Growth of III-V Semiconductor Quantum Dots by Droplet Epitaxy

ハ, ヌル

https://doi.org/10.15017/1500685

出版情報：九州大学, 2014, 博士（工学）, 課程博士
バージョン：

（様式２）

氏　　名　：Ha Neul　（ハ　ヌル）

論 文 名　：Growth of III-V Semiconductor Quantum Dots by Droplet Epitaxy
（液滴エピタキシー法による III-V 族半導体量子ドットの創生）

区　　分　：甲

論　文　内　容　の　要　旨

Research and development on semiconductor quantum dots (QD) have been intensively carried out during the last few decades. Due to the discrete density of states of QD, thermal broadening in emission spectra can be suppressed. Thus, we can expect QD lasers and LEDs, indicating high temperature stability. In addition, due to the atom-like electric structure, we can realize single and entangled photon emission.

Various fabrication methods for QDs structures have been proposed. Self-assembled growth based on Stranski-Krastanov (S-K) mode is the most widely investigated. However, the S-K growth can only be applied to the lattice-mismatched system. Droplet epitaxy (Fig. 1) is an interesting alternative to the S-K growth. QD self-assembly in this case is not strain driven, and allow us to use a variety of material combinations (which include GaAs QDs on Si and Ge) and substrate orientations (which include GaAs(100), (311)A, and (111)A).

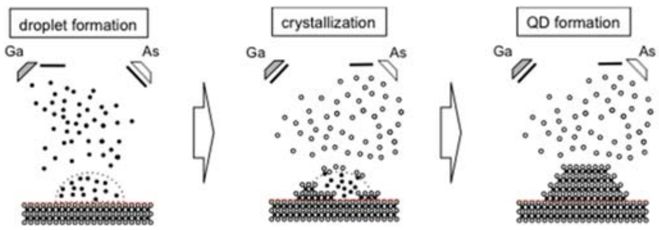

Fig. 1　Schematic of droplet epitaxy method

Since the droplet epitaxy method was developed, QD research on lattice-matched GaAs/AlGaAs system has been actively studied for single or entangled photon application. For the ideal single QD, the spectral emission should be sharp, and the emission should be entangled. However, the sharp emission has been observed only with small QDs, and the entangled emission has been observed with highly symmetrical QDs. Recently, in our group, highly symmetric GaAs QDs was formed on AlGaAs/GaAs(111)A, indicating the highest fidelity of entanglement among the reported results to date.

For the practical applications, systemic study of the relationship between the QD structure and their optical properties is essentially required, and extension of entangled photon emission to telecommunication wavelength is desired.

In this thesis, we studied the formation of GaAs and InAs QDs grown by droplet epitaxy. For GaAs QDs, we demonstrated the height-controlled GaAs QDs on AlGaAs/GaAs(100) by droplet epitaxy. Using these sample, we discussed that spectral line broadening of single QD depends on increasing the QDs height, which the quantum confined Stark effect (QCSE) is induced by surface charge.

To apply the entangled photon telecommunication wavelengths, we formed highly symmetric InAs QDs on InAlAs/InP (111)A by droplet epitaxy (Fig. 2). The photoluminescence (PL) spectrum covered telecom wavelengths of 1.3 μm and 1.55 μm, and the emission was observed at room temperature. Some of the QDs

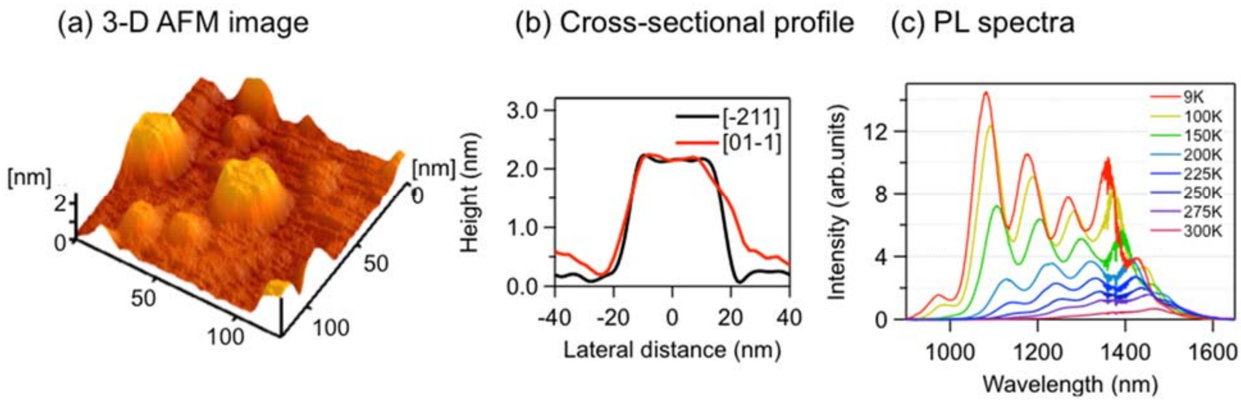

Fig. 2 (a) Three-dimensional AFM image. (b) Cross-sectional profile. (c) PL spectra

showed that the fine structure splitting is close to zero. We discovered the growth mechanism of InAs QDs in our system. We tuned the emission wavelength by changing the barrier from InAlAs to InAlGaAs.

The use of GaAs substrates is required because they have a lower cost, a higher thermal conductivity, and a higher quality distributed Bragg reflectors than InP substrates. However, the emission from a highly strained InAs QD on GaAs substrate is limited by ~ 1 μm, resulting in the lattice-mismatch between InAs and GaAs substrate. By inserting a thin InAs layer between InAlAs and GaAs(111)A substrate, we succeed the growth of a strain-relaxed metamorphic InAlAs layer. Thus, we formed the highly symmetric InAs QDs on the metamorphic InAlAs/InAs/GaAs (111)A emitting at 1.55 μm.

This thesis consists of five chapters. In chapter 1, the physics of QDs and other nanostructure are presented. Then, the related technology for fabrication of QDs is explained. The purpose of this study is referred.

Chapter 2 describes the structural and optical properties of GaAs QDs grown on GaAs (100). We demonstrated that the height of GaAs QDs was controlled by droplet epitaxy, and study the optical properties depending on a height of a single QD.

Chapter 3 presents the growth of highly symmetric InAs QDs on InAl(Ga)As/InP(111)A. The growth mechanism of InAs QDs on InAlAs/InP(111)A is identified, and the optical properties of ensemble and single QD are studied.

In chapter 4, we propose a new growth technique for the formation of InAs QDs on the GaAs substrate. A technique for strain-relaxation between InAlAs and GaAs is discussed. The growth of InAs QDs on InAlAs/InAs/GaAs(111)A are demonstrated, and also their optical properties are studied.

In chapter 5, we summarize the findings and conclusions, discussing the implications and future works.