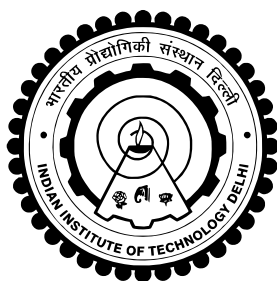


FABRICATION AND CHARACTERIZATION OF EFFICIENT LIGHT EMITTING DIODES

Parvez Akhtar



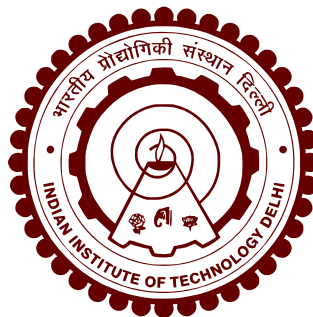
**Department of Electrical Engineering
Indian Institute of Technology Delhi
May 2025**

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Fabrication and characterization of efficient light emitting diodes

Parvez Akhtar

A dissertation submitted in partial fulfilment of the requirements
for the degree of Doctor of Philosophy



Department of Electrical Engineering
Indian Institute of Technology Delhi
May 2025

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This is to certify that the thesis entitled **Fabrication and characterization of efficient light emitting diodes**, being submitted by **Parvez Akhtar** to IIT Delhi, is worthy of consideration for the award of the degree of Ph.D. and is a record of the original research work carried out by this student under my/our supervision. The results contained in this thesis, which may have been previously communicated in the form of manuscripts, conference presentations or patent filings, have not been submitted in part or full, to any other University or Institute for the award of any academic degree.

I/We certify that this student has pursued the prescribed course of research.

Research Advisor(s):



MADHUSUDAN SINGH

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Parvez Akhtar
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Abstract

Light-emitting diodes (LED) are semiconductor devices that have changed the market scenario in display technology and lighting sources within a few decades of their inception. It surpasses the market compared to the existing technologies, especially LCD and CRT in the display, and incandescent bulbs and CFL tubes in lighting sources, due to their unique properties of high brightness and contrast ratio, lower driving current, thin and lightweight display and self-backlighting units. However, there are still issues with the organic light-emitting materials, such as wide spectral width (lower high color purity) and a high cost associated with the complex organic small molecules synthesis and required thermal deposition processes.

This dissertation focuses on developing a low-cost, solution-processable, and narrow colour spectrum, all-inorganic (CsPbBr_3) light-emitting material for applying LED devices. Despite such advantages, pinholes, poor surface coverage, and stability issues limit widespread perovskite light-emitting devices (PeLEDs) applications in solid-state lighting. We have developed a thin film of perovskite with PEG-PVP polymer to reduce the inherited pinhole issues of the thin film and compare their performance (control (without polymer) vs. test (with polymer)). We find that the test PeLED device shows a 12.1% reduction in the turn-on voltage (V_{on}), a 97.21% reduction in leakage current density, a 200%+ enhancement in maximum brightness, and a 700% increase in power efficiency compared to a control CsPbBr_3 device.

Alongside, we have developed a thin film of a high green index hole-injection layer (HIL) material (V_2O_5) (low surface roughness: 1.3 nm) as an alternative HIL to the well-established PEDOT:PSS for demonstrating a hybrid polymer-inorganic PeLED because the PEDOT:PSS has a detrimental effect on the device instability that is further associated well-established device failure mechanism. Test devices with the new hole injection layer demonstrate nearly identical maximum current efficiencies (4.23 cd/A vs. 4.19 cd/A), and luminous efficacies (2.99 lm/W vs. 2.32 lm/W) when compared to a control device fabricated with the conventional hole injection layer. To examine the transport of holes in the above hole injection layer, we carried out device simulations based on a physical charge control model, including defect-assisted tunneling for hole injection. Close agreement for current-voltage characteristics is observed.

Further, we synthesized a novel MFPy-POSS to apply the blue-emission organic LED. The device exhibited a turn-on voltage (6V) with an excellent blue emission color (437 nm) and CIE coordinates of (0.163, 0.134). Furthermore, we have also fabricated the white OLED devices by mixing the blue emitting (truxene) and orange emitter (DCM), observing the thickness effect on the performance of the OLED devices.

Finally, we developed an inbuilt, cost-effective, portable setup to measure the luminance lifetime of the LED (standard LT50).

In summary, this dissertation covers the synthesis and characterization of perovskite material (CsPbBr_3) and device fabrication. It also includes the development of an alternative HIL for perovskite LED. Additionally, the dissertation details the fabrication of blue organic LED using POSS blue emitter and white organic LED employing truxene-DCM, along with the development of the cost-effective LED lifetime measurement tool.

सार

प्रकाश उत्सर्जक डायोड (एलईडी) अर्धचालक उपकरण हैं जिन्होंने डिस्प्ले में बाजार परिदृश्य को बदल दिया है अपनी स्थापना के कुछ दशकों के भीतर प्रौद्योगिकी और प्रकाश स्रोत। यह बाजार की तुलना में आगे निकल जाता है मौजूदा प्रौद्योगिकियां, विशेष रूप से डिस्प्ले में एलसीडी और सीआरटी, और गरमागरम बल्ब और सीएफएल ट्यूब प्रकाश स्रोत, उच्च चमक और कंट्रास्ट अनुपात, कम ड्राइविंग करंट के अपने अद्वितीय गुणों के कारण, पतला और हल्का डिस्प्ले और सेल्फ-बैकलाइटिंग इकाइयाँ [1, 2, 3, 4, 5]। हालाँकि, इसमें अभी भी मुद्दे हैं कार्बनिक प्रकाश उत्सर्जक सामग्री अपने कम जीवनकाल, व्यापक रंग चौड़ाई (कम उच्च रंग शुद्धता) के कारण और थर्मल जमाव प्रक्रिया के लिए जटिल कार्बनिक छोटे अणुओं को संश्लेषित करने की उच्च लागत।

यह शोध प्रबंध कम लागत, समाधान-प्रक्रिया योग्य और संकीर्ण रंग स्पेक्ट्रम, एलिनऑर्गेनिक विकसित करने पर केंद्रित है (CsPbBr₃) एलईडी उपकरणों को लगाने के लिए प्रकाश उत्सर्जक सामग्री। ऐसे फायदों के बावजूद, पिनहोल, खराब सतह कवरेज, और स्थिरता के मुद्दे व्यापक पेरोव्स्काइट प्रकाश उत्सर्जक उपकरणों (पीईएलईडी) अनुप्रयोगों को सीमित करते हैं ठोस-अवस्था प्रकाश व्यवस्था में। हमने पीईजी-पीवीपी पॉलिमर के साथ पेरोव्स्काइट की एक पतली फिल्म विकसित की है पतली फिल्म के वंशानुगत पिनहोल मुद्दों को कम करें और उनके प्रदर्शन की तुलना करें (नियंत्रण (पॉलिमर के बिना) बनाम परीक्षण (बहुलक के साथ)। हमने पाया कि परीक्षण PeLED डिवाइस टर्न-ऑन वोल्टेज में 12.1% की कमी दिखाता है (वॉन), लीकेज करंट घनत्व में 97.21% की कमी, अधिकतम चमक में 200%+ की वृद्धि, और ए नियंत्रण CsPbBr₃ डिवाइस की तुलना में बिजली दक्षता में 700% की वृद्धि [6]।

साथ ही, हमने हाई ग्रीन इंडेक्स होल-इंजेक्शन लेयर (HIL) सामग्री (V2O₅) की एक पतली फिल्म विकसित की है। (कम सतह खुरदरापन: 1:3 एनएम) प्रदर्शन के लिए अच्छी तरह से स्थापित PEDOT: PSS के वैकल्पिक HIL के रूप में एक हाइब्रिड पॉलिमर-अकार्बनिक PeLED क्योंकि PEDOT:PSS का डिवाइस की अस्थिरता पर हानिकारक प्रभाव पड़ता है यह आगे अच्छी तरह से स्थापित डिवाइस विफलता तंत्र से जुड़ा है। नए छेद इंजेक्शन के साथ उपकरणों का परीक्षण करें परत लगभग समान अधिकतम वर्तमान क्षमता (4.23 cd/A vs. 4.19 cd/A), और चमकदार प्रदर्शित करती है दक्षता (2.99 vs. 2.32 lm/W) पारंपरिक के साथ निर्मित नियंत्रण उपकरण की तुलना में छेद इंजेक्शन परत। उपरोक्त छेद इंजेक्शन परत में छेद के परिवहन की जांच करने के लिए, हमने डिवाइस का उपयोग किया छेद इंजेक्शन के लिए दोष-सहायता सुरंग सहित भौतिक चार्ज नियंत्रण मॉडल पर आधारित सिमुलेशन। वर्तमान-वोल्टेज विशेषताओं के लिए करीबी सहमति देखी गई है [7]।

इसके अलावा, हमने ब्लू-उत्सर्जन कार्बनिक एलईडी को लागू करने के लिए एक उपन्यास एमएफपीवाई-पीओएसएस को संश्लेषित किया। डिवाइस का प्रदर्शन किया गया उत्कृष्ट नीले उत्सर्जन रंग (437 एनएम) और सीआईई निर्देशांक के साथ एक टर्न-ऑन वोल्टेज (6V) (0.163, 0.134)। इसके अलावा, हमने नीले उत्सर्जन को मिलाकर सफेद ओएलईडी डिवाइस भी तैयार किए हैं (Truxene) और ऑरेंज एमिटर (DCM), ओएलईडी उपकरणों के प्रदर्शन पर मोटाई के प्रभाव का अवलोकन करते हुए। अंत में, हमने चमक जीवनकाल (मानक) का अनुमान लगाने के लिए एक इनबिल्ट, लागत प्रभावी, पोर्टेबल सेटअप विकसित किया L-70)।

संक्षेप में, यह शोध प्रबंध पेरोव्स्काइट सामग्री (CsPbBr₃) के संश्लेषण और लक्षण वर्णन को शामिल करता है। और उपकरण निर्माण। इसमें ऑप्टोइलेक्ट्रॉनिक उपकरणों के लिए वैकल्पिक एचआईएल का विकास भी शामिल है और दोष-सहायक टनलिंग मॉडल का उपयोग करके डिवाइस का अनुकरण किया। इसके अतिरिक्त, शोध प्रबंध का विवरण है पीओएसएस ब्लू एमिटर और ट्रक्सिन-डीसीएम का उपयोग करके सफेद ऑर्गेनिक एलईडी का उपयोग करके नीली ऑर्गेनिक एलईडी का निर्माण, लागत प्रभावी एलईडी आजीवन परीक्षण सेटअप के विकास के साथ।

ਸਾਰ

ਲਾਈਟ-ਐਮੀਟਿੰਗ ਡਾਇਓਡ (LED) ਸੈਮੀਕੰਡਕਟਰ ਡਿਵਾਈਸ ਹਨ ਜਿਨ੍ਹਾਂ ਨੇ ਆਪਣੀ ਸ਼ੁਰੂਆਤ ਦੇ ਕੁਝ ਦਹਾਕਿਆਂ ਦੇ ਅੰਦਰ ਡਿਸਪਲੇ ਤਕਨਾਲੋਜੀ ਅਤੇ ਰੋਸ਼ਨੀ ਸਰੋਤਾਂ ਵਿੱਚ ਬਾਜ਼ਾਰ ਦੇ ਦ੍ਰਿਸ਼ ਨੂੰ ਬਦਲ ਦਿੱਤਾ ਹੈ। ਇਹ ਮੌਜੂਦਾ ਤਕਨਾਲੋਜੀਆਂ, ਖਾਸ ਕਰਕੇ ਡਿਸਪਲੇ ਵਿੱਚ LCD ਅਤੇ CRT, ਅਤੇ ਰੋਸ਼ਨੀ ਸਰੋਤਾਂ ਵਿੱਚ ਇਨਕੈਂਡੀਸੈਂਟ ਬਲਬ ਅਤੇ CFL ਟਿਊਬਾਂ ਦੇ ਮੁਕਾਬਲੇ ਬਾਜ਼ਾਰ ਨੂੰ ਪਛਾੜ ਦਿੰਦਾ ਹੈ, ਉੱਚ ਚਮਕ ਅਤੇ ਕੰਟ੍ਰਾਸਟ ਅਨੁਪਾਤ, ਘੱਟ ਡਰਾਈਵਿੰਗ ਕਰੰਟ, ਪਤਲੇ ਅਤੇ ਹਲਕੇ ਡਿਸਪਲੇਅ ਅਤੇ ਸਵੈ-ਬੈਕਲਾਈਟਿੰਗ ਯੂਨਿਟਾਂ ਦੇ ਆਪਣੇ ਵਿਲੱਖਣ ਗੁਣਾਂ ਦੇ ਕਾਰਨ। ਹਾਲਾਂਕਿ, ਜੈਵਿਕ ਰੋਸ਼ਨੀ-ਐਮੀਟਿੰਗ ਸਮੱਗਰੀਆਂ ਨਾਲ ਅਜੇ ਵੀ ਸਮੱਸਿਆਵਾਂ ਹਨ, ਜਿਵੇਂ ਕਿ ਚੌੜੀ ਸਪੈਕਟ੍ਰਲ ਚੌੜਾਈ (ਘੱਟ ਉੱਚ ਰੰਗ ਸ਼ੁੱਧਤਾ) ਅਤੇ ਗੁੰਝਲਦਾਰ ਜੈਵਿਕ ਛੋਟੇ ਅਣੂਆਂ ਦੇ ਸੰਸਲੇਸ਼ਣ ਅਤੇ ਲੋੜੀਂਦੇ ਥਰਮਲ ਡਿਪੋਜ਼ਿਸ਼ਨ ਪ੍ਰਕਿਰਿਆਵਾਂ ਨਾਲ ਜੁੜੀ ਉੱਚ ਲਾਗਤ।

ਇਹ ਖੋਜ ਨਿਬੰਧ LED ਡਿਵਾਈਸਾਂ ਨੂੰ ਲਾਗੂ ਕਰਨ ਲਈ ਇੱਕ ਘੱਟ-ਲਾਗਤ, ਹੱਲ-ਪ੍ਰਕਿਰਿਆਯੋਗ, ਅਤੇ ਤੰਗ ਰੰਗ ਸਪੈਕਟ੍ਰਮ, ਆਲ-ਅਜੈਵਿਕ (CsPbBr_3) ਲਾਈਟ-ਐਮੀਟਿੰਗ ਸਮੱਗਰੀ ਵਿਕਸਤ ਕਰਨ 'ਤੇ ਕੇਂਦਰਿਤ ਕਰਦਾ ਹੈ। ਅਜਿਹੇ ਫਾਇਦਿਆਂ ਦੇ ਬਾਵਜੂਦ, ਪਿੰਨਹੋਲ, ਮਾੜੀ ਸਤਹ ਕਵਰੇਜ, ਅਤੇ ਸਥਿਰਤਾ ਮੁੱਦੇ ਠੋਸ-ਅਵਸਥਾ ਰੋਸ਼ਨੀ ਵਿੱਚ ਵਿਆਪਕ ਪੇਰੋਵਸਕਾਈਟ ਲਾਈਟ-ਐਮੀਟਿੰਗ ਡਿਵਾਈਸਾਂ (PeLEDs) ਐਪਲੀਕੇਸ਼ਨਾਂ ਨੂੰ ਸੀਮਤ ਕਰਦੇ ਹਨ। ਅਸੀਂ ਪਤਲੀ ਫਿਲਮ ਦੇ ਵਿਰਾਸਤੀ ਪਿੰਨਹੋਲ ਮੁੱਦਿਆਂ ਨੂੰ ਘਟਾਉਣ ਅਤੇ ਉਹਨਾਂ ਦੀ ਕਾਰਗੁਜ਼ਾਰੀ (ਨਿਯੰਤਰਣ (ਪੋਲੀਮਰ ਤੋਂ ਬਿਨਾਂ) ਬਨਾਮ ਟੈਸਟ (ਪੋਲੀਮਰ ਨਾਲ) ਦੀ ਤੁਲਨਾ ਕਰਨ ਲਈ PEG-PVP ਪੋਲੀਮਰ ਨਾਲ ਪੇਰੋਵਸਕਾਈਟ ਦੀ ਇੱਕ ਪਤਲੀ ਫਿਲਮ ਵਿਕਸਤ ਕੀਤੀ ਹੈ। ਅਸੀਂ ਪਾਇਆ ਹੈ ਕਿ ਟੈਸਟ PeLED ਡਿਵਾਈਸ ਟਰਨ-ਆਨ ਵੋਲਟੇਜ (V_{on}) ਵਿੱਚ 12.1% ਕਮੀ, ਲੀਕੇਜ ਕਰੰਟ ਘਣਤਾ ਵਿੱਚ 97.21% ਕਮੀ, ਵੱਧ ਤੋਂ ਵੱਧ ਚਮਕ ਵਿੱਚ 200%+ ਵਾਧਾ, ਅਤੇ ਇੱਕ ਨਿਯੰਤਰਣ CsPbBr_3 ਡਿਵਾਈਸ ਦੇ ਮੁਕਾਬਲੇ ਪਾਵਰ ਕੁਸ਼ਲਤਾ ਵਿੱਚ 700% ਵਾਧਾ ਦਰਸਾਉਂਦਾ ਹੈ।

ਇਸਦੇ ਨਾਲ, ਅਸੀਂ ਇੱਕ ਉੱਚ ਹਰੇ ਸੂਚਕਾਂਕ ਹੋਲ-ਇੰਜੈਕਸ਼ਨ ਲੇਅਰ (HIL) ਸਮੱਗਰੀ (V_2O_5) (ਘੱਟ ਸਤਹ ਖੁਰਦਰੀ: 1:3 nm) ਦੀ ਇੱਕ ਪਤਲੀ ਫਿਲਮ ਵਿਕਸਤ ਕੀਤੀ ਹੈ ਜੋ ਇੱਕ ਹਾਈਬ੍ਰਿਡ ਪੋਲੀਮਰ-ਅਕਾਰਗਨਿਕ PeLED ਦਾ ਪ੍ਰਦਰਸ਼ਨ ਕਰਨ ਲਈ ਚੰਗੀ ਤਰ੍ਹਾਂ ਸਥਾਪਿਤ PEDOT:PSS ਦੇ ਵਿਕਲਪਕ HIL ਵਜੋਂ ਹੈ ਕਿਉਂਕਿ PEDOT:PSS ਦਾ ਡਿਵਾਈਸ ਅਸਥਿਰਤਾ 'ਤੇ ਨੁਕਸਾਨਦੇਹ ਪ੍ਰਭਾਵ ਪੈਂਦਾ ਹੈ ਜੋ ਕਿ ਚੰਗੀ ਤਰ੍ਹਾਂ ਸਥਾਪਿਤ ਡਿਵਾਈਸ ਅਸਫਲਤਾ ਨਾਲ ਜੁੜਿਆ ਹੋਇਆ ਹੈ। ਵਿਧੀ। ਨਵੀਂ ਹੋਲ ਇੰਜੈਕਸ਼ਨ ਲੇਅਰ ਵਾਲੇ ਟੈਸਟ ਡਿਵਾਈਸ ਲਗਭਗ ਇੱਕੋ ਜਿਹੀ ਵੱਧ ਤੋਂ ਵੱਧ ਮੌਜੂਦਾ ਕੁਸ਼ਲਤਾਵਾਂ (4.23 Cd/A ਬਨਾਮ 4.19 Cd/A), ਅਤੇ ਚਮਕਦਾਰ ਕੁਸ਼ਲਤਾਵਾਂ (2.99 lm/W ਬਨਾਮ 2.32 lm/W) ਪ੍ਰਦਰਸ਼ਿਤ ਕਰਦੇ ਹਨ ਜਦੋਂ ਰਵਾਇਤੀ ਹੋਲ ਇੰਜੈਕਸ਼ਨ ਲੇਅਰ ਨਾਲ ਬਣਾਏ ਗਏ ਇੱਕ ਨਿਯੰਤਰਣ ਯੰਤਰ ਦੀ ਤੁਲਨਾ ਕੀਤੀ ਜਾਂਦੀ ਹੈ। ਉਪਰੋਕਤ ਹੋਲ ਇੰਜੈਕਸ਼ਨ ਲੇਅਰ ਵਿੱਚ ਛੇਕਾਂ ਦੀ ਆਵਾਜ਼ਾਈ ਦੀ ਜਾਂਚ ਕਰਨ ਲਈ, ਅਸੀਂ ਇੱਕ ਭੌਤਿਕ ਚਾਰਜ ਨਿਯੰਤਰਣ ਮਾਡਲ ਦੇ ਅਧਾਰ ਤੇ ਡਿਵਾਈਸ ਸਿਮੂਲੇਸ਼ਨ ਕੀਤੇ, ਜਿਸ ਵਿੱਚ ਹੋਲ ਇੰਜੈਕਸ਼ਨ ਲਈ ਨੁਕਸ-ਸਹਾਇਤਾ ਪ੍ਰਾਪਤ ਸੁਰੰਗ ਸ਼ਾਮਲ ਹੈ। ਮੌਜੂਦਾ-ਵੋਲਟੇਜ ਵਿਸ਼ੇਸ਼ਤਾਵਾਂ ਲਈ ਨਜ਼ਦੀਕੀ ਸਮਝੌਤਾ ਦੇਖਿਆ ਗਿਆ ਹੈ।

ਇਸ ਤੋਂ ਇਲਾਵਾ, ਅਸੀਂ ਨੀਲੇ-ਨਿਕਾਸ ਜੈਵਿਕ LED ਨੂੰ ਲਾਗੂ ਕਰਨ ਲਈ ਇੱਕ ਨਾਵਲ MFPy-POSS ਦਾ ਸੰਸਲੇਸ਼ਣ ਕੀਤਾ। ਡਿਵਾਈਸ ਨੇ ਇੱਕ ਸ਼ਾਨਦਾਰ ਨੀਲੇ ਨਿਕਾਸ ਰੰਗ (437 nm) ਅਤੇ (0.163, 0.134) ਦੇ CIE ਕੋਆਰਡੀਨੇਟਸ ਦੇ ਨਾਲ ਇੱਕ ਟਰਨ-ਆਨ ਵੋਲਟੇਜ (6 V) ਪ੍ਰਦਰਸ਼ਿਤ ਕੀਤਾ। ਇਸ ਤੋਂ ਇਲਾਵਾ, ਅਸੀਂ ਚਿੱਟੇ OLED ਨੂੰ ਵੀ ਬਣਾਇਆ ਹੈ। OLED ਡਿਵਾਈਸਾਂ ਦੀ ਕਾਰਗੁਜ਼ਾਰੀ 'ਤੇ ਮੋਟਾਈ ਪ੍ਰਭਾਵ ਨੂੰ ਦੇਖਦੇ ਹੋਏ, ਨੀਲੇ ਐਮੀਟਿੰਗ (ਟਰੂਕਸੀਨ) ਅਤੇ ਸੰਤਰੀ ਐਮੀਟਰ (DCM) ਨੂੰ ਮਿਲਾ ਕੇ ਡਿਵਾਈਸਾਂ।

ਅੰਤ ਵਿੱਚ, ਅਸੀਂ LED (ਸਟੈਂਡਰਡ LT50) ਦੇ ਪ੍ਰਕਾਸ਼ ਜੀਵਨ ਕਾਲ ਨੂੰ ਮਾਪਣ ਲਈ ਇੱਕ ਇਨਬਿਲਟ, ਲਾਗਤ-ਪ੍ਰਭਾਵਸ਼ਾਲੀ, ਪੋਰਟੇਬਲ ਸੈੱਟਅੱਪ ਵਿਕਸਤ ਕੀਤਾ।

ਸੰਖੇਪ ਵਿੱਚ, ਇਹ ਖੋਜ-ਪ੍ਰਬੰਧ ਪੇਰੋਵਸਕਾਈਟ ਸਮੱਗਰੀ (CsPbBr_3) ਦੇ ਸੰਸਲੇਸ਼ਣ ਅਤੇ ਵਿਸ਼ੇਸ਼ਤਾ ਅਤੇ ਡਿਵਾਈਸ ਨਿਰਮਾਣ ਨੂੰ ਕਵਰ ਕਰਦਾ ਹੈ। ਇਸ ਵਿੱਚ ਪੇਰੋਵਸਕਾਈਟ LED ਲਈ ਇੱਕ ਵਿਕਲਪਿਕ HIL ਦਾ ਵਿਕਾਸ ਵੀ ਸ਼ਾਮਲ ਹੈ। ਇਸ ਤੋਂ ਇਲਾਵਾ, ਖੋਜ-ਪ੍ਰਬੰਧ POSS ਨੀਲੇ ਐਮੀਟਰ ਅਤੇ ਚਿੱਟੇ ਜੈਵਿਕ LED ਦੀ ਵਰਤੋਂ ਕਰਦੇ ਹੋਏ ਟਰੂਕਸੀਨ-DCM ਦੀ ਵਰਤੋਂ ਕਰਦੇ ਹੋਏ ਨੀਲੇ ਜੈਵਿਕ LED ਦੇ ਨਿਰਮਾਣ ਦਾ ਵੇਰਵਾ ਦਿੰਦਾ ਹੈ, ਨਾਲ ਹੀ ਲਾਗਤ-ਪ੍ਰਭਾਵਸ਼ਾਲੀ LED ਲਾਈਟ-ਐਮੀਟਿੰਗ ਮਾਪਣ ਟੂਲ ਦੇ ਵਿਕਾਸ ਦੇ ਨਾਲ।

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