論 文 の 内 容 の 要 旨

論文題目　Study on Single Photon Emission from III-Nitride Interface Fluctuation Quantum Dots
（窒化物半導体界面揺らぎ量子ドットからの単一光子発生に関する研究）

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Semiconductor quantum dots have been intensively studied because their atomic-like electric characteristics are expected to bring significant progress in optical and electric device applications. Single photon sources based on semiconductor quantum dots have attracted extensive attention due to their solid-state nature, high emission purities, and a large possible emission wavelength range, thanks to their possible applications in secure communication and quantum information processing. In particular, it has been shown that III-Nitride quantum dots can operate at high temperature and at the wavelength ranging from the Ultraviolet all the way to Infrared due to their large band offsets and wide ranges of bandgaps. However, III-Nitrides quantum dots have their limitations because they suffer from a spectral diffusion induced linewidth broadening (which can result in emission linewidths up to a few meV), compared with their III-V counterpart such as Arsenide. This spectral diffusion occurs due to an interaction between the internal-field induced exciton permanent dipole moment and the fluctuating electric field of charges trapped in relatively large densities of surrounding defects.

Recently interface fluctuation GaN quantum dots, have been successfully fabricated in recent years through a metal−organic chemical vapor deposition reactor. Thanks to the improved crystal quality with a low density of defects around the quantum dots, such interface fluctuation GaN quantum dots have been shown to exhibit a record narrow linewidth, as low as 87 μeV. This narrow linewidth is thought to be from the suppression of the inhomogeneous broadening down to the order of its limitation. Meanwhile, unprecedented purity of ultraviolet single photon emission has been obtained by such material system. In this thesis, we will focus on the investigation of the optical properties of interface fluctuation GaN quantum dots to achieve high-quality quantum sources.

In the beginning, we present the optical systems to perform the basic photon autocorrelation study by using a macroscopic photoluminescence measurement and Hanbury Brown and Twiss type correlation setup. Time-Integrated and time-resolved measurements of the ultraviolet luminescence can be realized to investigate the single photon emission properties from III-Nitride interface fluctuation quantum dot.

Secondly, we show the temperature dependence of the single photon emission from interface fluctuation GaN quantum dots and discuss their single photon purity decreasing due to increased spectral contamination from uncorrelated background emission related to quantum-well states. Quantum light emission is confirmed at temperatures up to ~ 77 K, by which point the background emission degrades the emission purity and results in a measured photon autocorrelation $g^{(2)}(0)$ in excess of 0.5. A discussion on the extent of the background contamination is also given though the comparison to extensive data taken under various ambient and experimental conditions, revealing that the quantum dots themselves are emitting single photons with high purity. This result reveals that it is possible to improve temperature characteristics achieved by reducing the volume of measured material- perhaps via the fabrication of mesa-like structures, or by local resonant excitation.

Furthermore, we have measured the exciton recombination time in a GaN interface fluctuation quantum dot using photon autocorrelation measurements. The exciton decay time of such a dot is evaluated to be 2.0 ± 0.1 ns by power dependent single photon dynamics. By comparing this measurement to the literature results of typical III-nitride quantum dots, we find that the lifetime measured for such an interface fluctuation quantum dot compares very well with that for typical Stranski Krastanow GaN quantum dots emitting at around the same energy. As both the lifetime and permanent dipole moment depend in effect on the separation of the electron and hole wavefunctions, this result has been used to infer that the relatively narrow emission linewidths of these quantum dots are likely resulting from a comparatively cleaner environment around such quantum dots， not from any inherent difference in the quantum dots themselves. These GaN fluctuation quantum dots may become an important technical solution for III-nitride based quantum sources, but will also act as a good platform for the study of fundamental properties of III-nitride nanostructures.

Finally, we investigate the temporal evolution of the emission spectrum of an excitonic emission line from a single GaN interface fluctuation quantum dot. the extremely stable emission line shows that the extent of any spectral wandering (long-term spectral diffusion) is much smaller than the energy resolution limit of our system. We develop the typical characteristic spectral diffusion time scale in the single photon emission of a GaN interface fluctuation quantum dot by using photon autocorrelation measurement with the careful spectral selection via the spectrometer and its exit slit connected onto the HBT setup. For the first time, the spectral diffusion time scale in III-Nitride quantum dot system was evaluated be of order ~20 nanoseconds. We have also presented the excitation power dependence of the spectral diffusion rate, showing the expected increase in rate as the excitation power is increased. It shows that indistinguishable photons may be produced from such quantum dots under excitation with pulse pairs separated by times less than such spectral diffusion time scale.

These results will have important consequences for the generation the high purity of the single photon emitters, indistinguishable photons, and bright quantum optical sources. This study will be a useful step towards the practical realization of high-quality quantum optoelectronic devices using the technologically important III-Nitride material system.