行政院國家科學委員會專題研究計畫 期中進度報告

子計畫一:半導體量子結構的成長，物理與元件應用

計畫類別： 整合型計畫
計畫編號： NSC91-2120-E-009-003-
執行期間： 91 年 08 月 01 日至 92 年 07 月 31 日
執行單位： 國立交通大學電子工程學系

計畫主持人： 李建平
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※　半導體量子結構與量子元件前瞻性研究(2/3)—
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中 華 民 國九十二年 五 月 三十日

行政院國家科學委員會專題研究計畫期中報告

半導體量子結構的成長，物理與元件應用(2/3)

The growth, physical property, and device application of semiconductor quantum structure (2/3)

計畫編號：NSC91-2120-E009-003

執行期限：91 年 8 月 1 日至 92 年 7 月 31 日

計劃主持人：李建平　國立交通大學電子工程系

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中文摘要

此報告為總結本實驗室在本年度於「半導體量子結構的成長，物理與元件應用」專題計畫的研究成果。利用分子束磊晶系統（Molecular Beam Epitaxy System; MBE），在線狀量子結構之成果有三大成果：砷化鎵（GaAs）反量子線（Anti Quantum Wires; anti-QWrs）結構於砷化銦鎵（InGaAs）基材、砷化銦（InAs）量子線（Quantum Wires; QWrs）結構於砷化銦鎵（InGaAs）基材、砷化銦量子線結構於砷化銦鋁（InAlAs）基材，今年有關量子線性結構之研究成果已有兩篇論文發表。[1][2]

此外，我們也成功的利用 MBE 成長出量子環(Quantum Rings)和類似量子點分子(Quantum dot molecules)。

關鍵詞：砷化鎵、砷化銦、砷化銦鎵、反量子線、量子線、量子環、分子束磊晶。

I. Abstract

This reports summarized the results of “The growth, physical property, and device application of semiconductor quantum structure” in this year. Using molecular beam epitaxy (MBE) system, there are three major results of wire-like quantum

structure: GaAs anti quantum wires in InGaAs matrix, InAs quantum wires in InGaAs matrix, and InAs quantum wires in InAlAs matrix. There have been two papers, about wire-like quantum structure, reported. [1][2]

In addition, we have also successfully fabricated quantum rings and quantum dot molecule-like nanostructures via MBE.

Keywords: GaAs, InAs, InGaAs, InAlAs, anti quantum wire, quantum wire, quantum ring, quantum dot molecule-like nanostructure, molecular beam epitaxy.

II. Introduction and Purpose

Quantum-structures attracted much attention currently for their potential in fascinating physical phenomena and in device applications. Among the various ways of fabricating semiconductor nanostructures, self-assembled growth method is most popular, because of no resolution limitation from the lithography and no defects induced by the etching processing. Using the different lattice constant between In(Ga)As and GaAs, strained In(Ga)As forms quantum dots (QDs) self-assembly in GaAs system and had remarkable success in the last decade []. As self-assembled quantum structure stacked closely, they show more interesting phenomena. For closely stacked In(Ga)As QDs in GaAs matrix，QDs stack vertically; however closely stacked PbSe QDs in PbEuTe matrix form face-centered-cubic (FCC) structure.

In “The growth, physical property, and device application of semiconductor quantum structure” of this years, we discussed the epitaxy of the InAs quantum structure in InGaAs matrix, GaAs quantum structurein InGaAs matrix, and InAs in InAlAs matrix. Furthermore, we used atomic force microscope (AFM) to observe the surface morphology and used the transport electron microscope to observe the cross-section of stacked structures of these three systems. Moreover, we used GaAs anti-QWrs embedded in 2DEGS in the InGaAs matrix to investigate the anti-QWrs influence on the anisotropic carrier transport behavior in 2DEGS.

Beside the wire-like quantum structure, we also demonstrated the preliminary results of ring-like and molecular-like quantum structure.

III. Results and Discussion

Varian GEN Ⅱ MBE system was used to epitaxy the required quantum structure on (100) InP substrate. Before epitaxy, the native oxide on InP wafer surface was first desorbed at 520^{o}C under As_2 flux. A 300 nm thick InGaAs or InAlAs layer, lattice matched to InP, was then grown and used as the matrix material for the nanostructures. The following deposition contained one or three periods of quantum structures. Each period consisted of several monolayers of InAs or GaAs for self-assembled quantum structure growth and a 6nm matrix material as the spacer. There was interruption before and after each self-assembled quantum structure growth. From the analysis of X-ray diffraction, the lattice constant difference between InGaAs (or InAlAs) and InP was within 0.2%.

Fig.1(a) is the AFM picture of InAs wire-like structure on InGaAs matrix. And Fig.1(b) is the AFM picture of GaAs wire-like structure on InGaAs matrix. Because InAs has smaller band gap than InGaAs and GaAs has larger one than InGaAs, InAs wire-like structure forms QWrs and GaAs wire-like structure forms anti QWrs in InGaAs matrix.

(a) (b)

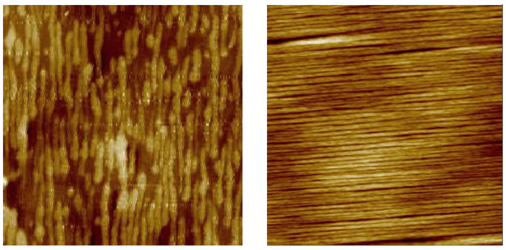
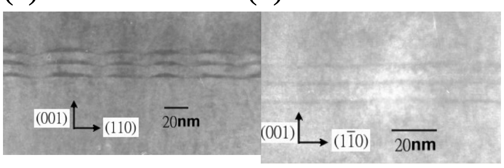


Fig.1.(a)The surface morphology of InAs wire-like quantum structure in InGaAs matrix. (b)The surface morphology of GaAs wire-like quantum structure in InGaAs matrix.

Fig.2(a), Fig.2(c), and Fig.2(e) were cross-sectional TEM pictures taken for $[1\bar{1}0]$ facets and revealed that all InAs or GaAs structures had dot-like patterns. However, Fig.2(a), Fig.2(c), and Fig.2(e), the $[110]$ cross-sectional TEM pictures, showed the InAs or GaAs structure had more uniform wire-like patterns. As a result, InAs and GaAs both formed wire-like structures, which extended along $[1\bar{1}0]$ direction. From the high-resolution TEM (HRTEM) images of these structures, no dislocation was observed. Moreover, the stacked wire-like quantum structure were both vertically aligned, however, the stacked InAs QWrs in InAlAs were spatial anti-correlated. The distinct adatom diffusion coefficient and different reactivity of step edge along $[110]$ and $[1\bar{1}0]$ direction should be the main factors for wire-like structure formation in InGaAs and InAlAs matrix. Phase separation was also observed for these wire-like quantum structures. The phase separation should be caused by sureface energy and the strain energy. And the different shape of phase separation makes wire-like structures in InGaAs be spatial correlated and makes wire-like structure in InAlAs be spatial anti-correlated.

(a) (b)



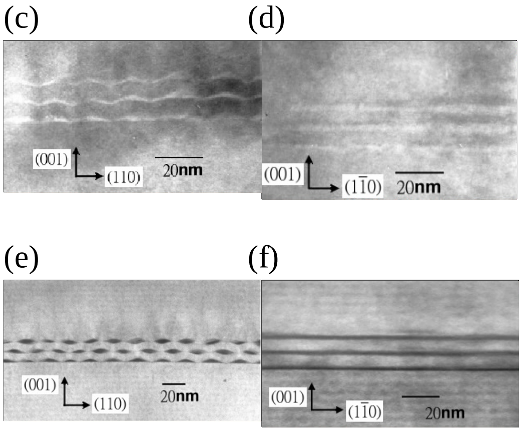


Fig.2.(a)(b)InAs quantum structure in InGaAs. (c)(d)GaAs quantum structure in InGaAs. (e)(f)InAs quantum structure in InAlAs.

We also investigated the property of the GaAs anti-wires using an InGaAs/InAlAs 2DEG structure. The GaAs anti QWrs were embedded below the 2DEG interface. Detailed structure is shown in Fig.3. For comparison, another sample with the same structure but without the wires was also grown under the same conditions. Then the temperature dependent mobility was measured in the temperature range between 8K and 295 K. The longitudinal resistance (R_{xx}) and the Hall resistance (R_{xy}) were measured. For the sample without GaAs anti QWrs, isotropic 2DEG mobility was observed. The low temperature mobility was around 50 000–60000cm^2/Vs. However, for the samples with anti QWrs, clear difference between the devices perpendicular and parallel to the wires was observed. Fig.4 shows the measured mobility as a function of temperature for the two devices with anti QWrs. This figure shows that there is a large difference in mobility for these two devices, which are orientated perpendicular to each other. This anisotropy can be readily explained by the difference in the electron's scattering cross section along the two different directions because of the presence of the wires near the conduction channel. When the electrons move parallel to the wires, the scattering cross section is much less than that perpendicular to the wires.

$In_{0.53}Ga_{0.47}As$ 20nm
$In_{0.52}Al_{0.48}As$ 20nm
$In_{0.52}Al_{0.48}As$ 5nm
Si-doping $1x10^{12}cm^{-2}$
$In_{0.52}Al_{0.48}As$ 5nm
Si-doping $1x10^{12}cm^{-2}$
$In_{0.52}Al_{0.48}As$ 20nm
Si-doping $5x10^{11}cm^{-2}$
$In_{0.52}Al_{0.48}As$ 70nm
$In_{0.53}Ga_{0.47}As$ 5nm
0 or 3ML GaAs
$In_{0.53}Ga_{0.47}As$ 95nm
$In_{0.52}Al_{0.48}As$ 500nm
(100) S. I. InP substrate

Fig.3.The structure of the InGaAs/InAlAs modulation doped structure used in this study.

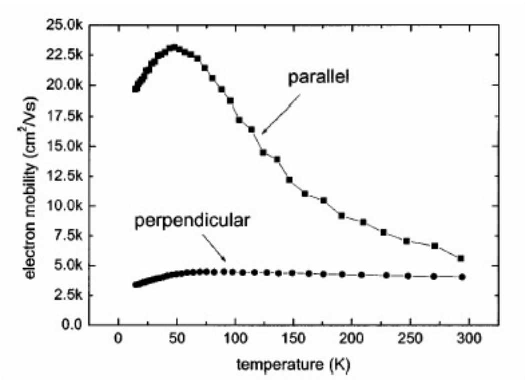


Fig.4. The temperature dependent mobility for the devices with GaAs anti QWrs.

Fig.5(a) is the AFM picture of surface morphology of our preliminary quantum ring. The way to obtain quantum ring is to cap GaAs layer, of which the thickness is smaller than the height of QDs, on QDs and than annealing the wafer. Fig.5(b) is the AFM picture of molecular-like quantum structure. The epitaxy recipe is similar to quantum ring but change the epitaxy condition.

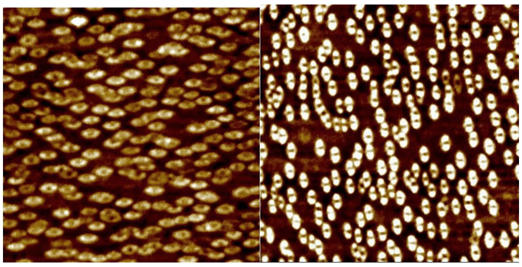


Fig.5.(a)The AFM picture of quantum ring. (b)The AFM picture of molecular-like quantum structure.

IV. The commentary on project results

From the investigation on wire-like quantum structure, the epitaxy mechanism of InAs/GaAs on InGaAs/InAlAs was more clarified. And from the closely stacked structures of these wire-like structures, we first observed the phase separation and their strange stacking behavior. With more clarification of the epitaxy mechanism of these structures, we can use these structures for device application, such as QWrs laser diodes or QWrs infrared photo detectors.

V. Reference

[1] S. D. Lin, C. P. Lee, W. H. Hsieh, and Y. W. Suen, "Self-assembled GaAs antiwires in $In_{0.53}Ga_{0.47}As$ matrix on (100) InP substrates", *Appl. Phys. Lett.*, Vol. 81(16), p.3007, Oct. 2002.

[2] Z. C. Lin, S. D. Lin, and C. P. Lee, "Growth of stacked InAs/GaAs quantum structures in InAlAs/InGaAs matrix on (100) InP substrate", *LDSD Proc. (2002), Ceara, Brazil.*