CHAPTER I

INTRODUCTION

Nanostructures have been attracting interest for the development of semiconductor technology because of their potentials for high performance devices. They are possible to respond the continuous increment of requirements of information transport, processing and storage. For examples, the miniaturizing process of traditional integrated circuits are physically limited by quantum size effect; using of QDs is the new concept of taking the devices beyond conventional limit such as single electron transistor (SET) and quantum cellular automata (QCA). They also lead to the improvement of switching speed and efficiency of optical devices as well as giving birth of the novel devices such as quantum cryptography and spintronics.

To implement devices based on QDs, their physical properties are required to be studied theoretically and experimentally. Not only macro-spectroscopy of QD ensembles has been widely done but physical behaviors of a single QD and only few coupled QDs also have been investigated by many laboratories. Basic requirements for QDs-based devices using in room temperature are [1]:

1. Sufficiently deep localizing potential and sufficiently small in QDs size is prerequiste for observation and utilization of zero-confinement effects.

2. QD ensembles should show high uniformity and a high volume filling factor.

3. The material should be coherent without defects

QDs can be created by several techniques. However, among all the different fabrication techniques, self-assembly by Stranski-Krastanov growth mode leads to the formation of defect-free QDs which provide very high optical quality and it has become a standard fabrication method. However, self-assemble process of QDs formation by conventional method is random in nature. Many researcher thus attempt to restrain the randomness. Uniformity in size of QDs can be improved by using optimized QDs growth conditions or by many different growth technique. For examples, optimized thickness of QDs material and optimized growth interruption time are generally used as well as using capping techniques to suppress the segregation during capping process. Beside, the density of QDs are also important for high effectiveness of optical devices. It can be increased by stacking more layers of QD. But this method have a limitation because the accumulation of strain from muti-layer of QDs can induce defects[2]. Several method for increasing amount of QDs in lateral plane was therefore introduced. One method, introduced by our laboratory, is thin-capping-and-regrowth process[3]. This method has been already realized in high density QD solar cells[4]. They was improved the efficiency up to 25% for 5-stack of high density QDs whereby each stack contain 10^{12} QDs in an area of 1 cm^{-2}. The QDs ordering has also attracted the interest for some specific application, especially in quantum informations such as quantum gate and QCA. Not only The vertical alignment of QDs is possible by strain induction but the lateral ordering has also been widely investigated. One approach is thin-capping-and-regrowth process.

Thin-capping-and-regrowth process originates from the effort of engineering strain by modifying MBE growth process. After growth of InAs QDs, the QDs are capped with few monolayer of GaAs at not too high substrate temperature. The substrate temperature is held for some seconds afterward the capping process has finished. During temperature-holding time (interruption time), In segregate to regions outside of the QDs. Nanohole structures are created after interruption. The structures have an asymmetric shape which demonstrates anisotropic inter-diffusion of material. The nanoholes is used as templates for subsequent regrowth of QDs. The regrown QDs nucleate above centre of nanoholes due to highest tensile strain. And stripes elongated in $[1\bar{1}0]$ crystallographic direction are also created on both side of the regrown QDs. This structures are called "nanopropellers" whereby the stripes are their blades. Moreover, if nanopropellers are used as templates for further growth of QDs, The additional QDs, so-called satellite QDs, are formed on the blades of nanopropellers so that the structures become QD molecules (QDMs), lateral close-packed QDs. QDMs have been attracting interest for their coupling behaviors as well as was proposed to have potential for quantum computing applications i.e. QCA [5]. Last but not least, thin-capping-and-regrowth can be applied for several cycles. This results in obtaining longer nanopropellers. They leads to possibility of the growth of long chains of QDMs aligned along $[1\bar{1}0]$ direction and the growth of high density QDMs.

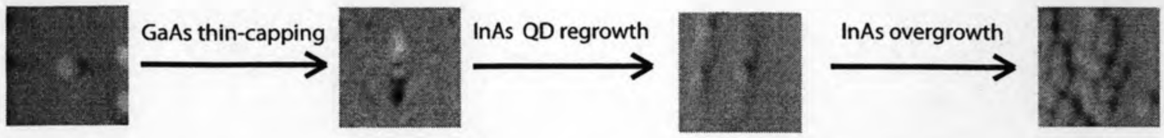

Figure 1.1: Growth process of quantum dot molecule by thin-capping-and-regrowth method

Moreover, aligned QDs in one specific direction are predicted to have anisotropic properties. In this thesis, chains of QDMs show optical anisotropic property i.e. polarization dependence of photoluminescence. In fact, the practical optical devices not only require high gain which respects to QD density, but they also require linear polarization. For examples, the polarization-uncontrolled laser has problems for optical communications i.e. increasing of relative intensity noise which leads to a deterioration of bit error rate [6]. The polarized emission of QD-based optical devices can be thus controlled by this method without requirement of an asymmetric device shape or high-index substrate.