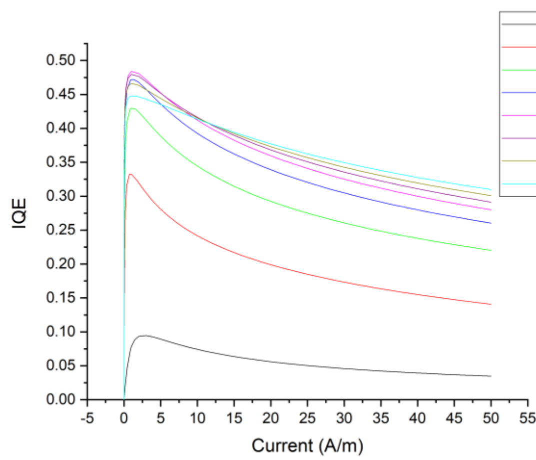
Effects of MQW thickness

MQW and barrier thickness was varied between 1 and 8 nm, here 3 total period was used for all cases. There are two interesting trends which may help select a specific design, IQE as a function of current is seen in figure 13. First, peak IQE as a function of thickness starts increasing as we increase QW thickness from 1nm to 5 nm, it peaks at 48% for 5nm. Then, the peak IQE starts decreasing slightly to about 45% for 8 quantum wells, although this decrease is not significant, if operating at low currents, one may consider picking the 5 nm thick wells to operate at peak efficiency. Droop is also affected by MQW thickness, as the thickness is increased. Droop is decreased and at higher currents, above 10A/m 6-8nm quantum wells out perform the 5nm thick quantum well. There are 3 trade offs we need to consider, peak IQE, droop in IQE and cost (thicker QW is more costly to grow). For higher current operations, more thickness is better, below 10A/m, the 5nm well performs the best. The 6 or 7 nm well is a good compromise between droop and peak IQE if performance over a wide range current performance is a big factor.



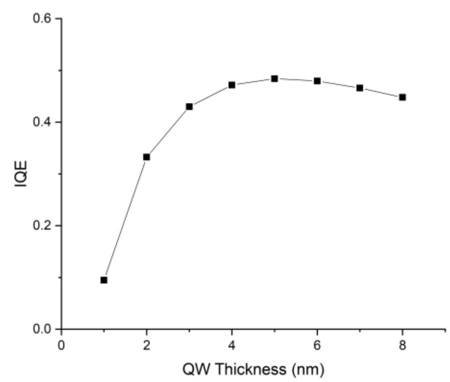


Figure 13: IQE as a function of current as QW thickness is varied (left), peak IQE as QW thickness is varied

Conclusion

With applications of display becoming more diverse and existing displays requiring higher specifications, high performance displays are needed. Conventional display technology such as OLED and LCD are reaching their limits in terms of performance and hence, next generation technology, micro LEDs are becoming a strong contender in replacing existing platforms. Micro LEDs brings in benefits from both LCD and OLED, furthermore, improves on the limits that LCD and OLED had. Smaller pixel size (hence, higher resolution), longer lifetime, higher brightness, and better color accuracy are only a few of the benefits. However, as the size of LEDs are scaled down efficiency decreases, therefore understanding and designing a micro LED suitable for display applications is important.

In this work, properties and behavior of LEDs are investigated as the size of the mesa is scaled down from 500um to 2um. Surface effects becomes increasingly important in micro LEDs because the surface area to bulk volume ratio increases as LEDs are scaled down. It is observed that efficiency begins to decrease significantly below 50um throughout the whole operation range. With surface treatment, LEDs efficiency can be improved, however, droop is still more significant for smaller LED sizes. Decrease in efficiency can be attributed to surface effects and increase in current density resulting in higher nonradiative recombination as the LED is scaled down. Therefore it benefits to use LEDs only as small as required; for ultra-high resolution sizes in the 10s of microns is enough and are still large enough to retain decent efficiency at lower currents. At 10um, effect of number of MQW periods and MQW thickness is investigated. We found that in the range of 2-3 periods and QW thickness above 5nm can result is a LED with good performance compared to others.

To improve this work, more detailed surface models and size effects can be taken into consideration for more accurate and deeper understanding of scaling effects in micro LEDs. Surface treatments that may affect surface trap level, densities and lifetimes may be modified and simulated. If possible, changing the simulation structure to include effects of a passivation layer may give further insights on how to improve micro LEDs. Size effects on carrier lifetime, carrier concentration distribution and recombination rate may also be included to improve simulation accuracy. Scaling adds another dimension to optimization of LED efficiency

References

[1] E.F. Schubert, *Light-Emitting Diodes*, 2nd ed. (Cambridge University Press, Cambridge, 2006).

[2] N. Holonyak and S.F. Bevacqua, "Coherent(Visible) Light Emission from Ga(As1-x Px) Junctions" , Appl. Phys. Lett. **1**, 82 (1962).

[3] Isamu Akasaki, Hiroshi Amano, Masahiro Kito, and Kazumasa Hiramatsu, *Photoluminescence of Mg-doped p-type GaN and electroluminescence of GaN p-n junction LED*, Journal of Luminescence **48–49**, 666 (1991).

[4] S. Nakamura, T. Mukai, and M. Senoh, *Candela-class high-brightness InGaN/AlGaN double-heterostructure blue-light-emitting diodes*, Appl. Phys. Lett. **64**, 1687 (1994).

[5] B. Kramer, editor , *Advances in Solid State Physics* (Springer-Verlag, Berlin Heidelberg, 2003).

[6] Y. Huang, E.-L. Hsiang, M.-Y. Deng, and S.-T. Wu, *Mini-LED, Micro-LED and OLED displays: present status and future perspectives*, Light: Science & Applications **9**, 105 (2020).

[7] H.-W. Chen, J.-H. Lee, B.-Y. Lin, S. Chen, and S.-T. Wu, *Liquid crystal display and organic light-emitting diode display: present status and future perspectives*, Light: Science & Applications **7**, 17168 (2018).

[8] Z. Liu, C.-H. Lin, B.-R. Hyun, C.-W. Sher, Z. Lv, B. Luo, F. Jiang, T. Wu, C.-H. Ho, H.-C. Kuo, and J.-H. He, *Micro-light-emitting diodes with quantum dots in display technology*, Light: Science & Applications **9**, 83 (2020).

[9] J. Kou, C.-C. Shen, H. Shao, J. Che, X. Hou, C. Chu, K. Tian, Y. Zhang, Z.-H. Zhang, and H.-C. Kuo, Impact of the surface recombination on InGaN/GaN-based blue micro-light emitting diodes, Opt. Express, OE **27**, A643 (2019).

[10] M.S. Wong, C. Lee, D.J. Myers, D. Hwang, J.A. Kearns, T. Li, J.S. Speck, S. Nakamura, and S.P. DenBaars, Size-independent peak efficiency of III-nitride micro-light-emitting-diodes using chemical treatment and sidewall passivation , Appl. Phys. Express **12**, 097004 (2019).

[11] J. Day, J. Li, D.Y.C. Lie, C. Bradford, J.Y. Lin, and H.X. Jiang, *Full-scale self-emissive blue and green microdisplays based on GaN micro-LED arrays* ,Quantum Sensing and Nanophotonic Devices IX (International Society for Optics and Photonics, 2012), p. 82681X.

[12] P. Tian, J.J.D. McKendry, Z. Gong, B. Guilhabert, I.M. Watson, E. Gu, Z. Chen, G. Zhang, and M.D. Dawson, *Size-dependent efficiency and efficiency droop of blue InGaN micro-light emitting diodes* , Appl. Phys. Lett. 101, 231110 (2012).

[13] S.S. Konoplev, K.A. Bulashevich, and S.Y. Karpov, *From Large-Size to Micro-LEDs: Scaling Trends Revealed by Modeling*, Physica Status Solidi (a) 215, 1700508 (2018).