AIXTRON's MOCVD Technology Breakthrough

For Micro LED High Volume Manufacturing

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Micro LED Display applications brings increased requirements for wavelength uniformity and defect density that cannot be addressed with current technology developed for solid state lighting (SSL). AIXTRON is bringing technology solutions for addressing the stringent requirements in uniformity and defect density for micro LED high volume manufacturing. A major step forward in wavelength uniformity in a batch reactor is achieved through enhancement of the AIX G5+, a Planetary Reactor®, with individual wafer temperature control. Furthermore the defect performance is improved through cassette-to-cassette (C2C) automation combined with in-situ cleaning.

1. Introduction

Micro LED displays have the potential to outperform LCD and OLED displays in categories such as efficiency, pixel density, refresh rate, brightness, contrast and color gamut [1,2]. These features are attractive for a number of display technology applications. For example, the high achievable efficiency is important for the battery lifetime of mobile devices such as smart watches; and the improved brightness, contrast and color gamut are desirable for automotive and TV displays.

Micro LED displays use individual 3-40 µm sized red, blue and green sub pixels that can originate from separate red, green and blue LED epiwafers or from blue LEDs combined with green and red color conversion using quantum dots. The LED epiwafer structures are grown by MOCVD. Due to the large amount of sub-pixels required for a full display, a parallel transfer method based on the transfer of chips without sorting or binning will be used [3,4] based on stamps of 10 x 10 mm or greater.

Blue and green LEDs incorporating InGaN / GaN MQW are typically on sapphire substrates. For solid state lighting (SSL) applications the LED chips are normally individually sorted and binned, with a total wafer area wavelength range of 99% of in 10 nm range being typical. However for micro LED displays without sorting the requirement is a range of 5 nm or lower and the area yield requirements become a major cost factor in micro LED high volume manufacturing.

The defect control requirements for MOCVD epiwafers are based on only utilizing stamps that are free of measureable defects that lead to failure (typically ≥ 1 µm diameter). Over 90% measurable defect free stamp yield is targeted to reduce impact on the cost of ownership (CoO). The defect free stamp yield, based on the well-known Murphy's model [5], is shown in figure 1 for three stamp sizes. The targeted 90% stamp yield corresponds to ≤ 0.1 defects / cm^2 for a 10 x 10 mm stamp. This is an order of magnitude more stringent than the requirements for SSL where the larger chip is more resilient to small defects and failure only results in one LED chip being discarded.

2. Method

The challenge is to develop a MOCVD solution that shows major improvement in wavelength uniformity and defect control with high productivity. We developed dedicated MOCVD solutions based on the AIX G5+ C to address these requirements in an 8 x 150 mm batch wafer configuration [6,7]. This Planetary Reactor® is a horizontal flow reactor with a ring of 8 satellite wafer disks surrounding a central gas injector. This provides the required throughput along with identical symmetrical surroundings with the capability of flow tuning and individual wafer temperature control. The wafer disks rotate using Gas Foil Rotation® to enable uniform growth across the wafer and the entire susceptor has a second rotation around the injector to improve wafer to wafer uniformity. For improved composition and thickness uniformity of the blue and green micro LED structures we introduced a 5 level injector with group V precursor (NH_3) in plenums 1,3,5 and group III precursor (e.g. TMGa, TEGa, TMAl, TMIn) in plenums 2,4.

Temperature uniformity is identified as the critical parameter to achieve wavelength uniformity. To improve wafer-to-wafer reproducibility individual wafer temperature control was introduced, controlling the flying height of each satellite above the heated susceptor based on measured wafer temperature using an in-situ pyrometer. Because sapphire wafers are transparent to visible radiation, a 405 nm UV pyrometer was selected to measure the actual temperature of the growing film on each individual wafer.

3. Results

The wavelength yield was benchmarked for 460 nm blue LEDs on Sapphire over 24 wafers grown in 3 runs in the 8 x150 mm wafer configuration. PL Analysis of all wafer area of all 24 wafers yielded ~99% in a 5 nm wavelength range (with 3mm edge exclusion), as shown in figure 2b. This yield is achieved through a combination of on-wafer, wafer-to-wafer and run-to-run uniformities. State of the art on-wafer uniformities of around σ~ 0.7 nm due to the rotation of the individual wafer, as shown in figure 2c. Excellent wafer-to-wafer and run-to-run reproducibility values of $\sigma_{w/w} \sim 0.5$ nm and $\sigma_{R/R} \sim 0.3$ nm corresponding to ~95% of wafer averages in a 2 nm range were obtained, as shown in figure 2a.

To reduce particle and defect density automated cassette-to-cassette loading was introduced avoiding human handling and exposure to the surroundings. The wafers are removed from the chamber with a satellite ring which is the separated in the handler. To go further we introduce a Cl2 in-situ clean maintaining a clean reactor at the start of each LED process. We measured the total defect density of sample wafers using a Candela CS20. Measurements of a batch of wafers yielded typical total defect densities above 1 μm in size of 29 per wafer corresponding to <0.14 cm^{-2}. This represents a reduction of defect density by an order of magnitude due to the improved wafer and handling.

4. Conclusion

Blue and green Micro LED high volume manufacturing requires a major leap in wavelength uniformity and particle control as compared to SSL. To address these new requirements we have developed a dedicated MOCVD solution based on the AIX G5+ C Planetary Reactor® for 8 x 150 mm sapphire wafers. Individual wafer temperature control based on a UV pyrometer in combination with the sophisticated flow control and thermal design deliver a breakthrough in wavelength yield to 99% of the total wafer area in a 5nm range demonstrated over all 24 wafers in a series. Particle and defect requirements of <0.14 cm^{-2} are achieved through use of cassette to cassette automation. These performance requirements are delivered in a high volume manufacturing batch reactor.

References

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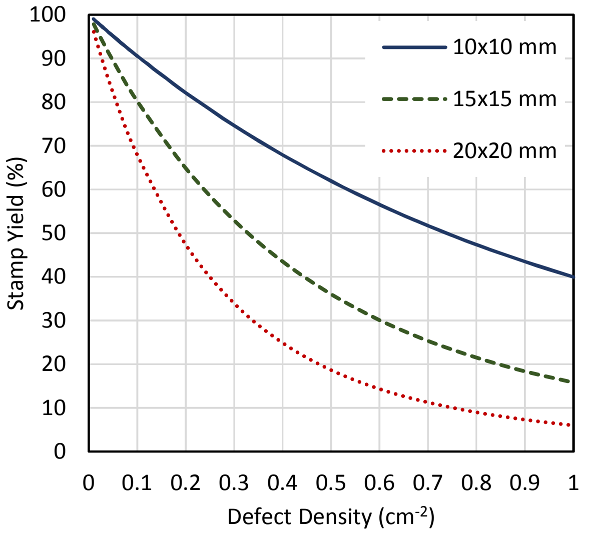

Figure 1. Graph of stamp yield against defect density with varying stamp sizes. For a 10 x 10 mm stamp, a defect density of 0.1 cm^{-2} corresponds to 90% stamp yield.

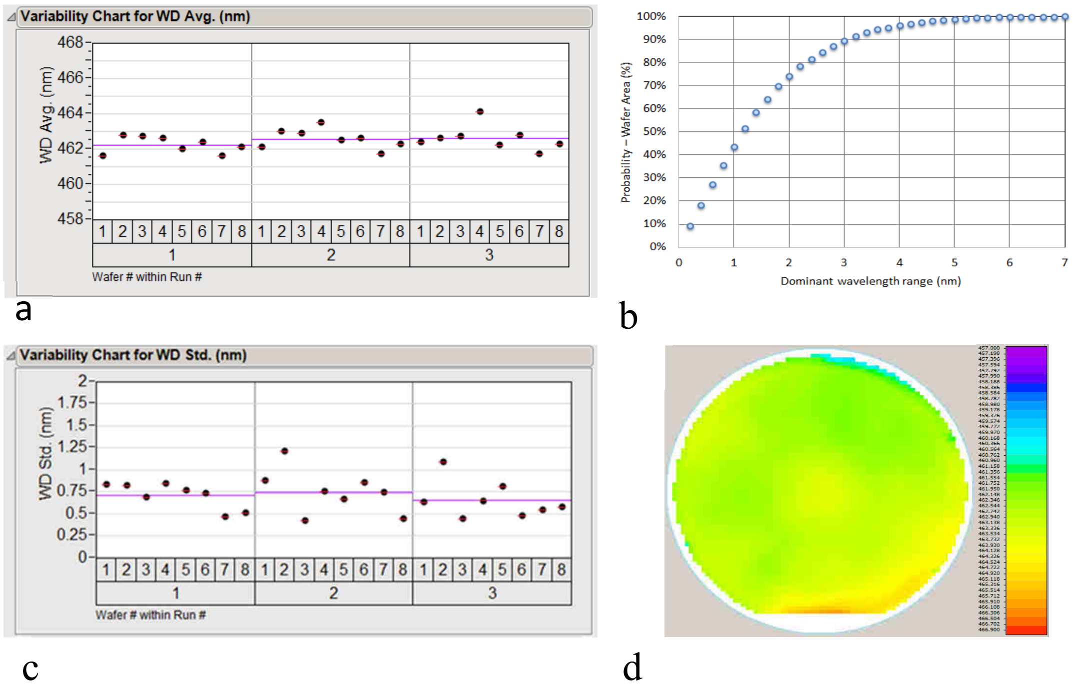

Figure 2. PL Wavelength Uniformity of a 24 wafer series for 460 nm blue LED grown on 150mm sapphire (with 3 mm edge exclusion): a, Variability chart showing the wafer averages for all 24 wafers; b, Cumulative distribution plot for the total wafer area over 24 wafers (with 3 mm edge exclusion), showing ~99% in a 5 nm range; c, Variability chart showing on-wafer uniformity for all 24 wafers over 3 runs showing typical σ ~0.7 nm; d, PL map of a typical 150 mm wafer;