Design and Performance Optimization of Monochromatic Laser-like Microcavity Amorphous Thin-Film LEDs.

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***Abstract*— We report on the innovative development of narrow linewidth amorphous thin-film Light Emitting Diodes (LEDs), including Organic Light Emitting Diodes (OLEDs), Colloidal Quantum Dots Light Emitting Diodes (QLEDs), and Perovskite Light Emitting Diodes (PeLEDs). Despite significant advancements, these devices still underperform due to material limitations and structural inefficiencies. To enhance monochromaticity and integration with existing technologies, we propose a novel microcavity design using a metal-dielectric distributed Bragg reflector (DBR) planar structure, compatible with current LED manufacturing processes. Our goal is to elevate the monochromatic to rival that of lasers, targeting applications in on-chip optical interconnects and smart wearables. This approach promises to resolve critical issues in traditional microcavity configurations and advance the field of optoelectronics.**

Keywords*— *Amorphous thin-film LEDs, narrow linewidth, optical microcavity, Monochromatic

I. INTRODUCTION

The development of high-efficiency amorphous thin-film Light Emitting Diodes (LEDs), including Organic Light Emitting Diodes (OLEDs), Colloidal Quantum Dots Light Emitting Diodes (QLEDs), and Perovskite Light Emitting Diodes (PeLEDs), has advanced rapidly, finding broad applications in lighting and display technology [1]. Despite this progress, these devices still do not meet their full potential due to material limitations, such as low mobility, and structural issues like interface states and carrier injection imbalances. Traditional optical microcavity structures fall short in achieving the necessary standards to enhance the monochromaticity of these devices, which also restricts the benefits of the low-substrate-selectivity of amorphous films and impedes their direct integration with existing optoelectronic devices [2-3].

To overcome these obstacles, we propose an innovative microcavity design that employs a metal-dielectric distributed Bragg reflector (DBR) planar microcavity structure. This design is highly compatible with current high-efficiency LED fabrication processes [4-5]. Our goal is to achieve a level of monochromaticity comparable to lasers, ultimately creating a new class of high-quality light sources suitable for applications such as on-chip optical interconnects, smart wearables, and more.

Our approach integrates fundamental optics and materials science principles, tailored to the unique properties of amorphous thin films and the manufacturing requirements of high-efficiency LEDs. By capitalizing on our distinctive microcavity design, we aim to boost the performance of amorphous thin-film LEDs and address the challenges of balancing optical and electrical performance in current devices. We are enthusiastic about the potential of our research to significantly advance the field of optoelectronics and continue contributing to this dynamic and rapidly evolving area.

II. RELATED WORK

To overcome these challenges, we plan to employ a novel microcavity design, utilizing low-loss optical spacer layers to adjust the effective cavity length of the microcavity devices. This design is tailored to facilitate efficient electrical injection in amorphous thin-film electroluminescent devices (Fig.1). Our goal is to develop microcavity LEDs whose monochromaticity can rival that of lasers, anticipating their use as a new type of high-quality light source in fields such as plastic optical fiber communications, on-chip optical interconnects, and smart wearable devices.

This optical microcavity design is based on fundamental principles of optics and material science, while also considering the characteristics of amorphous films and the demands of efficient LED manufacturing. Through our unique microcavity design, we aim to enhance the monochromaticity of amorphous thin-film LEDs and address the balance challenges between optical and electrical performance in existing microcavity devices. We believe this research will be significantly meaningful for the development of new optoelectronic devices.

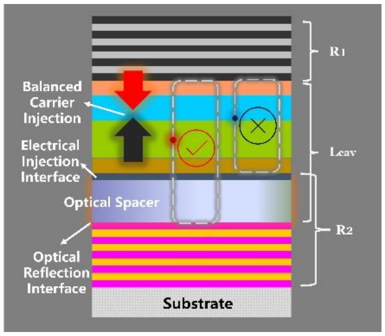

Figure 1. Schematic Diagram of the Novel Microcavity Structure

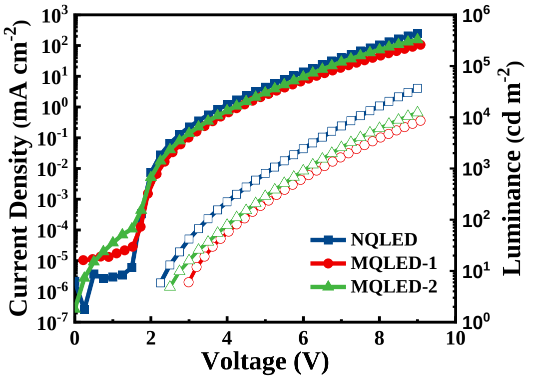

Figure 2. IVL Curves for Reference and Microcavity Devices

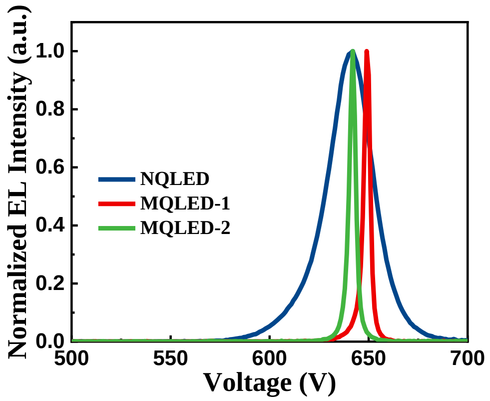

Figure 3. Spectra of Microcavity and Reference QLEDs

We designed a non-quarterwave Distributed Bragg Reflector (DBR) with optical spacer layers of varying thicknesses, and incorporated them as the bottom reflective mirrors in red inverted QLEDs. Together with the top anode metal, silver, we constructed a distributed Bragg reflector plane (FP) optical microcavity. Figure 2 shows that the IV characteristic curves of the reference and microcavity devices are similar, indicating consistent carrier injection. The microcavity device's decreased brightness results from a narrower spectral linewidth and a redshift to around 650 nm. Nonetheless, its peak spectral intensity exceeds that of the reference device by more than tenfold. By controlling the microcavity resonance effects and mode selection of light output, we achieved adjustment of the spectral peak position and linewidth. Based on the DBR-3, the emission peak of MQLED-1 shifted from 642 nm to 650 nm, and the device's Full Width at Half Maximum (FWHM) narrowed significantly from 27.1 nm to 3.6 nm, achieving the narrowest linewidth reported for red light-emitting diodes, meeting the optical requirements for applications like fiber optic communications. For the MQLED-2, prepared using DBR-4, the emission peak remained stable at 642 nm, but the FWHM was reduced to 3.8 nm. Moreover, the light emission intensity of the device in the normal direction increased significantly, more than tenfold. Both MQLEDs exhibited excellent optical anisotropy and spectral stability.

III. CONCLUSION

To address the challenge of further reducing the spectral linewidth in high-efficiency amorphous thin-film LEDs, we introduced a non-quarterwave DBR at the light output interface of inverted red QLEDs. Combined with a top anode metal silver, this configuration formed a robust optical microcavity. Adjusting the effective cavity length without compromising charge balance, we effectively controlled the device's emission peak and linewidth. The experimental results show that with this microcavity design, the linewidth was reduced from 27.1 nm to 3.6 nm, making it suitable for specific narrow-band applications and paving the way for future electrically pumped amorphous thin-film lasers.

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