行政院國家科學委員會補助專題研究計畫成果報告

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※　　可控制之單一量子點成長與其元件應用(I)　　※

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計畫編號：NSC96－2221－E－009－218
執行期間：　96 年　08 月　01 日至 97 年　7 月　31 日

計畫主持人：林聖迪
共同主持人：無
計畫參與人員：田健中 傅英哲

執行單位：交通大學電子工程系

中　華　民　國　　97　年　9　月　30　日

可控制之單一量子點成長與其元件應用

“Controllable Single-Quantum Dots Growth and its Device Applications”

計畫編號：NSC96-2221-E-009-218

執行期間：96 年 08 月 01 日 至 97 年 07 月 31 日

主持人：林聖迪 交通大學電子工程系助理教授

一、中文摘要

在此為期一年的計畫中，我們進行自組式量子點之定位成長的相關研究。運用本研究群首先提出並發展出來的一個方法，我們預計結合電子束微影與分子束磊晶再成長,於預先圖樣過之平台上形成單一量子點；因為量子點的成長對於應力場相當敏感，我們可以利用事先設計的應力分佈，來達成選擇性成長；我們的方法與其他人的主要不同在於，量子點可成長在遠離製程接觸過的表面；在計畫執行的一年中，利用我們提出的結構與程序，實現高品質之量子點成長；我們藉由細心的製程步驟以確保再成長樣品的潔淨性，並檢驗與形成單一量子點的相關參數；我們使用光學量測來分析所成長的量子點。

I. Abstract

With the financial support of this one-year project, the self-assembled growth of positioning single quantum dots has been investigated. By using a method that was first proposed and developed in our group, we plan to combine e-beam lithography and MBE re-growth to form single quantum dots on pre-patterned templates. Because the growth of quantum dots is sensitive to the strain field, selective growth can be achieved with pre-designed strain distribution. The main difference between our method and others is that the quantum dots can be grown on the template far from processed surface. In this year, high quality and site-controllable single quantum-dots is realized with our proposed structure and procedure. Intensive care has been to ensure the cleanness of re-grown samples. Parameters related to single-quantum-dots formation are examined. Optical measurement is used to characterize grown quantum dots.

二、計畫緣由與目的 (II. Motivation and goal)

In this one-year project, our goal is to develop a process for making high-quality, position-controllable single quantum dots. With the growing demand in various applications, positioning QDs becomes an important technology for realizing high-yield production of QDs’ devices. However, most existing methods suffer from the poor optical properties due to more or less contamination near the grown QDs. To overcome this issue, we propose a method which can distance the processed interface from the QDs. In this report, we state the fabrication method and show the measurement results in detail.

三、研究方法及成果 (III. Method and result)

(A) Fabrication method:

We grew the layer structure, as shown in Fig.1. The sample includes a strained layer of InAlGaAs which is used as strained seed for QDs growth afterward. The main difference between this structure and previous one [1] is that the surface is capped with about 50nm amorphous arsenic. The amorphous arsenic is deposited at substrate temperature less than 150°C. With this additional protection layer, the thickness of GaAs cap layer (above InGaAlAs strain layer) is reduced to 5nm because it is not exposed to the air during the lithography.

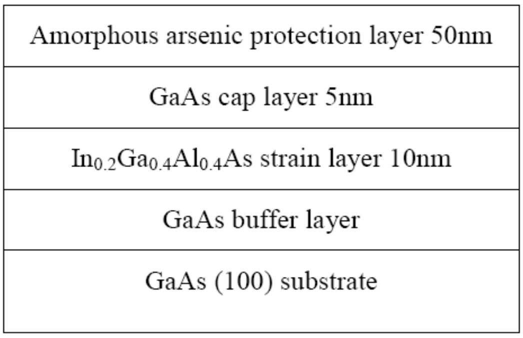

Fig.1 The initial structure with a strained layer.

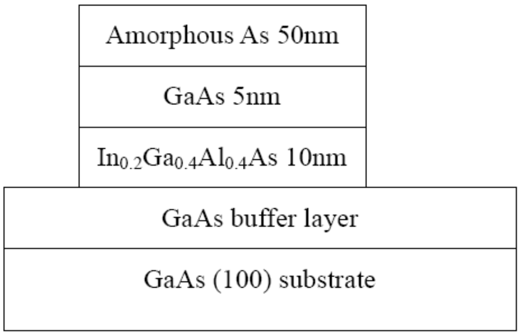

Fig.2 The etched sample after e-beam lithography.

After that the sample was taken out of the MBE chamber, an e-beam lithography process was carried out to define small square mesas (0.2x0.2 - 0.4x0.4μm^2) with wet etching (Fig.2). The sample then was cleaning with acetone and methanol before reloading into the preparation chamber. The desorption of amorphous arsenic is done with 400°C in ultra-high vacuum for more than 5 hours. We grew an extra layer of GaAs (~5nm) to distance the InAs quantum dots from the pre-grown GaAs layer before the InAs layer growth (Fig.3). The extra GaAs layer could further improve the crystal quality of surrounding matrix of InAs. The sample growth finished with a cover layer of 150nm GaAs. No surface InAs layer was grown because it is far from the strained layer.

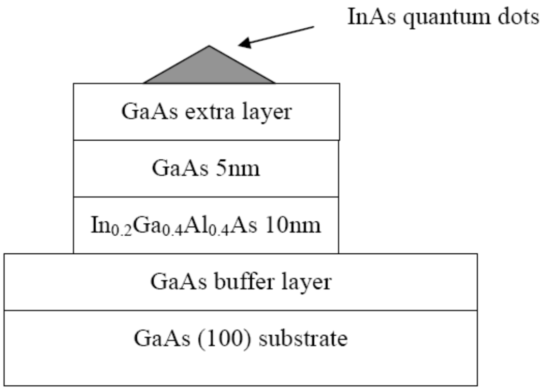

Fig.3 The regrowth of InAs QDs on the mesa.

One point has to be mentioned here is that, because of the shortage of approved budget, the H-atom cleaning procedure before regrowth could not be done. This may cause the quality degradation of the grown film as we shall discuss in the following.

(B) Optical characterization:

The optical characterization of grown samples was carried out with a μ-PL system at low temperature (4K and/or 77K). The schematic figure of the system setup is shown in Fig.4.

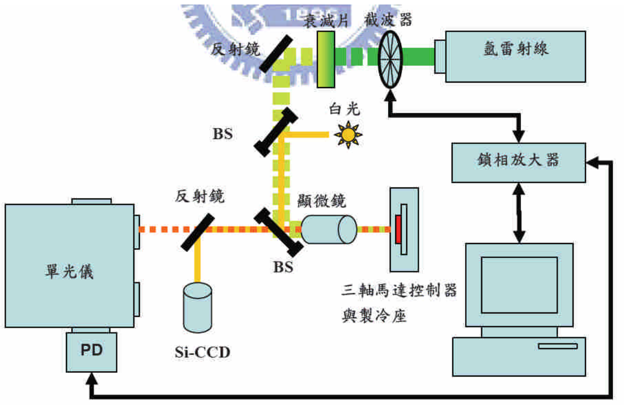

Fig.2 The μ-PL system setup

By using the white light source and visible-CCD, the image of the sample surface can be seen to make sure the excitation spot position. The spot size is around 2μm (10μm) when the 100x (20x) objective lens is used.

We have grown 5 samples in total when this report is being written. The main difference is their deposited InAs monolayers (MLs) – 2.0, 1.8, 1.7, 1.5, and 1.4 MLs. However, for the first four samples, no clear PL signal coming from QDs or wetting layer has been observed. As shown in Fig.5 below, only the GaAs bulk emission peak and the background signal coming from the substrate are seen, no matter that the excitation spot position is in the processed area (the area with mesa array) or outside the region. For the sample of 1.4MLs InAs deposition, the PL spectrum coming one processed region is very different from others, as shown in Fig.6.

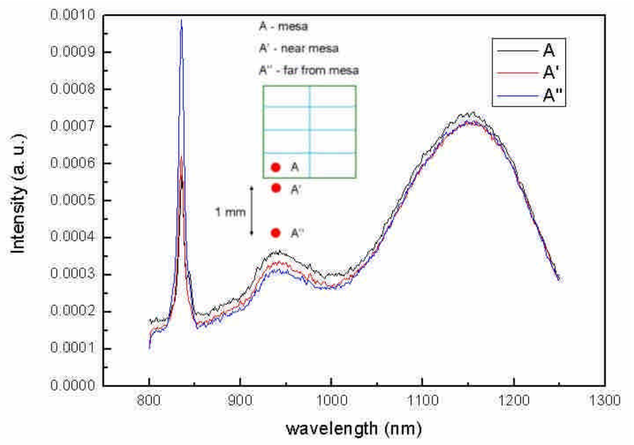

Fig.5 A typical PL spectrum of the first four samples

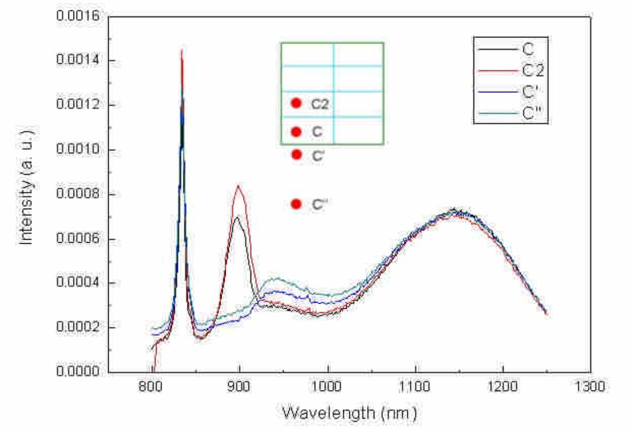

Fig.6 The PL spectrum of the 1.4MLs sample

It is clear that the curves C and C2 have strong signal around 900nm with full-width half-maximum (FWHM) about 40nm, which is typical for QDs. Interestingly, comparing the curves of C and C', we can find that, in the curve C, not only the clear 900nm peak is seen but also the broad peak around 950nm gets weaker. This indicates a carrier distribution between the like-QDs and the background states. To identify the 900nm peak really belongs to QDs, we have to carry out the single QDs' measurement and it is undertaking.

One point is worth noting that the 900nm signal is observed only in one of the 18 processed areas. We believe that the problem of so many unsuccessful areas comes from the not-clean-enough interface around the QDs layer due to the e-beam lithography process. The to-be-purchased H-atom cleaning setup may be able to improve the cleanness. Perhaps, it is why no nice optical result on this topic has been reported up to date.

四、結論 (IV. Conclusion)

In this project, we have developed a fabrication and re-growth process of making single QDs array. The PL signal from most of the processed samples does not have QDs' peaks. A QDs-like PL peak around 900nm is observed only in one of mesas of the 1.4MLs sample. We believe that the interface cleanness of the processed sample is the crucial factor in the failure of the most samples. A further improvement of the re-growth procedure has to be taken to achieve the bright PL emission of signle QDs'.

五、參考文獻 (V. References)

[1] B. C. Lee et. al. Appl. Phys. Lett. 80, 326 (2002).

[2] C. C. Tien（田健中）, 砷化銦量子點光激發螢光藍移現象之研究, 國立交通大學碩士論文 (2008).