of amorphous TFLEDs, so-called multi-color type, dual surfaces type and tandem type, and amorphous optoelectronic integrated circuits (OE-ICs) were proposed and their structures are shown in Fig. A.1 - A.5.

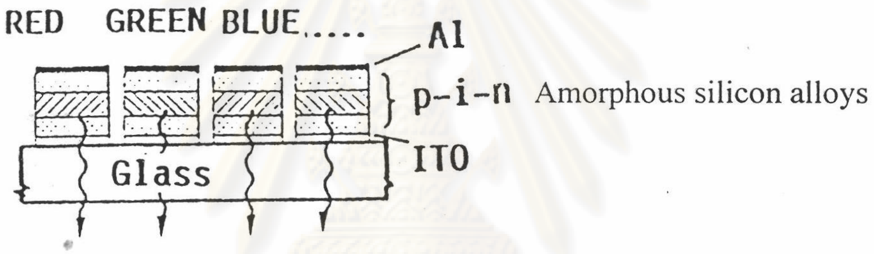


Figure A.1 Structure of multi-color amorphous TFLEDs.

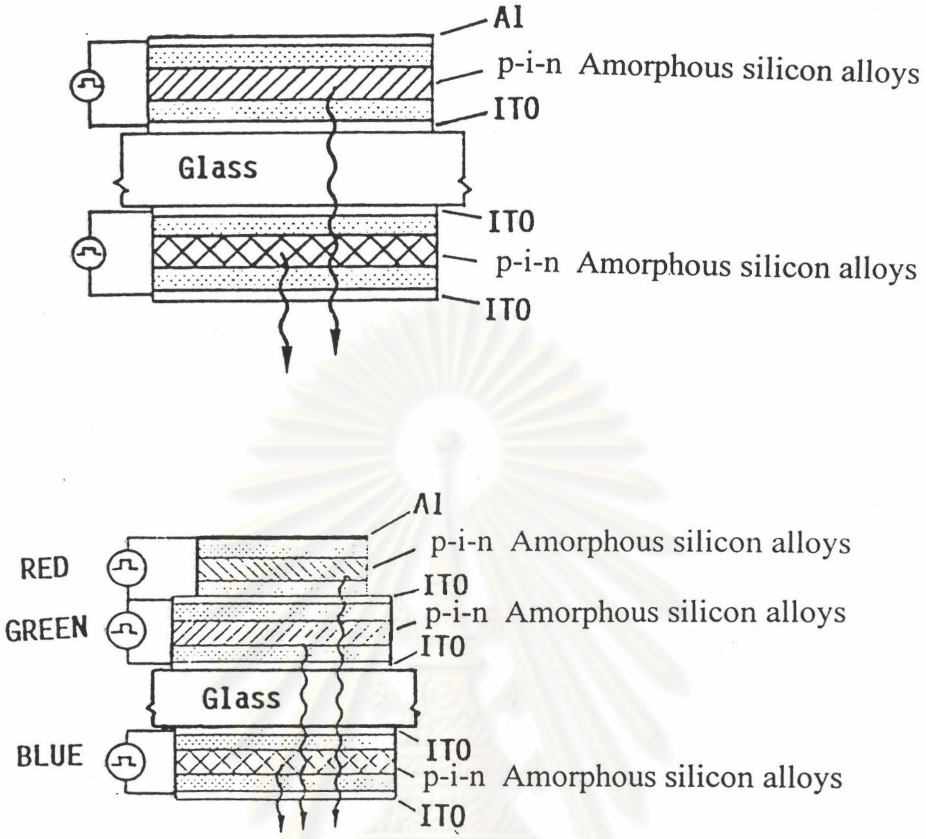


Figure A.2 Structures of dual surfaces of amorphous TFLEds.

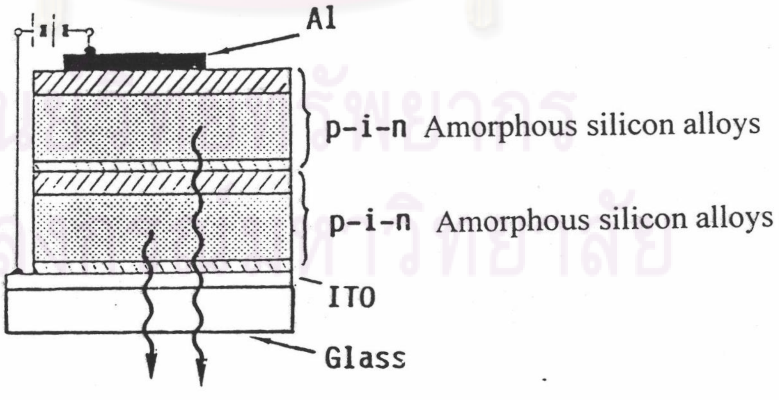


Figure A.3 Illustration of the structure of p-i-n/p-i-n tandem amorphous TFLEDs.

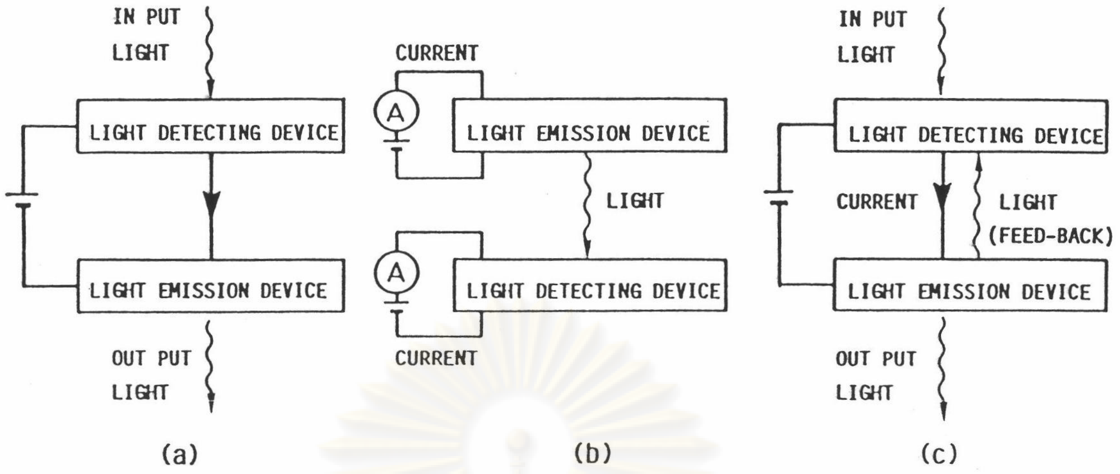


Figure A.4 Example of the combination TFLEDs and TFPDs (thin film photodiode) for utilizations in a novel optoelectronic functional devices.

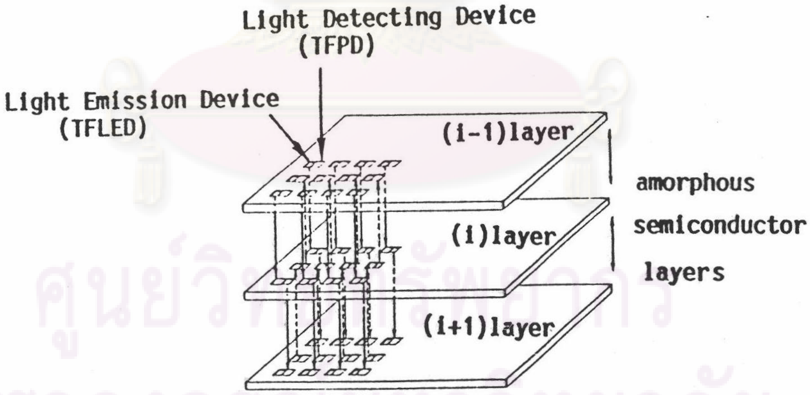


Figure A.5 Example of the spacing optical connection of multi-layer structures using amorphous TFLEDs & TFPDs.

Appendix B

Optimization of Thickness of the i-layer

In general, to obtain a high EL intensity, a thick i-layer (that is a large volume of radiative recombination centers) is required. Since the dominant current across the a-SiN:H p-i-n junction is a tunneling current, a thick i-layer should generally limit the probability of tunneling due to a lowering of the electric field for tunneling. The trade-off between these two parameters, then determines the thickness dependence of the EL intensity. In this appendix, we present a series of experimental data on the i-layer thickness dependence of EL intensity and make a theoretical analysis [1-2].

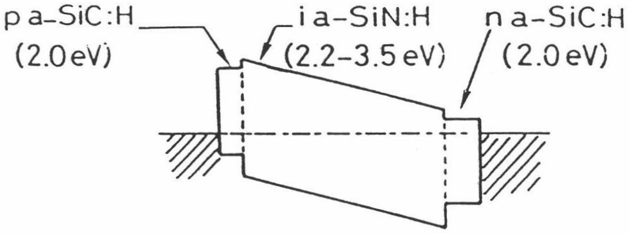
First we will semi-quantitatively discuss the relation between the EL intensity *(B)* and the injection current density *(J)* on the basis of a simple model for carrier transport and radiative recombination in the a-SiN:H/a-SiC:H p-i-n junction. Let us consider an a-SiN:H/a-SiC:H p-i-n junction of infinite extent in the y-z plane, and the i-layer stretches from $x = 0$ (at p/i interface) to $x = d$ (at i/n interface) in the x-axis (Fig. B.1). Since the carrier injection process operating in the a-SiN:H/a-SiC:H p-i-n diode is considered to be of tunneling process, the electron and hole currents in the vicinities of i/n and p/i interfaces may be expressed as:

$$J_n = E^2 \exp\left[\frac{-4\sqrt{2m_e^*}(\Delta E_c)^{3/2}}{3q\hbar E}\right] \quad , at \quad x \approx d \qquad \text{(B.1)}$$

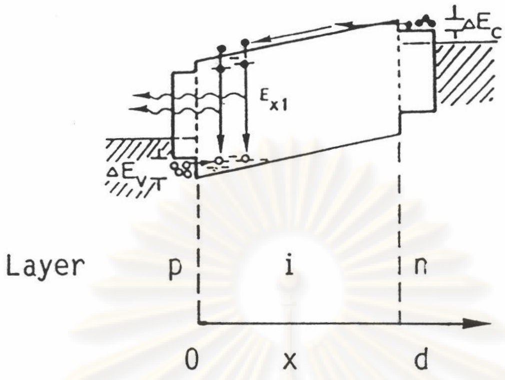
$$J_p = E^2 \exp\left(\frac{-4\sqrt{2m_h^*}(\Delta E_v)^{3/2}}{3q\hbar E}\right) \quad , at \quad x \approx 0 \qquad \text{(B.2)}$$

where m_e^*, m_h^*, is the effective mass of electrons and holes, respectively. ΔE_c represents the conduction band discontinuity at the i/n interface and ΔE_v the valence band discontinuity at the p/i interface.

If we assume that the luminescence active i-layer behaves as an n-type semiconductor and the carrier transport in the p-i-n junction is a drift-type in the high



(a) Zero Bias



(b) Forward Bias

Figure B.1 Schematic illustrations of band diagrams of a-SiN:H p-i-n junctions in thermal equilibrium (a) and in forward bias (b) conditions.

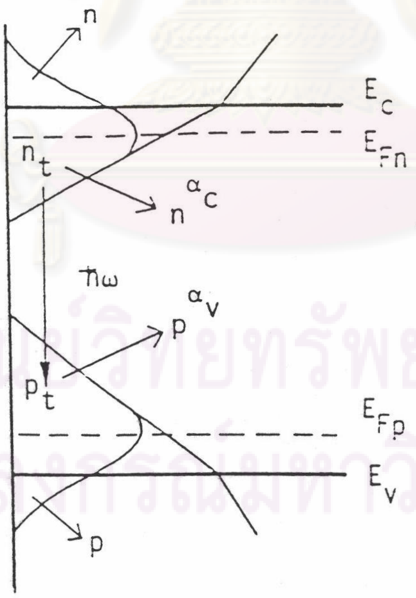


Figure B.2 Illustration of the distribution of the tail states for the i-layer used in the analysis of the electroluminescent properties of TFLEDs [5].

electric field limit, the distributions of electrons and holes in the i-layer can be easily calculated by solving the carrier continuity equations under the boundary conditions; equation (B.1) and equation (B.2). The results obtained for the case of a uniform electric field are written as:

$$n(x) \quad = \quad \frac{J_n}{q\mu_n E} \;-\; \frac{J_p\mu_p}{q\mu_n E}\left(e^{-x/\gamma_p} - e^{-d/\gamma_p}\right) , \qquad \text{(B.3)}$$

and

$$p(x) \quad = \quad \frac{J_p}{q\mu_p E} e^{-x/\gamma_p} \qquad (\gamma_p \;=\; \mu_p \tau_p E) \qquad \text{(B.4)}$$

where γ_p denotes the hole range $(\mu_p \tau_p E)$, μ_n and μ_p are the electron and hole mobilities, respectively, and τ_p the non-radiative recombination life time of holes. The net diode current is readily calculated by using equation (B.3) and equation (B.4), and expressed in terms of J_n and J_p as :

$$J \quad = \quad J_n \;+\; J_p e^{-d/\gamma_p} \qquad \text{(B.5)}$$

The magnitude of hole tunneling current J_p should be much smaller than the electron tunneling current J_n since ΔE_v is about three times larger than ΔE_c. Moreover, the factor $exp(-d/\gamma_p)$ reduces the contribution of hole current to the net diode current. This is consistent with the qualitative conclusion of the previous section, and then it may be allowed to write

$$J \quad \cong \quad J_n \qquad \text{(B.6)}$$

The EL intensity is essentially proportional to the rate of the radiative recombination of electrons and holes. The rate of the radiative recombination is in turn determined by the product of excess electron (n_t) and hole (p_t) densities at the initial and final states of the radiative transitions. For the take of simplicity, we here represent these densities as being proportional to $n(x)^{\alpha}{}_{c}$ and $p(x)^{\alpha}{}_{v}$, where α_c and α_v are parameters characterizing the radiative recombination process in the i-layer. When bimolecular recombination of free electrons and holes dominates, α_c and α_v are set at unity. The parameter set, $\alpha_c = 0$ and $\alpha_v = 1$, represents monolecular recombination of minority holes. On the other hand, the main radiative transition in amorphous semiconductors is considered to take place between localized states. If we assume that the localized states involved in the radiative recombination process are exponential band tails, the parameters; α_c and α_v are regarded to be, so called, the dispersive parameters characterizing the slope of conduction and valence band tail states [3,4], respectively, as shown in Fig. B.2. In all the case, α_c and α_v are in the range from 0 to 1. Provided that the hole range γ_p is much smaller than the i-layer thickness (*d*). The EL intensity (*B*) is related to the densities *n(x)* and *p(x)* by

$$B \quad \propto \quad \int_0^d n(x)^{a_c} \,.\, p(x)^{a_v} \; dx \qquad \text{(B.7)}$$

Combining equation (B.2) - (B.7) leads to a simple expression;

$$B \quad \propto \quad \frac{d^{1+a_c+a_v}}{V^{\alpha_c + \alpha_v}} \exp\left[\frac{-da_v}{d_c}\right] J^{a_c+a_v} \qquad \text{(B.8)}$$

with

$$d_c \quad \cong \quad \frac{3q\hbar V}{4\sqrt{2m^*}\left(\Delta E_v^{3/2} - \Delta E_c^{3/2}\right)} \qquad \text{(B.9)}$$

where V is the applied voltage across the i-layer. Equation B.8 indicates that the EL intensity has a relation with the current as,

$$B \quad \propto \quad J^n \qquad \text{(B.10)}$$

where the exponent n is given by $n = \alpha_c + \alpha_v$. Since the exponent n in Fig.3.33 is close to unity, the EL mechanism in a-SiN:H/a-SiCH p-i-n TFLED might be a classical monolecular recombination or a tail-tail recombination. At the constant current density (J) and applied voltage (V), the EL intensity B expressed by equation B.9 has its maximum at a thickness d_{max} ;

$$d_{\max} \approx \frac{(1 + a_c + a_v)}{a_v} d_c \qquad \text{(B.11)}$$

where d_c is defined in equation B.9. At present, due to the lack of the detailed information about the radiative recombination process and the nature of the electronic states in a-SiN:H, it is difficult to conclude whether monolecular, or tail-tail states recombination dominates radiative recombination in a-SiN:H/a-SiC:H p-i-n junctions. However , if we assume that the tail-tail recombination is the dominant process in the TFLEDs, as for a red TFLED (i-layer gap = 2.50 eV), the optimum i-layer thickness d_{max} is calculated to be about 500 - 600 Å. Here the values of ΔE_v and ΔE_c was used from section 3.5.2, and the values of the dispersive parameters ; α_c , α_v = 0.8 and 0.3, respectively have been determined by means of the Time of Flight and sub-band gap absorption measurements. This calculated optimum i-layer thickness is consistent with the experiment results in Fig. 3.34.

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List of Publications

1. International Journals and International Conferences

1. **Wirote Boonkosum**, Dusit Kruangam and Somsak Panyakeow, “Amorphous Visible-Light Thin Film Light-Emitting Diode Having a-SiN:H as a Luminescent Layer”, Japanese Journal of Applied Physics, Part I, No. 4, Vol. 32, (1993) : 1534-1538.
2. **Wirote Boonkosum**, Dusit Kruangam and Somsak Panyakeow, “Visible-Light Amorphous Silicon-Nitride Thin Film Light Emitting Diode”, Symposium Proceedings of Spring Meeting of Materials Research Society (MRS), Vol. 297-Amorphous Silicon Technology 1993-, San Francisco, U.S.A, April 12-16 (1993) : 1005-1010.
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VITA

Wirote Boonkosum was born in Ayudthaya Province, Thailand on December 21, 1962. He entered Military Technical Training School, Bangkok, in May 1980 and received the Certificate of Vocational Education in Trade and Industry major in Electronics in April 1982. In May 1984, he entered Ratchaburi Technical College, Ratchaburi Province, and received the Technical Diploma Degree in Electronics from Ratchaburi Technical College in March 1986. In June 1986, he entered Rajamongkala Institute of Technology and received the Bachelor of Engineering in Electronics Engineering from Rajamongkala Institute of Technology in May 1989.

He entered the Graduate School of Chulalongkorn University in October 1989, as a scholarship student supported by Science & Technology Development Board (STDB, Ministry of Science, Technology and Environment). He received his Master of Engineering Degree in Electrical Engineering in May 1992. His Master thesis was selected as the outstanding thesis from Chulalongkorn University and he received the award from His Majesty the King of Thailand. Since June 1992 he has got the schorlaship from the Division of Research, Chulalongkorn University as an Research Assistance.

He started working at the Telephone Organization of Thailand (TOT) in April 1987 and on left from TOT in February 1990 to continue studying at the Graduate School of Chulalongkorn University. After February 1996 he went back to become a staff at the TOT.

He is a member of the Materials Research Society (MRS) in U.S.A..

During this thesis course the author got several domestic and international awards as follows:

1. In 1993, he received **"The First Device Invention Award"** from National Research Council of Thailand (NRCT). The device is "Amorphous Semiconductor Visible-Light Thin Film Light Emitting Diode -Toward New Type of Flat Panel TV &Display-". He received the certificate from the Prime Minister of Thailand.

2. In 1993, he won **"The Outstanding Master Degree Thesis Award"** in the physical science category of Rachadapiseksompoch Research Fund by Chulalongkorn University. The title of the thesis was "Fabrication and study of basic properties of electroluminescent display made of thin film zinc sulfide". He received the certificate from His Majesty the King of Thailand.

3. In 1993, he was selected as **"MRS Graduate Student Award Finalist"** at the 1993 MRS Spring Meeting, San Francisco, C.A., U.S.A. The title of the paper was "Visible-Light Amorphous Silicon Nitride Thin Film Light Emitting Diode".

4. In 1994, he was selected as **"MRS Graduate Student Award Finalist"** at the 1994 MRS Spring Meeting, San Francisco, C.A., U.S.A. The title of the paper was "Novel Amorphous Photocoupler Consisting of a-SiC:H Thin Film LED and a-Si:H Thin Film Photodiode".

Some achievements in this work have been applied for several patents as follows:

1. "Amorphous Semiconductor Thin Film Light Emitting Diode"
   (Government of Thailand, Application No. 021257).
2. "Amorphous Semiconductor Thin Film Light Emitting Diode"
   (Government of Australia, Application No. PM4832).
3. "Amorphous Semiconductor Thin Film Light Emitting Diode"
   (Government of United States, Application No. 08/414738).
4. "Amorphous Semiconductor Photocoupler"
   (Government of Thailand, Application No. 021258).
5. "Amorphous Semiconductor Photocoupler"
   (Government of Australia, Application No. PM5121).
6. "Amorphous Semiconductor Photocoupler"
   (Government of United States, No. 08/421089).
