특집 : 정보 디스플레이의 광원 응용기술

LCD 배면광을 위한 무수은 평면방전램프

《Mercury Free Flat Discharge Lamps for LCD Backlighting》

TOMOKAZU SHIGA〈志賀 智一〉
〈The University of Electro-Communications〉

국 문 요 약

LCD는 비발광형 소자이므로 배면광이 필요하다. 현재의 LCD 배면광용 냉음극 형광램프는 전기-광학적 특성을 좋게 하기 위하여 수은방전을 사용한다. 그러나 수은의 이용은 외부 온도에 따라 특성이 변하는 결점과 환경문제가 있다. 이 결점을 보완하기 위하여 원통방전형, 미세방전형 그리고 평면방전형등 세가지 방식의 무수은 램프가 개발되어 왔다.

원통 방전형 무수은 램프는 수은 대신 Xe을 사용한다. Xe 방전이 수축되는 것을 막기 위하여 한쪽 전극은 외벽에 코일형태로 감아서 사용한다. 그리고 코일형태의 전극의 권선 간격을 조절하여 균일한 방전을 얻는다. 이 형태는 종래의 무수은 냉음극 형광램프의 두배의 광속을 얻을 수가 있다. 미세방전형 무수은 램프는 두 개의 절연체로 절연된 금속 전극사이의 방전공간에 수많은 미세방전을 일으켜 발광시킨다. 이 방식은 대향 방전구조와 면 방전구조의 두가지가 있다. 이 방식은 전극이 유전체로 둘러쌓여 있으므로 수명이 높다.

새로운 평면방전형 무수은 램프를 개발하였다. 이 램프는 두 개의 유리평판 사이에 방전공간을 만들고 한쪽 유리면의 양쪽 가장자리에 두 개의 전극을 설치하여 면방전을 유도한다. 양쪽 유리면에는 삼원색 형광체를 도포하고 Xe을 봉입하여 Xe의 진공자외선으로 형광체를 발광시킨다. 이 램프는 전극이 유전체로 덮혀있어 수명이 길다. 실험결과 기체압력 6.7[kPa], 구동전압 1,130[V]에서 최대휘도 9,200[cd/m^2], 광효율 20.4[lm/W]을 얻었고, 기체압력 2.7[kPa] 구동전압 1,120[V]에서 최대효율 34.1[lm/W], 휘도 1,080[cd/m^2]을 얻었다.

현재 무수은 램프는 수은 램프에 비해서 광학적 특성이 좋지 못하다. 무수은 램프에서 좋은 광학적 특성을 얻기 위해 가장 중요한 것은 수축이 없이 방전을 확산시키는 것이다. 이를 위해서 램프구조와 구동법을 최적화하는 것이 필요하다. 또한 기체압력을 높임으로서 Xe의 여기복사를 얻을 수 있었다.

1. Introduction

Recently, research works on mercury free fluorescent lamps for LCD backlightings are becoming active. In the Society for Information Display International Symposium 2000 (California, USA), four papers out of seven in the backlighting session were about mercury free fluorescent lamps. There was none in 1999.

Liquid crystal displays are widely used as information display devices for notebook/desktop computers, car navigation systems, and TVs. These displays need backlightings because the liquid crystal materials are non emissive. The backlighting for the notebook computers generally uses a light guide plate with a cold cathode fluorescent lamp(CCFL) as shown in Fig.1(a). For the desktop computers and TVs, multiple number of CCFLs are used with a reflector and a diffuser plate as shown in Fig.1(b) because they needs higher luminance. At present the CCFLs for LCD backlightings employ mercury discharge because of its good electro-optical characteristics. The use of mercury, however, causes difficulty in igniting the lamp under low ambient temperatures. Also a relatively long build-up time is necessary for the lamp to reach the saturated luminance level. In addition, a use of mercury is not recommended for environmental protection. In order to eliminate these problems, mercury free lamps are developed. The discharges utilized in the mercury free lamps are roughly classified into three types, (1) cylindrical discharge type, (2) micro-discharge type, and (3) flat discharge type.

2. Cylindrical discharge type

The cylindrical discharge tube is identical to that found in the typical Hg-CCFLs, since it is easy to replace Hg with Xe. The positive column has a tendency to contract to a narrow channel and this tendency is stronger for Xe than Hg. To avoid this, a Xe CCFL with a new structure was developed[1]. Figure 2 shows the structure of the lamp. An inner electrode is positioned at one of the edges of the glass tube, while a wire electrode is coiled around outer surface of the lamp. This structure, together with pulse voltage drive provides a cylindrical discharge without contraction. To obtain uniform luminance distribution along the tube axis, spaces between the wire electrode are changed according to the distance from the inner electrode as shown in Fig.2. The total luminous flux is over twice as much as that of the conventional mercury free CCFLs.

3. Micro-discharge type

A micro-discharge is alternatively called a

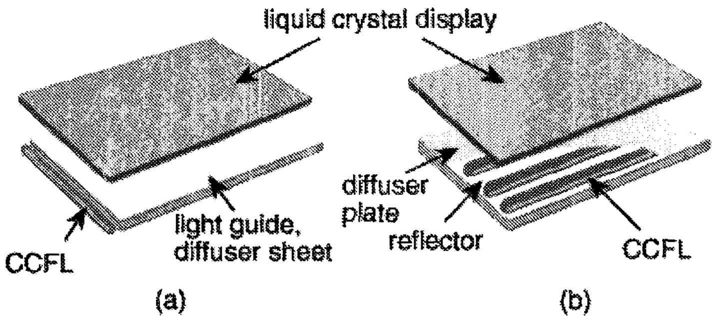


Figure 1. Backlighting System with CCFLs

dielectric barrier discharge. In the backlighting, micro-discharges are formed in the discharge space for which insulating layers coat metal electrodes. Flat light source is provide by a large number of micro-discharges in the discharge space.

There are two types of barrier discharge lamps. One of them utilizes the micro-discharges formed between parallel electrodes covered by dielectric layers[2,3,4]. Figure 3 shows the basic structure of the lamp. The spacing of the two plates is 0.5-2mm. Pure Xe or Xe-Ne mixture is contained at a pressure of 10-80[kPa]. Phosphor is coated on the dielectric layers. When the lamp is driven with 20-30[kHz] ac voltage of 1,000[Vrms], many micro-discharges with a diameter of about 0.1mm are formed between the gap. Luminance of 3,500[cd/m^2] with luminous efficacy of 27[lm/W] were obtained in a 3.5 inch diagonal lamp[2].

Figure 4 shows a structure of the other type of the barrier discharge lamp[5,6]. Anodes and cathodes with projections are provided on the rear glass plate. Distance between the anode and the cathode is about 10[mm]. The electrodes are covered with a dielectric layer. Front and rear glasses are sealed with a gap of few millimeters and Xe gas is filled at a pressure of 13[kPa] or less. When pulse voltage is applied between the electrodes, many triangular micro-discharges are formed between the electrodes. Each vertex of the discharge lies at the projection. A diffuser plate is employed to keep away the shape of discharges from sight.

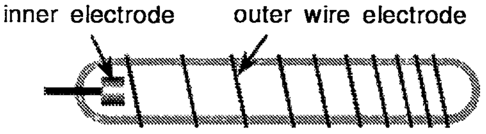


Figure 2. Harison's Xe CCFL

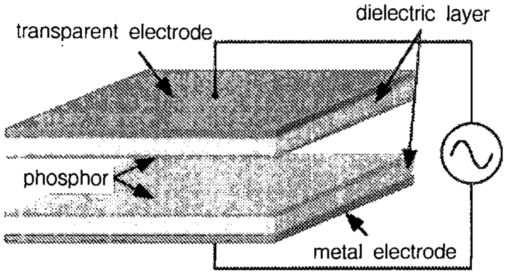


Figure 3. Xe barrier discharge lamp

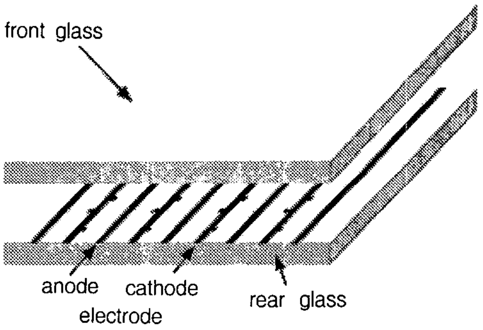


Figure 4. Osram's barrier discharge lamp

Because the electrodes of the above two lamps are covered with dielectric layers, it is expected that they have a long life. In order to utilize the Xe excimer which does not suffer from self-absorption, the pressure of these lamps is kept relatively high.

4. Flat discharge type

Flat discharge is generated in a flat discharge type lamp. Initial flat discharge lamp was developed for a car navigation LCD backlighting and it contained mercury. Although a luminance of 30,000[cd/m^2] and efficacy of 50[lm/W] were

Table 1. Specifications of mercury free flat discharge lamps

diagonal size [inch]		0.5	1.8	2.5	2.8	5.2	5.2
active area [mm^2]		13×10	37×29	51×41	57×42	108×75	
electrode separation [mm]		14	38	52	58	75	
gap[mm]		1.6	1.7	1.8	1.8	2.4	
gas mixture [%]	Ar	60				72	
	Ne	32					
	Xe	8				28	
pressure [kPa]		5.3				1.3 6.7	
lamp weight [g]		1.2	7.7	16.7	22.5	190	

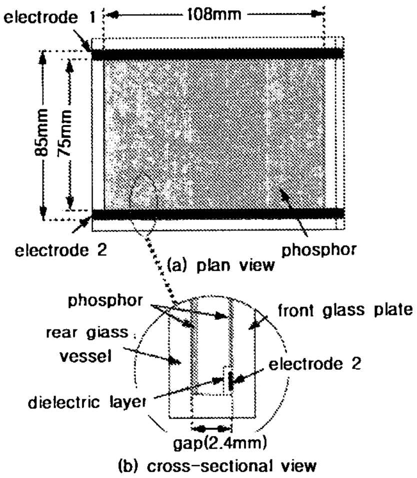


Figure 5. Structure of a 5.2-in. -diagonal Xe flat discharge lamp.
(a) plan view, (b) cross-sectional view at the circle of (a)

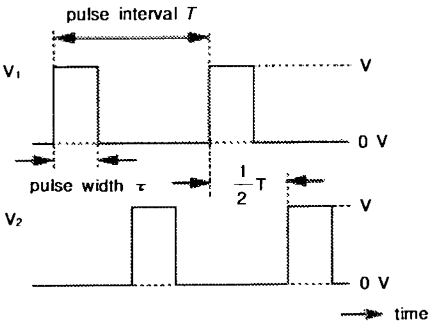


Figure 6. Waveforms of drive pulses

achieved[7], there were problems caused by use of mercury as mentioned earlier. We then developed 0.5 5.2 in.-diagonal mercury free Xe flat discharge lamps[8,9].

4.1 Structure of lamps

The structures of the Xe flat discharge lamps of various sizes are basically similar. An example of the 5.2-in.-diagonal lamp is shown in Fig.5. The lamp has a simple structure with a front glass plate and a rear glass vessel. The gap of the discharge space is 2.4 mm. On the inner side of the front glass plate (thickness 3 mm) is a couple of thick-film Ag electrodes which are covered with a 0.06 mm thick transparent dielectric layer. Tri-color phosphor is deposited on both front and rear glasses except for the regions above the electrodes. Thicknesses of the phosphor layers are 0.01mm for the front glass and 0.1mm for the rear glass. Vacuum ultraviolet radiation of wavelength 147nm from Xe atoms excites the phosphor. Since the electrodes are insulated from the discharge by the dielectric layer, sputtering of the Ag electrodes by ion bombardments does not occur. The lamp, therefore, is expected to have a long life. Specifications of the lamps are summarized in Table I.

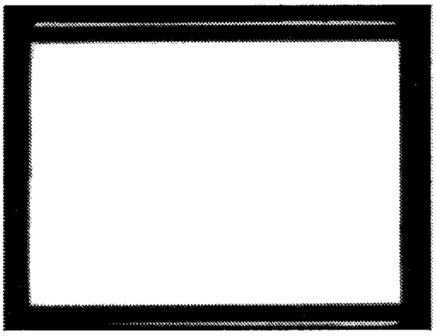
4.2 Driving of lamp

The electrodes are driven with trains of rectangular pulses V1 and V2 of Fig.6. The pulses have an identical amplitude V, pulse width t, and pulse interval T, but there is a 180° phase difference between them. Charges produced by the discharge are accumulated on the dielectric layer at the vicinity of the electrodes. Since these accumulated charges reduce the voltage across the electrode gap, the discharge gradually weakens and eventually terminates automatically along with current flow. An electric field induced by the following voltage pulse has an opposite polarity and the discharge ignites again.

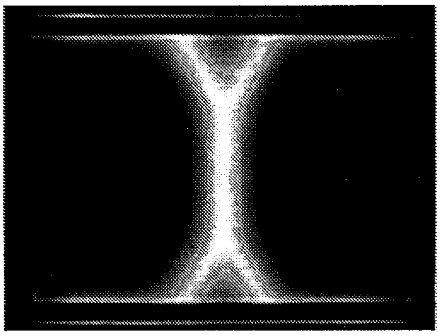
It is difficult to produce a uniform discharge in a rectangular solid shaped discharge space such as that of Fig.5. When the values of V, t, and T are set properly, a uniform and stable discharge extends over the entire volume as shown in Fig.8(a). If not, the power dissipation becomes so large that it heats the gas, and as a result, the discharge contracts to a narrow channel as shown in (b). In this case, the current density at the electrodes sometimes becomes very high and destroys the insulation of the dielectric layer.

4.3 Comparison of Hg and Xe lamps

Figure 8 compares the luminance and efficacy of the 5.2-in.Ar-Kr-Hg and Ar-Ne-Xe lamps. Both luminance and efficacy increase with voltage for the Hg lamp, since the lamp temperature, and hence Hg pressure increases. Ultraviolet radiation in the Ar-Ne-Xe lamps is the 147nm resonance line, which is easily trapped by the surrounding ground state Xe atoms. Because of the prolonged effective life time of the excited Xe atoms due to the trapping, free electrons have higher chances to destroy the excited state of the Xe atoms when the discharge current is increased. Therefore efficacy decreases as the voltage is increased. The peak luminance of the Ar-Ne-Xe lamp is one-third that of the Hg lamp, and the peak efficacy of the Ar-Ne-Xe lamp is three-fifths that of the Hg lamp. Efficacy of the Ar-Ne-Xe lamp exceeds that of Hg at low luminance levels.



(a) uniform and stable discharge



(b) contracted discharge

Figure 7. Examples of discharges

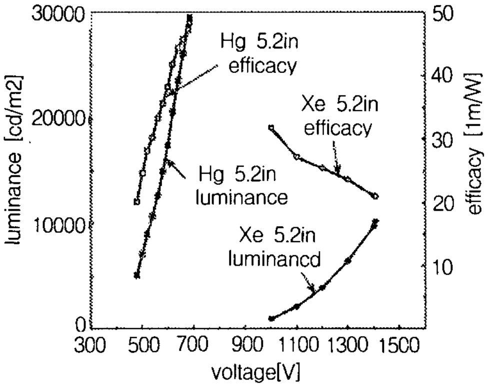


Figure 8. Luminance and efficacy vs. drive pulse voltage. For Ar-Ne-Xe lamps, pulse width: 1[μs], pulse interval: 60[μs]. For Ar-Kr-Hg lamp, pulse width: 30[μs], pulse interval: 60[μs].

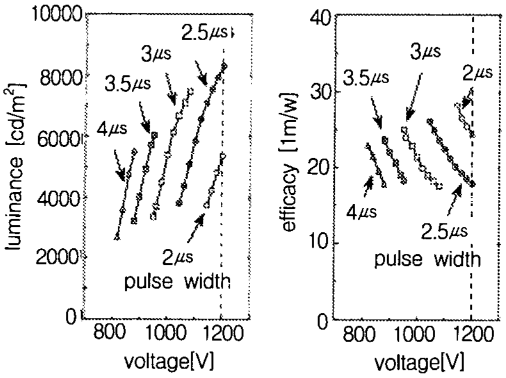


Figure 9. Luminance and efficacy vs. applied voltage of a 5.2-in. Ar-Xe lamp for various pulse widths. pressure: 5.3kPa, pulse interval: 40[μs]

4.4 Optical characteristics of 5.2-in.Ar-Xe lamp

Figure 9 shows the luminance and efficacy at various pulse widths as a function of drive voltage for 5.2-in. Ar-Xe lamp. The pressure is 5.3[kPa] and pulse interval is 40[ms]. Broken lines indicate the limitations of the drive electronics. Above the maximum drive voltage for each pulse width except for 2 and 2.5ms, the discharges contracts because the current density becomes too high. The shorter pulse width gives wider operating voltage margin because it can keep the current density low. Therefore high luminance can be obtained with shorter pulse widths. Also high efficacy can be obtained with shorter pulse widths provided that the luminance is kept constant.

Figure 10 shows luminance vs. efficacy at various pressures. The pulse width is 2ms. The curves are obtained by varying the drive voltage and pulse interval. The higher pressure needs higher drive voltage and shorter pulse interval. The higher pressure gives high efficacy when the luminance is kept constant. The maximum luminance of 9,200[cd/m^2] with efficacy of 20.4[lm/W] was obtained at the pressure 6.7[kPa], drive voltage 1,130[V], and drive pulse interval 25[ms]. Power consumption of the lamp under these conditions was 11.7[W]. The maximum efficacy of 34.1[lm/W] was realized with luminance of 1,080[cd/m^2] at the pressure 2.7[kPa], drive voltage 1,120[V], and drive pulse interval 120[ms]. Input power was 0.8[W].

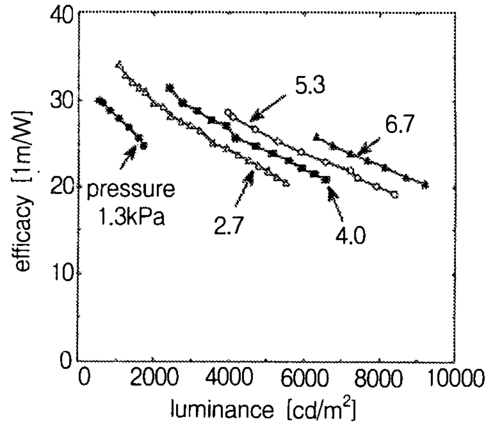


Figure 10. Efficacy vs. luminance of a 5.2-in. Ar-Xe lamp for various gas pressure. pulse width: 2[μs]

Figure 11 is an example of the luminance distribution at nine regions of the lamp. Upper and lower numbers indicate, respectively, luminance in cd/m^2 and their percentages with respect to the maximum luminance. Luminance uniformity defined by the ratio of the minimum to maximum luminance is 87.2[%].

4.5 Lamp size dependence

The shadowed region of Fig.12 shows an operating voltage window for various diagonal sizes. As the size increases, the operating voltage becomes higher due to slower build-up time of the discharges. The width of the voltage margin,

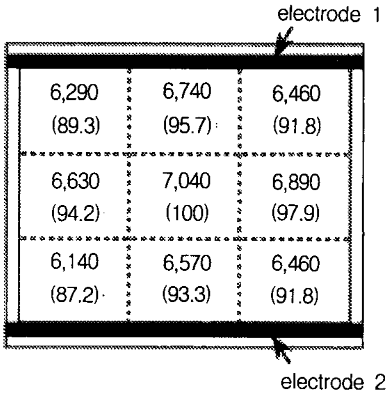


Figure 11. Luminance distribution in a 5.2-in. Ar-Xe lamp.

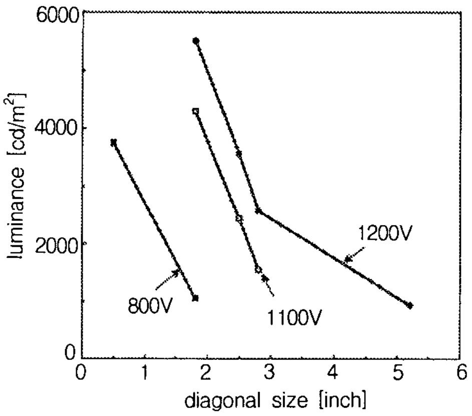


Figure 13. Luminance vs. diagonal size for Ar-Ne-Xe lamps. Pulse width: 1 [μs], pulse interval: 60[μs].

however, is independent of the diagonal size.

Dependence of luminance and efficacy on the diagonal size are shown in Figs.13 and 14. The smaller size gives higher luminance and lower efficacy, provided that the drive voltage is kept constant. Since the discharge current required to sustain the stable discharge does not depend on the diagonal size very much, the current density increases as the lamp becomes smaller. This leads to higher luminance, but lower efficacy due to the imprisonment effect.

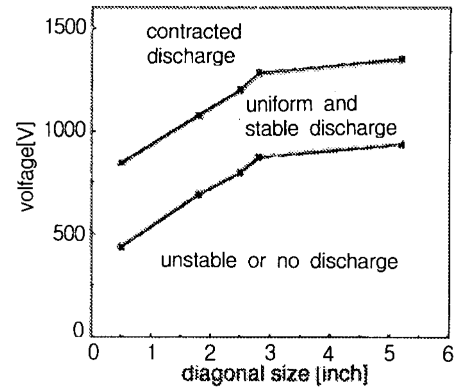


Figure 12. Voltage-diagonal size windows for obtainig flat discharge for Xe lamps. Pulse width: 2[μs], pulse interval: 60[μs].

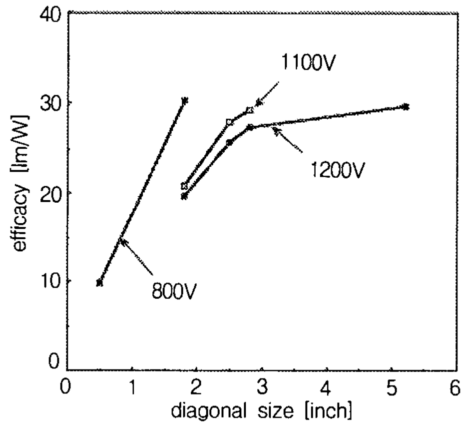


Figure 14. Efficacy vs. diagonal size for Ar-Ne-Xe lamps. Pulse width: 1[μs], pulse interval: 60[μs].

Table II. Maximum performances of Ar-Ne-Xe flat discharge lamps

diagonal size [inch]	0.5	1.8	2.5	2.8	5.2
max luminance [cd/m²]	5,000	6,100	6,600	6,600	10,200
uniformity [%]	83	89	94	88	97
max efficacy [lm/W]	12.7	30.2	28.7	30.5	31.9

Table II summarizes the maximum performances of the Ar-Ne-Xe flat discharge lamps. The drive pulse amplitude, width, and interval are different for each condition. The 5.2-in. lamp yields the highest luminance, since the voltage can be made higher than the rest of the lamps. Maximum efficacy can be achieved at lower voltages, shorter pulse widths, and longer pulse intervals. The luminance decreases when the efficacy is maximized.

5. Conclusions

At present, the optical performance of the mercury free Xe lamps is poor compared with the mercury lamps. However they are improving gradually. The most important for obtaining the good optical characteristics on the mercury free lamps is to diffuse the discharge in the discharge space without contraction. In order to obtain the diffused discharge, the optimizations of the lamp structure and driving method are required. Also Xe excimer radiation is obtained in various lamps by increasing gas pressure.

References

[1] H. Noguchi, et al., 2000 Intl. Symp. Digest of Tech. Pap., pp.935-937 (2000).

[2] T. Urakabe, et al., J. Light and Vis. Env., Vol. 20, No.2, pp.20-25, 1996.

[3] Min-Gip Kwak, et al., Proc. 18th Intl. Display Res. Conf., pp.467-470, 1998.

[4] J. Y. Choi, et al., Proc. 1st Intl. Display Manufacturing Conf., pp. 231-232, 2000.

[5] M. Ilmer, et al., Proc. 6th Intl. Display Workshops, pp.1107-1108 (1999).

[6] M. Ilmer, et al., 2000 SID Intl. Symp. Digest of Tech. Pap., 931-933 (2000).

[7] T. Shiga, et al., J. of the SID, vol.7, no.3, pp.151-156, 1999.

[8] T. Shiga, et al., Proc. 6th Intl. Display Workshops, pp.347-350, 1999.

[9] Y. Ikeda, et al., 2000 Intl. Symp. Digest Tech. Pap., pp.938-941, 2000.

◇ 著者紹介 ◇

TOMOKAZU SHIGA(志賀 智一)

Tomokazu Shiga received his B. Eng., M. Eng., and Ph. D. degrees in Electronic Engineering all from the University of Electro-Communications, Tokyo, in 1994, 1996, and 1999. He has been working as an assistant of the same university after his graduation. His research interests include low pressure gas discharge devices for displays, especially plasma displays and LCD back lightings.

1994년 전기·통신대 전자공학과 졸업(학사), 1996년 전기·통신대 대학원 졸업(석사), 1999년 전기·통신대 대학원 박사과정 졸업(박사), 1999년~현재 전기·통신대 전자공학과 조교, 주요연구분야 플라즈마 디스플레이, LCD 백라이트.