# The Effect of Interdigitated Layout Design on the Improvement of Optical and GHz Modulation Bandwidth of Tilted-Charge Light-Emitting Diodes

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**Abstract**

**To enhance the optical output and modulation bandwidth, the interdigitated tilted-charge light-emitting diodes with different geometries are fabricated and measured. The optical output scales with the emitter area only when the emitter lateral-feeding width is less than 5 μm. When emitter size exceeds certain width, the light output is more dependent on the peripheral effect. Increasing the distance between the bottom contact and emitter mesa can also improve the light output by 1.8 times. However, it limits the optical modulation bandwidth due to the increasing resistance effect. The fast spontaneous modulation of tilted-charge LED is also demonstrated by the 3 Gb/s eye diagram.**

## INTRODUCTION

Recently, the heterojunction bipolar light-emitting transistor (HBLET) has been demonstrated a reduced recombination lifetime and enhanced spontaneous optical modulation capability. The new concept of the tilted-charge light-emitting diode (LED) based on the HBLET operation was also proposed by employing a "drain" layer at bottom of the p-type base active region to remove slow-recombining carriers. This tilted-charge LED has shown a 7 GHz modulation bandwidth, which is capable of applying to short communication system and interconnect readily [1-4] .

In this paper, the interdigitated finger design is applied on light-emitting transistor and tilted-charge LED to further decrease the resistance effect compared to the conventional circular layout design. Studies have been focused on the device geometry and scaling effect on DC optical output and modulation bandwidths. Three layout variables (see Fig. 1) including top emitter mesa length (L), distance from top contact to top mesa (W), and distance from top mesa to bottom contact (d), are varied and examined to obtain optimal device performance.

## DEVICE DESIGN AND FABRICATION

Because of the edge-recombining characteristic of the tilted-charge LED and HBLET, the optimization of the distance between top and bottom contact is important for improving the optical RF performance. The lateral resistance between two contacts, however, strongly depends on the layout design. Figure 1 shows the new layout design proposed in this study. The top emitter mesa and bottom metal are formed interdigitated structures, where the holes are provided from bottom contact to emitter mesa. The lateral resistance for this layout design can be expressed as:

$$R_{lat} = R_{sh} \times \frac{d}{L} \qquad (1)$$

where L is the emitter mesa length and d is the distance between bottom contact and mesa. Large L and d provide larger active region and higher light output, but meanwhile larger parasitic capacitance effect. Eq. (1) indicates that the device can be further scaled down to reduce the parasitic capacitance effect while maintaining the same d/L ratio. The smaller device geometries, on the other hand, also indicate smaller light output.

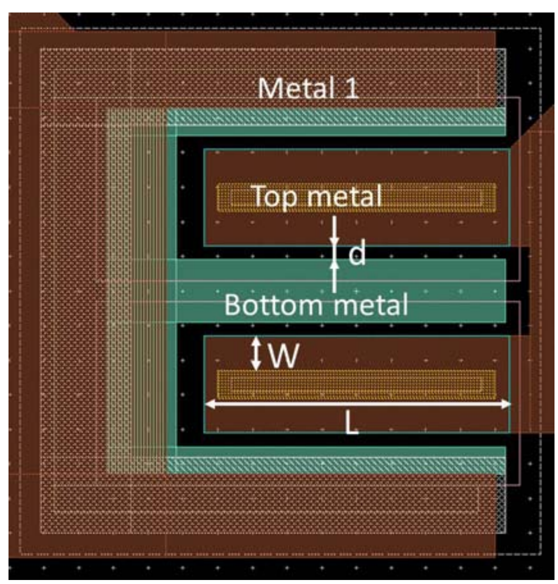

Fig.1. Interdigitated Layout design of tilted-charged LED

The material structure is similar to Ref. 4 besides we increase the base thickness to reduce the sheet resistance. The whole process precedes 8 lithography steps, three wet etching steps, one nitride deposition, and three metallization steps. Devices with different geometries are designed to investigate the light emission efficiency and their modulation bandwidths.

EMITTER WIDTH EEFECT

Figure 2 shows the L-$I_E$ curve of the tilted-charge LED with different top mesa width, which is defined as two times of W plus the top metal width. The light emission intensity is around 70 μW, depending on the device geometries. In the inset of Fig. 3 shows the light emission versus the total top mesa width normalized with respect to the 14 μm top mesa device. When top mesa varies from 14 μm to 19 μm, the light output increases 35% and is well consistent with scaling prediction. However, when the mesa width changes from 24 μm to 34 μm, the light output starts to deviate from the prediction line. This implies that holes cannot fully transport into the top mesa, resulting in mostly the recombination happening at the edge of top mesa.

The modulation bandwidth and the light output of the devices with different W are summarized in Table 1. At constant bias $I_E$ of 15 mA, the modulation bandwidth decreases from 3.13 GHz to 1.75 GHz when W increases from 1μm to 5μm, while the optical output coupled into top fiber increases from 130 nW to 800 nW. The faster modulation bandwidth is due to smaller parasitics (resistance and capacitance) caused in W1L10d1 device.

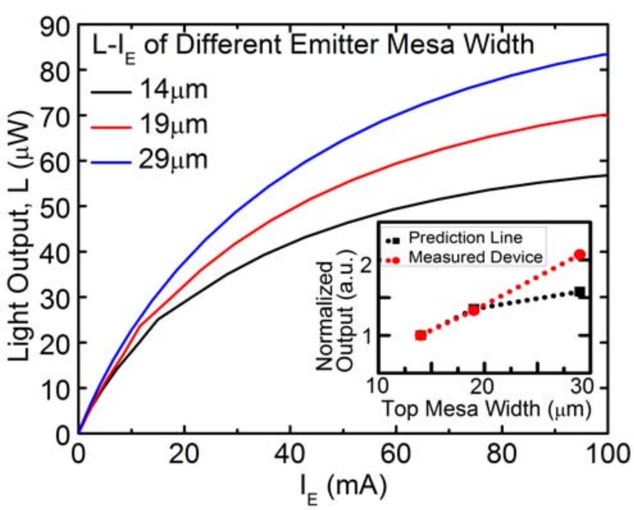


Fig. 2. The L-$I_E$ curve of tilted-charge LED with different top mesa, the inset shows the normalized light output intensity versus the mesa width

BASE-METAL-TO-EMITTER-MESA EEFECT

We examined the effect of the top mesa to bottom metal distance (d) on RF performance. The RF bandwidth and light output of devices having d= 1, 3 and 5 μm are tested. Figure 3 shows the L-I curve of device with W=5 and L=10. The light output increases from 800nW to 1420nW under 15mA emitter current when the d increases from 1μm to 5μm. Electrons are injected from emitter to base and recombine radiatively with holes along the base region. For shorter distance d, the greater chance for electrons to recombine non-radiatively at the base contact, resulting in a smaller optical output. The lateral resistance, on the other hand, increases as increasing the distance, d. As shown in Fig. 3, the slope of the turn-on current goes down as d increases. The increase in lateral resistance would reduce the ability to supply the holes through the contact, resulting in the lower bandwidth performance. Figure 4 shows the frequency response of each device. The 3dB bandwidth decreases from 1.94GHz to 1.37GHz under 15mA emitter bias current when d increase from 1μm to 5μm.

It is worth noting that increasing the light output can be achieved by increasing W or d dimensions. However, increasing W from 1μm to 5μm increases light output around 5 times while increasing d from 1 to 5μm only increases 1.8 times. Under the same dimension increases in W and d, both of the bandwidth decrease percentages are almost the same, around 42% of reductions. However, when W exceeds 5 μm, some of the active areas cannot be fully used and act nothing but the parasitics.

Table 1. The geometry effect on HBLET performance

| Device Geometries | -3dB BW (GHz) | Light output (nW) |
|---|---|---|
| W1 L10 d1 | 3.13 | 129.8 |
| W3 L10 d1 | 2.2 | 484 |
| W5 L10 d1 | 1.94 | 800 |

All devices are operated at 15mA base current

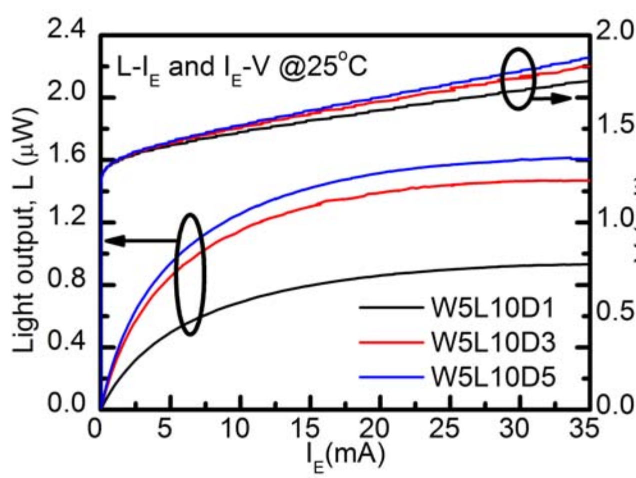

Fig. 3. The L-$I_E$ and $I_E$-V characteristic. Note that the increase in d gives higher resistance as the slope of I-V curves goes down.

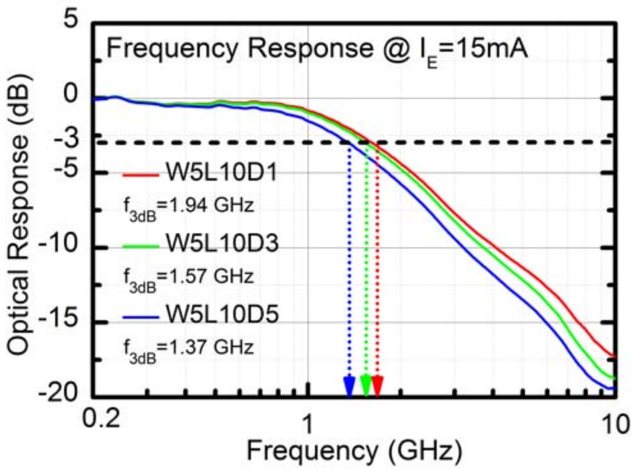


Fig. 4. The frequency response of devices with d=1, 3, and 5µm.

Figure 5 shows the PRBS eye diagrams of tilted-charge LED with W=5, L=10, and d=5 under 15mA bias current. The light output was collected by optical fiber, and connect to commercial SFP transceiver. From Fig. 5, the -3dB bandwidth of the device is 1.37GHz, and eye diagram shows the clear and open eye at 1 Gb/s and 2 Gb/s. The 3 Gb/s eye diagram is not as clear, which can still be improved in the future.

## CONCLUSION

In summary, the interdigitated tilted-charge LEDs with different emitter width (W) and distance from top mesa to bottom contact (d) are fabricated and tested. The emitter width scaling is only valid when dimension is smaller than 5µm. Increasing d also increases the light output but doesn't follow the scaling law, and the output is smaller than the prediction. We also shows the 3Gb/s eye diagram of the device with frequency response of 1.37 GHz, having great potential for commercial short distance communication system.

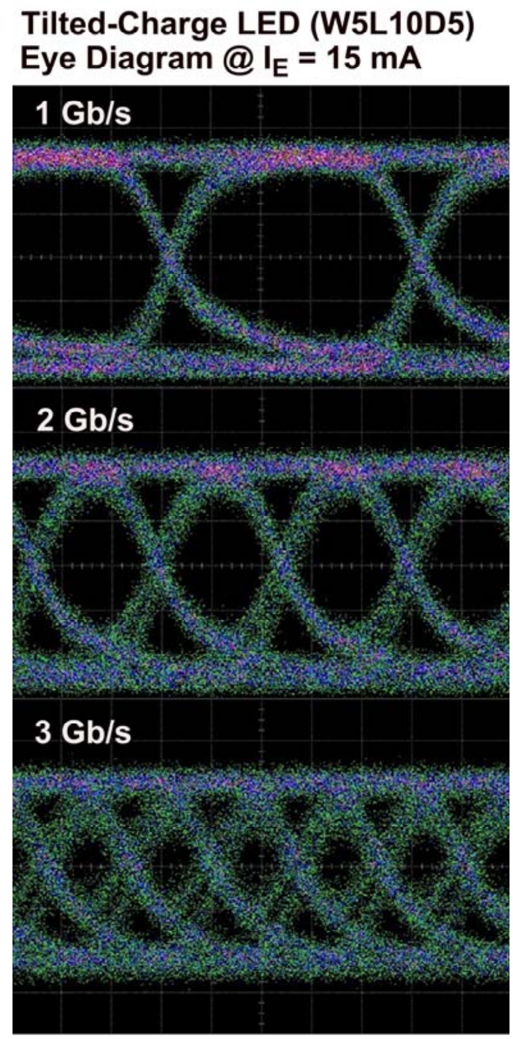


Fig. 5. The eye diagrams of tilted-charge LED operating at 1, 2, and 3Gb/s, respectively.

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## ACRONYMS:

HBLET: Heterojnunction light-emitting transistor
LED: Light-emitting diode
RF: Radio frequency