

A lighting mechanism for flat electron emission lamp

Jung-Yu Li, Shih-Pu Chen, Chia-Hung Li, Yi-Ping Lin, Yen-I Chou, Ming-Chung Liu, Po-Hung Wang, Hui-Kai Zeng, Tai-Chiung Hsieh, and Jenh-Yih Juang

Citation: *Applied Physics Letters* **94**, 091501 (2009); doi: 10.1063/1.3093802

View online: <http://dx.doi.org/10.1063/1.3093802>

View Table of Contents: <http://scitation.aip.org/content/aip/journal/apl/94/9?ver=pdfcov>

Published by the [AIP Publishing](#)

Articles you may be interested in

[On the Intensity Profile of Electric Lamps and Light Bulbs](#)

Phys. Teach. **51**, 491 (2013); 10.1119/1.4824947

[Rare earth doped core-shell particles as phosphor for warm-white light-emitting diodes](#)

Appl. Phys. Lett. **98**, 261919 (2011); 10.1063/1.3606540

[Important Atomic, Molecular and Radiative Processes in Low Pressure Discharge Lamps](#)

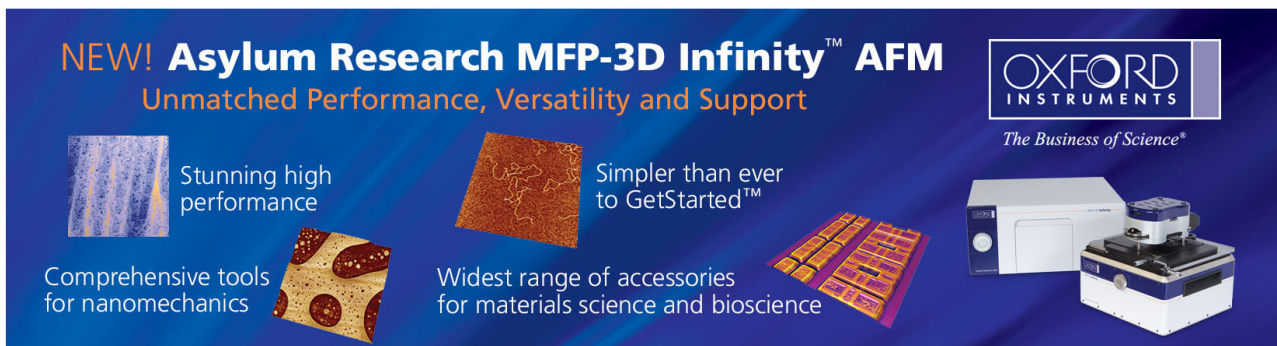
AIP Conf. Proc. **926**, 281 (2007); 10.1063/1.2768860

[Efficiency of cathodoluminescent phosphors for a field-emission light source application](#)

J. Vac. Sci. Technol. B **21**, 1618 (2003); 10.1116/1.1587134

[Organic light-emitting devices for illumination quality white light](#)

Appl. Phys. Lett. **80**, 3470 (2002); 10.1063/1.1478786



NEW! Asylum Research MFP-3D Infinity™ AFM
Unmatched Performance, Versatility and Support

OXFORD INSTRUMENTS
The Business of Science®

Stunning high performance

Simpler than ever to GetStarted™

Comprehensive tools for nanomechanics

Widest range of accessories for materials science and bioscience

A lighting mechanism for flat electron emission lamp

Jung-Yu Li,^{1,a)} Shih-Pu Chen,^{1,b)} Chia-Hung Li,^{1,2,c)} Yi-Ping Lin,¹ Yen-I Chou,¹ Ming-Chung Liu,¹ Po-Hung Wang,¹ Hui-Kai Zeng,³ Tai-Chiung Hsieh,^{1,2} and Jenh-Yih Juang^{1,2,d)}

¹Energy and Environment Research Laboratories, Industrial Technology Research Institute, 195, Sec. 4, Chung-Hsin Road, Chutung 310, Taiwan

²Department of Electrophysics, National Chiao Tung University, 1001 Ta-Hsueh Road, Hsinchu 300, Taiwan

³Department of Electronic Engineering, Chung Yuan Christian University, Chung Li 320, Taiwan

(Received 8 December 2008; accepted 3 February 2009; published online 4 March 2009)

We propose a lighting mechanism for generating uniform planar light. The device integrates electron beams induced by gas discharge with cathodoluminescence at the anode, where the spectra of the emitted light depend entirely on the phosphor materials coated on the anode. Consequently, ultraviolet is not required and the usage of mercury can be avoided. In addition, the features of double-side lighting, transparency, and gray-scale images indicate that the flat electron emission lamp might become potential candidate for the next generation green lighting source. © 2009 American Institute of Physics. [DOI: 10.1063/1.3093802]

The incandescent lamp invented in the 19th century drastically changed human civilization. Afterward, various kinds of lighting and display technologies were developed and categorized based on their lighting mechanisms:^{1–6} (1) fluorescent lamps (FL),^{1,2,4} (2) cathodoluminescence (CL),³ (3) solid-state lightings,¹ and (4) gas-discharge lamps.^{1,5,6} However, due to the increasing environmental concerns and demands for uniform planar lighting sources,² alternative lighting means are hotly pursued. The left panel of Fig. 1 displays the lighting processes of the FL widely used in daily lighting and back light of most display devices, wherein electrons emitted from the cathode collide and excite the gas molecules, resulting in the emission of the ultraviolet (UV) light, which in turn excites the photoluminescent phosphor and gives rise to the light. In this kind of device, two essential ingredients are required: the gas must be able to emit UV when excited and its pressure in the tube should be high enough (a few torr \sim 1 atm)^{5,6} in order to sustain the stable glow discharge and high UV intensity.⁷ Unfortunately, it is the environmentally hazardous mercury that meets the requirement. Alternatively, the lighting mechanism for the CL (middle panel of Fig. 1) directly utilizes the electrons emitted from the cathode to bombard the CL phosphor coated on the anode and, thus, requires a much higher vacuum ($<10^{-6}$ torr).⁸ In addition, due to its emission nature, the device usually produces pointlike light and needs a driving mechanism to scan the light for displaying purposes. Cathode ray tube is the typical example operating with this mechanism.⁹ It is interesting to note that manufacturers working in these two separated fields had seldom communicated to each other. With the increasing demands of developing environmentally sustainable planar lighting devices, exploring mechanisms for the next generation lighting is in order. Here we propose a device, termed as flat electron emission lamp (FEEL), which integrates the two abovementioned lighting processes to produce planar light with reasonable luminescence intensity and, more importantly, without toxic substances involved.

As is depicted in the right panel of Fig. 1, the lighting mechanism of FEEL consists of three steps. First, analogous to the FL mechanism, the secondary electron emission is induced by ion bombardment at the cathode surface from the discharged gas,⁵ albeit that the discharge is initiated in a much lower gas pressure ranging from 10^{-1} to 10^{-2} torr. Then, the electrons are accelerated by the electrical field established between cathode and anode. Due to the low gas pressure, the occurrence of scattering between the electrons and the gas molecules will be relatively rare compared to that in FL tubes. Finally, the energetic electrons will impact on the phosphor-coated anode and activate the phosphor to emit visible light.¹ Unlike the FL tube that uses UV light to excite photoluminescence phosphor for emitting light, the entire process of FEEL lighting does not require UV, and therefore no mercury is required inside the device.

As illustrated in Fig. 2, the FEEL device consists of a cathode glass, a glass spacer, and a CL phosphor-coated anode glass with nitrogen (N_2) as the working gas. The height

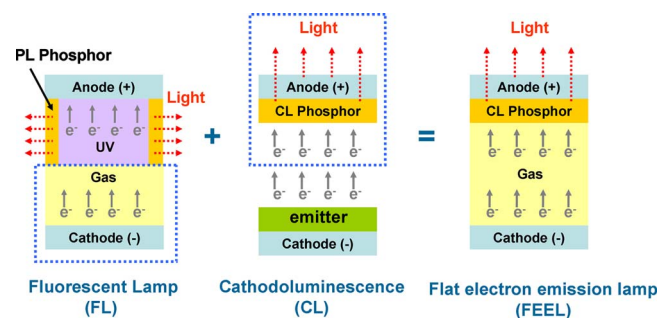


FIG. 1. (Color online) The lighting mechanism of FEEL consists of the integration of modified mechanisms of FL cathode and CL anode. Electron beams are first induced by discharge from cathode and then accelerated toward the anode by the electrical field. Finally, the electron impacts on the phosphor-coated anode to induce light emission. This combination easily generates planar electron sources for exciting the phosphor screen covering the entire anode to produce uniform photon distribution.

^{a)}Electronic mail: jy_lee@itri.org.tw.

^{b)}Electronic mail: chenshihp@itri.org.tw.

^{c)}Electronic mail: itri401884@itri.org.tw.

^{d)}Electronic mail: jyuang@cc.nctu.edu.tw.

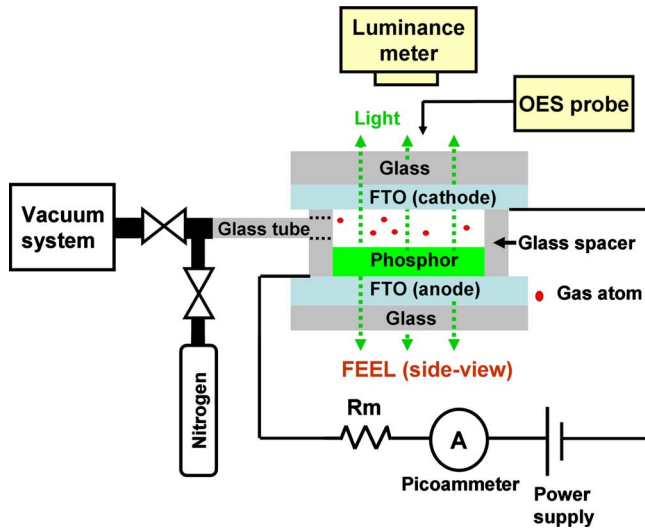


FIG. 2. (Color online) The schematics of the FEEL device structure and the experimental setup for measuring the lighting and discharge behaviors. The device was constructed by cathode, glass spacer, gas, and CL phosphor-coated anode. The pressure inside the device can be adjusted via a vacuum system. The experimental setup for simultaneously measuring I - V curves, Paschen curves, luminance, and OES spectrum indicates the correlation between discharge and lighting mechanism of FEEL.

of spacer was 10 mm and the size of lighting screen (phosphor surface) was $30 \times 30 \text{ mm}^2$. The electrode glasses were deposited with a layer of fluorine-doped tin-oxide film. A glass tube connected the glass spacer and vacuum system for evacuating and adjusting the pressure inside the device. The dc voltage power (Keithley 248) and picoammeter (Keithley 6485) were used for analyzing the discharge and electrical behavior; Multi-Function Color Analyzer (Ruyico Tech.) and optical emission spectroscopy (OES) probe (StekkarNet EPP200V) were positioned on top of device for measuring the optical properties.

To obtain the optimal conditions for FEEL lighting, we gradually decrease the gas pressure inside the device and simultaneously observe the transitions of the lighting mode from the lighting images. Figure 3 depicts the prevailing mechanisms in different regimes. With an applied dc voltage of 5 kV, which ensures the turn-on status for FEEL, the top-view and side-view images of the device show that the glow discharge features [Fig. 3(a)] gradually transform to the FEEL mechanism [Fig. 3(c)] as the N_2 pressure is approaching to an optimized condition. To further confirm the predominant lighting source(s) in each pressure regime, the OES spectra are also displayed in Fig. 3. It is clear that only the glow excitation is active when the N_2 pressure is higher than 0.2 torr [Fig. 3(a)], consistent with what is seen in the images. The four distinguished peaks identified in the OES spectrum with the wavelength respectively locating at 337, 358, 391.5, and 427.5 nm are originated from the nitrogen gas excitations belonging to the first negative system ($B^2\Sigma_u^+ - X^2\Sigma_g^+$) (358.2, 391.4, and 427.8 nm) and the second positive system ($C^3\Pi_u - B^3\Pi_g$) (337.1 nm).¹⁰ In this case, obviously the kinetic energy of electrons is too low to activate the emission from the phosphor, presumably due to the frequent scattering in such high pressure environment. The frequent scattering between the electrons and gas molecules is exactly what one would expect for causing the glow excitation.

As the N_2 pressure is decreased to the range between 0.11 and 0.20 torr [Fig. 3(b)], the side-view image shows the emergence of phosphor emission with attenuating glow background. The OES spectrum evidently shows the weakened peak intensity from the N_2 excitations, with an apparent peak centering at the characteristic wavelength (530 nm) of the phosphor used in this study. We believe that in this lower pressure range, there exists some population of electrons with residual kinetic energy higher than the threshold energy for activating phosphor emission. In this regime, nonethe-

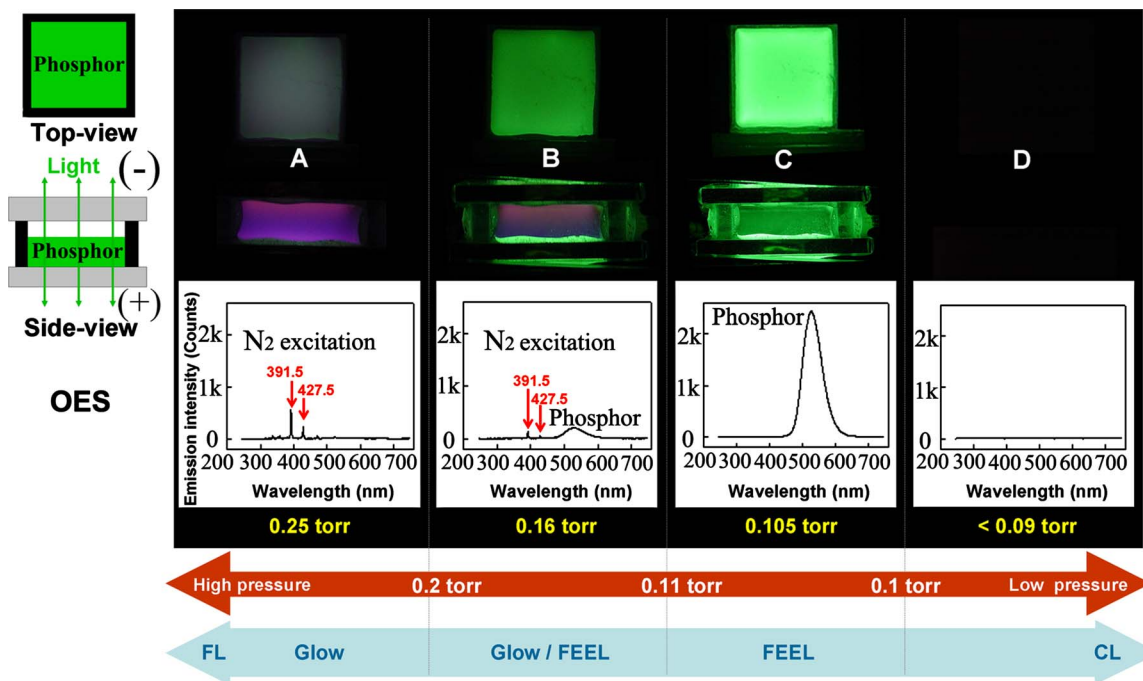


FIG. 3. (Color online) The lighting mode transitions as a function of gas pressure inside the FEEL devices with a fixed applied voltage of 5 kV. Both the device images and OES spectra show the close interplay between the scattering-induced glow discharge and the prevailing of electron emission lighting.

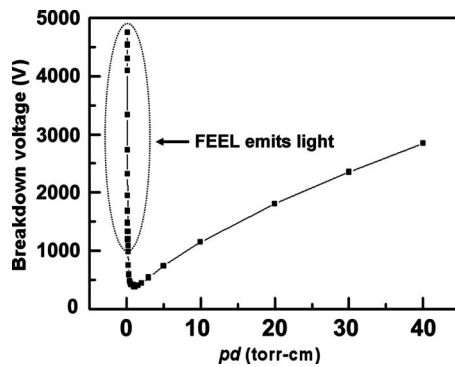


FIG. 4. The Paschen curve of FEEL device with N_2 as the working gas. The area circled by the red dots indicates the operation regime of the FEEL device.

less, the gas excitation glow and phosphor emission are co-existent, indicating that the predominant mechanisms operating in the system are strongly dependent on the gas pressure and, in fact, controllable. As the N_2 pressure is further decreased to the range between 0.10 and 0.11 torr [Fig. 3(c)], the OES spectrum displays only a strong peak at 530 nm, reflecting the green light emitted from the anode phosphor and the characteristic peaks of the N_2 glow excitations disappeared altogether. We refer this state as the FEEL state because it appears to be the dominant lighting mechanism. Although the pressure (0.11 torr) at which the system switches from the glow/FEEL coexistent state to the pure FEEL state [Figs. 3(b) and 3(c)] appears to be somewhat arbitrary, the marked effect of even a slight portion of glow on the device luminance indicates that the electron-gas scattering can affect the luminance efficiency significantly.

As the N_2 pressure falls below $P=0.1$ torr, neither any lighting is seen in the images, nor any peak is revealed in the OES spectrum. It indicates that the glow excitation of N_2 gas and lighting from phosphor emission are all not active under this condition [Fig. 3(d)]. Intuitively, one would expect that at this low pressure condition, the device should operate similarly to the CL mode prevailing in field-emission display (FED). However, for FED applications, usually the turn-on electrical field of cathode emitter is well above the order of $V/\mu\text{m}$. Consequently, as indicated by the Fowler–Nordheim theory,^{11,12} in order to lower the turn-on field, high aspect ratio cathode emitters such as carbon nanotubes (CNTs) are preferred. Indeed, recent CNT-FED has demonstrated a reduced turn-on field of $E=0.5\text{--}2.1$ $V/\mu\text{m}$.^{3,12} In our case, the estimated electrical field is about 0.5 $V/\mu\text{m}$, near the turn-on field of CNT. However, without glow discharge, there will be no electron because the applied external field is not enough to trigger the FED mechanism, leading to virtually no response in the FEEL device when operated in low gas pressure regime [Fig. 3(d)].

Finally, we discuss the behaviors of the breakdown voltage V_b near the operation conditions of FEEL devices by measuring the Paschen curve.⁵ As shown in Fig. 4, the Paschen curve demonstrates that FEEL is indeed operating in the lower pressure regime located on the left hand side of the

curve. Obviously, the steep change in V_b within a slim region of pressure change is currently the major hurdle to be dealt with. Improvements by using different working gases and cathode materials with better secondary electron emissions are currently under extensive investigations. Nevertheless, the current structure immediately exemplifies one of the advantages that can be accomplished with the mechanisms implemented in the FEEL devices—generation of large area planar lighting source with uniform photon distribution.¹³ The efficacy of the device was estimated by dividing the luminance obtained from an integrating sphere by the operating dc input power of 1.3 W. With our current setup, an efficacy of 40 lm/W is routinely obtained in 4 in. devices with green phosphor. Although, it is still lower than the typical efficacy of 80–100 lm/W in FL lamps, it is nevertheless very close to the performance of cold cathode FLs ubiquitously used in display industries.

In summary, we have demonstrated a lighting mechanism based on the innovative integration of two mature technologies, namely, the gas discharge and CL. The characteristic spectra show that the electron kinetic energy is the dominant factor for the eventual luminance of the device. Currently, an efficacy of 40 lm/W has been obtained for 4 in. FEEL devices with green light phosphor. It is anticipated that by improving the electron emission coefficient of the cathode and optimizing the phosphor composition, the efficiency of FEEL can be further improved. Despite many obstacles still needed to be overcome, the current FEEL devices have indeed demonstrated the high flexibility and application potential for the next generation mercury free green lightings.

We acknowledge the financial support from the Ministry of Economic Affairs of Taiwan, ROC. J.Y.J. is partly supported by the MOE-ATU program at NCTU.

¹T. Jüstel, H. Nikol, and C. Ronda, *Angew. Chem., Int. Ed.* **37**, 3084 (1998).

²M. Ilmer, R. Lecheler, H. Schweizer, and M. Seibold, *SID Int. Symp. Digest Tech. Papers* **31**, 931 (2000).

³A. A. Talin, K. A. Dean, and J. E. Jaskie, *Solid-State Electron.* **45**, 963 (2001).

⁴U. Kogelschatz, *Proc. SPIE* **5483**, 272 (2004).

⁵G. G. Lister, J. E. Lawler, W. P. Lapatovich, and V. A. Godyak, *Rev. Mod. Phys.* **76**, 541 (2004).

⁶K. W. Park, H. S. Hwang, M. H. Han, H. K. Baik, and K. M. Song, *Appl. Phys. Lett.* **92**, 061502 (2008).

⁷J. P. Boeuf, *J. Phys. D* **36**, R53 (2003).

⁸M. Itoh and L. Ozawa, *Annu. Rep. Prog. Chem., Sect. C: Phys. Chem.* **102**, 12 (2006).

⁹L. Ozawa and M. Itoh, *Chem. Rev. (Washington, D.C.)* **103**, 3835 (2003).

¹⁰R. W. B. Pearse and A. G. Gaydon, *The Identification of Molecular Spectra*, 3rd ed. (Chapman and Hall, London, 1965), pp. 209–220.

¹¹Y. Saito and S. Uemura, *Carbon* **38**, 169 (2000).

¹²J.-M. Bonard, H. Kind, T. Stöckli, and L.-O. Nilsson, *Solid-State Electron.* **45**, 893 (2001).

¹³See EPAPS Documents No. E-APPLAB-94-003910 for some information on the OES spectrum of phosphor illumination and N_2 excitation and on the application of FEEL, such as the color tunable double-side gray-scale ambient lightings, power-saving building, and heat insulation materials. For more information on EPAPS, see <http://www.aip.org/pubservs/epaps.html>.