InGaN/GaN Nanowire LEDs and Lasers on nonconventional substrates

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Conventional planar group-III nitride epitaxy for light-emitting diode (LED) is typically grown on sapphire, which results in high threading dislocation densities in the order of 10^6-10^8 cm^{-2} because of thermal- and lattice-mismatch. The challenge in realizing efficient InGaN QWs in the green gap and beyond stems from the spontaneous and piezoelectric polarization fields induced electron-hole wave functions separation as the indium composition increased to 25% and above.[1] SiC and GaN bulk substrates, and nonpolar nitride materials have been used to address the lattice-mismatch, efficiency-droop, polarization field, and green gap issues, at the expense of high development and material costs.[2] Nanowire LEDs on silicon has numerous advantages over planar epitaxial LEDs, such as a reduced polarization field, wavelength tunability by increasing indium composition and light extraction.[3, 4] The blue, green, red and infrared LEDs grown using molecular beam epitaxy (MBE) demonstrated the potential of nanowires emitters for practical applications.[5, 6]

However, the large specific surface, and therefore a high density of surface states was found to limit the quantum efficiency and output power of nanowire devices.[7] The phonon and carrier confinement in nanowires also led to junction heating and reduced heat dissipation. In this talk, we will present our investigations on nanowires LEDs and lasers emitting at green-to-infrared wavelength range. The approach in surface states passivation in InGaN/GaN quantum-disk-in-nanowires LEDs, as well as enhancing heat dissipation by growing nanowires-crystal on metal substrates will also be presented.

Ammonium sulfide was used to passivate the nanowires in the laser fabrication process to reduce the p-contact resistance of GaN:Mg.[5] We also developed octadecylthiol (ODT) passivation process for LEDs, which led to a ~4 times increase in photoluminescence peak intensity, and 50% increase in relative peak external-quantum-efficiency in passivated LEDs.[8] The passivation changed the surface dynamic charge and recovered the band-edge emission. The faster-increasing trend in quantum efficiency is due to the reduced Shockley–Read–Hall (SRH) non-radiative recombination on the nanowires surface, which was confirmed using 4D scanning ultrafast electron microscopy technique, and the associated rate-equations simulations.[9]

Current high-power planar LEDs have to be transferred to a heat sink, such as Cu or CuMo, via laser liftoff or wafer bonding because of the high junction temperature during operation. It is more severe for nanowire LEDs on Si because of the small diameter, and the formation of SiN layer before nanowires growth. We developed the first high-power red InGaN/GaN Qdisks-in-nanowire LEDs on bulk polycrystalline Mo; the platform simultaneously implements buffer layer, reflector, n-metal contact, and heat-sink, thus greatly simplifies the fabrication process for high-power devices.[10] The LEDs showed a low turn-on voltage of ∼2 V without droop, much lower junction temperature compared to LEDs on Si, and longer lifetime, thus is promising for high-power device operation.

In conclusion, the InGaN/GaN nanowire edge-emitting lasers at green-to-infrared wavelength range on Si were demonstrated. We showed the first organic chemical passivation treatment on nitride nanowires, to increase external quantum efficiency and reduce SRH non-radiative recombination. We also reported the first nanowires device growth process on metal substrates. The fabricated device from the high-crystal-quality nanowires shows low turn-on voltage, high-power, droop-free, and stable operation.

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