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Classical and quantum light generation with nitride-based semiconductor nanostructures

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Group III-nitride semiconductor based low-dimensional nanostructures have attracted a lot of attention owing to their unique optical characteristics and their versatile classical and quantum photonic applications. Here, we present various nitride-based quantum nanostructures grown on pyramidal, annular, columnar, and tapered structures as a template. First, we demonstrated multi-color and broadband visible light emitting diodes (LEDs) based on GaN hexagonal nano-pyramid and hexagonal annular structures. The pyramid LEDs emit a broad-band spectrum originated from quantum dots (QDs), quantum wires, and quantum wells (QWs) with different emission wavelengths, which are formed at the tops, edges, and sidewalls of the pyramids, respectively. The annular and double concentric truncated pyramidal LEDs provide broad-band, white light generation from the QWs formed on various planes. Red-color emission using InGaN/GaN double heterostructures on GaN nano-pyramid structures was also observed. Second, GaN-based rod structures were directly grown on Si substrates without using any catalysts or mask processing and then InGaN/GaN multiple QWs were deposited on the surface of GaN rods. By using tapered GaN/InGaN core–shell QW semiconductor rods having a large gradient in their bandgap energy along their growth direction, highly asymmetric photonic diode behavior was observed with low scattering loss. Third, we developed a dislocation-eliminating top-down chemical vapor etching method for fabricating high-quality GaN nanostructures. InGaN-based single QD arrays were formed on obelisk-shaped GaN nanostructures by growing an ultrathin QW layer. Ultrafast and high efficiency single photon generation was demonstrated by virtue of spontaneous formation of single QD on the apex of tapered GaN nanostructures. Moreover, a broad spectrum of the entire visible range was achieved by growing multiple QW structure with various QW thicknesses on the obelisk-shaped GaN nanostructures. . Fourth, we demonstrate a novel approach of the self-aligned deterministic coupling of single QDs to nanofocused plasmonic modes. Site-controlled InGaN QD array was grown by selective growth method using metal-organic chemical vapor deposition, and then a silver film was deposited on the single QD array. Using this approach, we achieved strong spontaneous emission enhancement as high as ~ 22 of QDs over a wide spectral range. Furthermore, we found that the majority of the extracted light from the quantum dot is guided toward the bottom of the pyramid with high directionality. Nanopyramid structures were detached from a substrate and the far-field radiation pattern was measured using Fourier microscopy, thus demonstrating great potential of this structure in various applications [5]. Finally, the hybrid nature of exciton polaritons opens up possibilities for developing a new concept nonlinear photonic device. We developed a novel polariton system resulting from strong coupling between a two-dimensional exciton and whispering gallery mode photon using a core–shell hexagonal wire with GaN/InGaN multiple QW. This approach overcomes the major hurdles in the implementation of practical solid-state quantum devices and shows great promise for various applications including quantum cryptography, quantum logic gates, integrated on-chip nano-emitters, and energy-harvesting devices.

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