III 族窒化物量子ドットの光子取り出し効率の向上

Increasing the photon extraction efficiency from III-nitride quantum dots

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Single photon emitters based on quantum dots (QDs) are becoming increasingly important due to their high emission purity and a large possible emission wavelength range. In particular, it has been shown that III-nitride nanowire QDs can operate at high temperatures[1], but they are still susceptible to spectral diffusion induced linewidth broadening. Recently (2014), the formation of III-nitride interface fluctuation QDs, that exhibit dramatically narrower emission linewidths compared to other III-nitride QDs, has been reported[2]. These structures have also been demonstrated to act as single photon emitters.[3] However, a low extraction efficiency of photons from QDs in bulk materials limits their practical application, and leads to long $g^{(2)}(0)$ measurement times (to evaluate the purity of the single photon emission). In the Arsenide material system, bullseye photonic structures based on second-order Bragg reflection[4] have been developed to reach theoretical extraction efficiencies of ~80% (NA 0.7). However, it would be difficult to realistically fabricate such devices in III-nitrides due to their short emission wavelengths. Here, for application to III-nitride materials, and considering fabrication issues, we present the design of a similar but alternative bullseye-like structure based on radial 5λ/4 Nitride-Air gap DBRs around a central waveguide structure on a planar mirror to efficiently out-couple photon emission into a desired direction. 5λ/4 DBR structures are used as they are relatively large (nitride section width: 162nm, air section width: 437nm), and can therefore be fabricated more easily, whilst still presenting a stop-band of width ~50nm. A schematic and simulation results are shown in figure 1. We use FDTD calculations to simulate the structures with commercially available software. In the structure the QD is located 100nm from the top surface, and the height of the etched DBRs is set to 450 nm. Our simulation results show that we can achieve an optimized extraction efficiency of ~69% for collection in an NA of 0.7, representing an increase of ~8 times relative to a QD embedded in bulk material. This value is comparable to the calculated values for the aforementioned 2nd order DBR structures, but should be more easily fabricated for III-nitride materials. This result is also comparable to the largest reported extraction efficiencies reported to date using trumpet-like photonic wires on mirrors.[5]

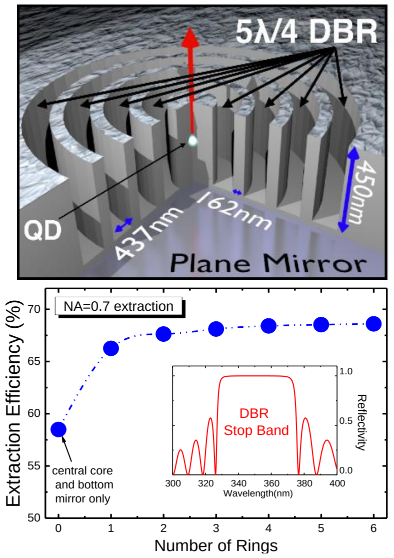

Figure. 1. (top) Schematic of the designed bullseye structure. (bottom) Calculated Extraction efficiency and stop band for DBRs structure.

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