論文の内容の要旨

論文題目： Fabrication and Characterization of Air/III-Nitride Distributed Bragg Reflector Microcavity for Exciton Cavity Polariton

（励起子共振器ポラリトンの実現に向けた空隙/III族窒化物半導体分布ブラッグ反射型微小共振器の作製と評価に関する研究）

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In distributed Bragg reflector (DBR) microcavities (MCs), strong exciton-photon coupling gives arise to new quasi-particles: exciton-polaritons, and III-nitrides are important candidates for room temperature (RT) exciton-polariton applications. However, the refractive index contrast in III-nitrides is relatively low, undermining the performance of microcavities. Air-gap DBR is an ideal solution in terms of refractive index contrast. Unfortunately, fabricating such air-gap structures is very difficult, especially with III-nitrides. On the other hand, nonpolar nitride cavities are promising in terms of better quantum efficiency, but their optical characteristics have not been elucidated so far.

This thesis presents the original research work on the MOCVD growth of non-polar m-plane III-nitride structures, the fabrication of air-gap/III-nitride DBR MCs using thermal decomposition technique and the demonstration of cavity modes with high quality (Q) factors and strong coupling phenomenon. A Q factor of 1600 has been demonstrated for a pure cavity mode and a record Rabi-splitting of 84 meV is estimated for a cavity sample working at strong coupling regime. In addition, due to the thickness fluctuations in the cavity layers, we also observed the emission from trapped photons and trapped exciton-polaritons. This is actually the first demonstration of such trapped states in III-nitride DBR MCs. At the same time, we observe a quantized energy of 6 meV for exciton-polaritons, which is also the largest value reported to date in a solid cavity system. These results show that our air-gap DBR MCs are versatile for many interesting researches.

The structure of this thesis and the content in each chapter are shown as follows.

Chapter 1 gives the introduction to this thesis.

Chapter 2 presents some basic but non-trivial design issues for air-gap cavities. Transfer matrix method is used to simulate air-gap DBR cavity structures. By simulation, it is found that $\lambda/2$-cavity should be avoided since there are no anti-nodes inside the cavity. Besides, the high efficiency of air/III-nitride DBR MCs and their difference from conventional DBR MCs are revealed either.

Chapter 3 contains the growth techniques for multilayer structures on m-plane free-standing GaN substrates. The normal direction tilt of the substrate surface and the growth temperature are found to be the key parameters that affect the surface morphology of epitaxial multiple GaN/AlGaN layers. We use the substrates with their normal directions tilted toward -c axis by 1° and the optimal growth temperature is between 930°C and 970°C. On the other hand, we also find that the InGaN single quantum well with its AlGaN barriers grown at the same temperature as DBR AlGaN layers could still have a strong enough PL emission intensity. At the end of Chapter 3, complete cavity samples are grown and some special considerations in design and detailed parameters are given.

Chapter 4 describes the development of the fabrication process for non-polar nitride air-gap DBR MCs by using thermal decomposition of GaN. First of all, during GaN decomposition, it is found that the decomposition rate is asymmetric, depending on crystal facets and ammonia flow rates. At lower ammonia flow rate, the decomposition rate along −c direction is fast and the difference between -c and a direction was large. We could utilize this feature to fabricate air-gap layers. Finally two types of DBR cavities have been grown and fabricated. The parameters used in each fabrication step were given. Images of the fabricated structures taken by scanning electron microscope and atomic force microscope reveal the good quality of these structures.

Chapter 5 presents optical characterization for the fabricated non-polar air-gap/III-nitride MCs by micro photoluminescence measurements at room temperature. In the cavity center, a single InGaN QW is embedded as active layer. A Q factor of 1600 is estimated and anisotropic optical properties have been investigated. Especially, to analyse the optical anisotropy, $k \cdot p$-based theoretical calculation is performed, whose results are in good agreement with experimental measurements.

Chapter 6 contains the experimental demonstration of strong exciton-photon coupling in air-gap/III-nitride DBR MCs. A Rabi-splitting of 84 meV is estimated. This is actually the largest Rabi-splitting reported to date in a III-nitride DBR cavity. As expected to exhibit both a large Ω and a high Q, air-gap DBR MCs are potential candidates for realizing high Ω/κ systems (where κ is the cavity loss, $\propto 1/Q$), and thus for realizing exciton-polariton lasers with ultra-low threshold. In addition, anisotropic coupling strength is revealed by the phenomenon that strong coupling regime is reached for light with polarization E//a while weak coupling regime is often observed for E//c.

Chapter 7 presents the first observation of emission from trapped photon states and trapped exciton-polariton states in III-nitride cavity systems. The photonic traps here are formed by the cavity thickness fluctuations. Due to the anisotropic coupling conditions in non-polar nitride cavities, trapped photons and trapped exciton-polaritons are demonstrated for E//c and E//a respectively. In the observation, it is found that a spatial pinhole can be employed to intentionally select particular states. These observations are also confirmed by theoretical calculations based on a linear Hamiltonian. Another very interesting thing is that a quantized energy up to 6 meV is demonstrated for trapped exciton-polaritons, which is also the largest value ever reported so far.

Finally, Chapter 8 makes conclusions to this thesis and also indicates possible prospective researches that could be achieved based on the results presented in this thesis.