

規則化量子點成長及一維量子傳輸之研究

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摘要

本論文致力於低維度半導體結構之研究，主要包含兩部份：規則化量子點成長及一維量子傳輸效應。在進入兩大主軸前，首先介紹電子束微影技術，並展示其結合熱回流光阻技術來製作奈米 T 形閘極。

在第一部份裡，我們展示自組銻點受控制地排列在圖形化矽(001)基板上。而這些銻點的尺寸估計為 10 奈米左右，並傾向沿著矽高台邊緣成長，且矽圖形排列能控制銻點的分佈。另外，進一步以局部間接張力表面化學能模型來計算銻點在圖形化矽高台上的成長及分佈情形，模擬的結果和實驗部份相當符合，顯示或許基材的表面形貌，能增進銻點成長於矽基材上的規則化及均勻度。

在第二部份裡，以三閘極結構來研究一維狹窄制限的電子傳輸特性。元件種類包含單量子井及雙量子井砷化鎵/砷化鋁鎵異質結構兩種。一方面，著重於單量子井元件，發現固定表面模型，能合理描述對於不同通道寬度及長度在中央閘極電壓為零時的截止電壓。比較有無中央閘極的樣品，發現中央閘極即使為零偏壓時，也顯著地影響表面位能，從而促進在較深的二維電子氣體中的一維制限。非線性傳輸量測顯示出次能帶能量分離隨著中央閘極電壓呈線性變化，並在中央閘極為 0.8V 時可以提高 70%。另外，以一個簡單的模型來計算最低的次能帶能量分離，模擬的結果和實驗整體行為相當一致。藉由加一正中央閘極電壓，可大大抑制偶然在長通道(寬度大於 $1\mu\text{m}$)發現的雜質效應，由此提高最低的次能帶能量分離。此外，也呈現出所謂低於第一個傳導高原的 0.7 異常傳輸現象，顯示三閘極結構，在一維系統中，很適合來做電子密度相關的研究。另一方面，我們著重在雙量子井元件。利用各別歐姆接點製程技術，成功地製作垂直排列制限，並觀察到兩層各別的傳導特性，發現上量子井的次能帶能量分離比下量子井大。最後，也觀察到狹窄制限所造成的少量的拖拉訊號。

The Study of Regular Quantum Dots Growth and One-Dimensional Quantum Transport

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Abstract

This dissertation is devoted to the study of low-dimensional semiconductor structures and mainly consists of two parts: regular quantum dots growth and one-dimensional (1D) quantum transport. Prior to getting into the two parts, the electron beam lithography incorporating thermally reflowed resist technique for fabricating nanometer T-shaped gate is introduced and demonstrated.

In the first part, the controlled placement of self-organized Ge dots on patterned Si (001) substrate is presented. The sizes of the Ge dots are characterized and estimated to be around 10 nm. The Ge dots tend to form along the Si mesa edge, and their distribution could be controlled by the pattern arrangement. In addition, the formation of Ge dots on patterned Si mesas was further calculated by a local strain-mediated surface chemical potential. The simulation results are quite consistent with the experimental data. It may be possible using substrate morphology to improve the ordering and uniformity of the Ge dots formed on Si substrate.

In the second part, the transport characteristics on 1D narrow constrictions defined by a triple-gate structure are investigated. The device structures include single quantum well (SQW) and double quantum well (DQW) GaAs/Al_xGa_{1-x}As

heterostructures. On one hand, we focus on SQW device. The pinch-off voltages at zero center gate voltage (V_{CG}) for various channel widths W ($= 0.4-0.8 \mu\text{m}$) and lengths L ($= 0.2-2 \mu\text{m}$) are well described by pinned-surface model. Comparison between samples with and without a center gate reveals that the center gate, even when zero-biased, significantly affects the surface potential and thereby facilitates the 1D confinement in a deep 2DEG. Nonlinear transport spectroscopy shows that subband energy separation (ΔE) changes linearly with V_{CG} and can be enhanced by 70% for $V_{CG} = 0.8 \text{ V}$. A simple model is used to calculate the lowest subband energy separation ($\Delta E_{1,2}$), which well reproduces the overall behavior of the measured $\Delta E_{1,2}$. In addition, effects of impurities, occasionally found for long-channel devices ($L \geq 1 \mu\text{m}$), are shown to be greatly suppressed by applying a positive V_{CG} and thereby enhancing $\Delta E_{1,2}$. We also present data for the transport anomaly below the first conductance plateau, the so-called ‘0.7 anomaly’, to demonstrate that the triple-gate structure is useful for the study of density-dependent phenomena in a 1D system. On the other hand, we put emphasis on DQW device. The upper electron layer is supplied via modulation doping, while the lower one is induced through back gate. Vertically aligned constrictions in DQW with separate Ohmic contacts have been fabricated. Clear conductance plateaus for both layers were observed showing that ΔE of the upper quantum well is larger than that of the lower quantum well. Finally, the frictional drag signal caused by narrow constriction was observed.

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Contents

Abstract (in Chinese)

Abstract (in English)

Acknowledgement

Contents

Figure Captions

Chapter 1 Introduction

1.1 Research Background of Low-Dimensional Semiconductor Structures.....	1
1.2 Overview of the Dissertation.....	4
1.3 References.....	7

Chapter 2 Electron Beam Lithography Incorporating Reflowed

Resist Technique

2.1 Introduction to Electron Beam Lithography.....	9
2.2 Nanometer T-Gate Fabricated by Thermally Reflowed Resist Technique.....	11
2.2.1 Introduction.....	11
2.2.2 Experimental method.....	12
2.2.3 Results and Discussion.....	13
2.2.4 Summary.....	15
2.3 References.....	16

Chapter 3 Controlled Placement of Self-Organized Ge Dots on

Patterned Si Substrate

3.1 Introduction.....	23
3.2 Experimental Details.....	26

3.3 Ge Dots Grown on Si Dot Mesas.....	27
3.4 Ge Dots Grown on Si Anti-Dot Mesas.....	29
3.5 Simulation on Si Dot Mesa.....	31
3.6 Simulation on Si Anti-Dot Mesa.....	32
3.7 Summary.....	33
3.8 References.....	35

Chapter 4 Electronic Transport Characteristics in One-Dimensional Constrictions Defined by a Triple-Gate Structure

4.1 Introduction.....	51
4.2 Sample Design, Fabrication and Bonding.....	54
4.2.1 Single Quantum Well Structure.....	54
4.2.2 Double Quantum Well Structure.....	55
4.2.3 Magnetoresistance Measurement.....	57
4.2.4 Device Fabrication.....	60
4.2.5 Wire Bonding.....	61
4.3 Measurement Set-ups.....	63
4.3.1 Low Temperature Set-up.....	64
4.3.2 Four-Terminal Current Bias Measurement.....	66
4.3.3 Four-Terminal Voltage Bias Measurement.....	67
4.4 Experimental Results and Discussions.....	68
4.4.1 Experimental Results on SQW devices.....	68
4.4.1.1 Effects of Center Gate on the Surface Potential.....	68
4.4.1.2 Control of 1D Confinement with Center Gate.....	71
4.4.1.3 Effects of 1D Confinement and Electron Density on Transport Anomalies	
A. Impurity Effects.....	73

B. The 0.7 Anomaly.....	74
4.4.2 Experimental Results on DQW devices.....	75
4.4.2.1 Basic operation on DWQ sample.....	75
4.4.2.2 Conductance measurement with separate contacts.....	76
4.4.2.3 Coulomb Drag measurement.....	78
4.5 Summary.....	79
4.6 References.....	81
Chapter 5 Conclusions.....	120

Appendix A

Appendix B

Publication List

Vita



Figure Captions

Chapter 2

Fig. 2-1. Schematic diagram of the EB control system. First, a computer-aid design (CAD) pattern was generated using UNIX workstation and transferred to the computer control unit. Second, the CAD pattern was transformed to executable job file that accordingly control the beam blanking unit and mechanical stage to manipulate the EB to directly deposit energy on specific positions.

Fig. 2-2. Schematic process steps of the EB lithography in our laboratory. (a) The mesa formed using optical lithography process was chemically cleaned. (b) An EB resist, PMMA, was spin-coated and baked in hotplate. (c) The EB was used to define desired patterns. (d) A developer of MIBK and IPA (1:3) was prepared to etch the resist exposed by EB. (e) Ti/Au metals were deposited using electron gun evaporation. (f) The expected patterns were transferred by lift-off process.

Fig. 2-3. Process flow of the thermally reflowed T-gate.

Fig. 2-4. SEM cross-sectional images of (a) as-developed resist structure, (b) thermally reflowed resist configuration and (c) 30-nm-T-gate after lift-off.

Fig. 2-5. Dependence of different reflow temperature and reflow time on critical dimension (C.D.) of gate length for thermal reflow technique.

Fig. 2-6. Distributions of the pattern-sizes across the wafer with different reflow time at a fixed reflow temperature of 125 °C (Total 10 data points across the wafer for each reflow time).

Chapter 3

Fig. 3-1. Process flow for the fabrication of self-organized Ge dots on patterned Si (001) substrates. The Si templates include dot and anti-dot mesas.

Fig. 3-2. AFM images of (a) the irregular PMMA pattern caused by insufficient EB dosage and (b) the well-defined 100 nm PMMA dots array with 200 nm period.

Fig. 3-3. AFM images of (a) three-dimensional 3×3 Si dots array and (b) cross-sectional analysis of one Si dot mesa, resulting in the size of 65 nm.

Fig. 3-4. SEM pictures of typical arrangements of the self-organized Ge dots on patterned Si dot mesas with mesa dimensions of 65/23/200 nm in diameter/height/period.

Fig. 3-5. AFM image of the distributed self-organized Ge dots on patterned Si mesas.

Fig. 3-6. 3D AFM image of uniformly distributed self-organized Ge dots on patterned Si dot mesas.

Fig. 3-7. AFM image of the 3D PMMA anti-dot array. The diameter and pitch of the holes are 100 nm and 200 nm, respectively.

Fig. 3-8. SEM images of regimented arrays of the self-organized Ge dots on patterned Si anti-dot mesas. (a) Mesa over etched with discontinued edges. (etch depth > 50 nm) (b) Mesa over etched with rough edges. (etch depth = 23 nm) (c) Mesa properly etched with smooth edges. (etch depth = 13 nm)

Fig. 3-9. 3D surface profile of the artificial Si dot mesa generated by Gauss function. The diameter/height is all 100 nm.

Fig. 3-10. 3D distribution of the total surface chemical potential along the artificial Si dot mesa.

Fig. 3-11. 1D variation of the total surface chemical potential along the Si dot mesa

on x-axis.

Fig. 3-12. 3D surface profile of the artificial Si anti-dot mesa generated by Gauss function. The diameter/depth is 100 nm/ 50 nm, respectively.

Fig. 3-13. 3D distribution of the total surface chemical potential along the artificial Si anti-dot mesa.

Fig. 3-14. 1D variation of the total surface chemical potential along the Si anti-dot mesa on x-axis.

Chapter 4

Fig. 4-1. Schematic cross-sectional view of the single quantum well structure.

Fig. 4-2. Conduction band edge diagram around the single quantum well (SQW). The depth displayed is between 2200 and 3000 angstrom. The red dash line at $E = 0$ meV represents the Fermi level. The blue solid line denotes electron density distribution. The sheet electron density (n_{2D}) of the SQW is calculated to be $1.48 \times 10^{11} \text{ cm}^{-2}$ at 1.5K.

Fig. 4-3. Schematic cross-sectional view of the double quantum well (DQW) structure. Between 1st growth and 2nd growth, in-situ focus ion beam lithography was employed to selectively define back gate region. All growth processes are under vacuum using multi-chamber MBE.

Fig. 4-4. Conduction band edge diagram around the DQW structure. The depth displayed is between 1200 and 2400 angstrom. The red dash line at $E = 0$ meV represents the Fermi level. The blue solid line denotes electron density distribution. The n_{2D} of the upper layer is calculated to be $1.46 \times 10^{11} \text{ cm}^{-2}$ at 1.5 K.

Fig. 4-5. Electric circuit set-up in the measurement of the source-drain resistance as a

function of perpendicular magnetic field (B). The longitudinal resistance (R_{xx}) and transverse resistance (R_{xy}) as a function of perpendicular B can be acquired through two lock-in amplifiers by HP 4142b multi-meter, which also serves as a voltage source to back gate.

Fig. 4-6. Shubnikov-de Haas (SdH) oscillations of the DQW sample at $T = 1.5$ K. The SdH oscillations with three different back gate biases (V_{BG}) near the equal electron densities of both quantum wells are displayed. The unit of y-axis is set to be arbitrary for simplicity.

Fig. 4-7. $1/B$ Fast Fourier Transforms of SdH oscillations for V_{BG} from -1 to 3 V in steps of 0.2 V at $T = 1.5$ K. When V_{BG} is between 2.2 and 2.4 V, n_1 is almost equal with n_2 .

Fig. 4-8. Measured electron densities as a function of V_{BG} determined by FFT analysis of SdH oscillations (symbols) and the Hall effect (solid line).

Fig. 4-9. Measured Hall mobility, μ_H (close squares), and estimated mobility, μ_2 , (open triangles) of the lower quantum well as a function of V_{BG} .

Fig. 4-10. Longitudinal resistance (R_{xx}) and transverse resistance (R_{xy}) as a function of perpendicular B ($V_{BG} = 2.3$ V). The filling factor 1 occurs when $R_{xy} = 12.9$ K because of the equivalent electron densities on both layers. The spin splitting can be seen at $\nu = 3$ at around 2 Tesla.

Fig. 4-11. Optical picture of the device layout after metallization. This mask pattern was designed specifically for the fabrication of the DQW sample. However, it is also compatible for SQW wafer. Two quantum wells in the DQW sample can be operated independently through isolation gate and focus ion beam (FIB) lithographic back gate.

Fig. 4-12. SEM photographs of the triple-gate structure with six different EB dosages

after lift-off process. The EB dosage decreases as the figure number increases. As shown in figure (f), the incomplete structure is due to insufficient EB dosage in comparison with figure (a) showing the sharp and clean structure with gap of about 200 nm.

Fig. 4-13. Enlarged SEM image of the triple-gate structure. The length (L) and width (W) of the split gates were varied as $L = 0.2\text{-}2\ \mu\text{m}$ and $W = 0.4\text{-}0.8\ \mu\text{m}$, respectively, while the width of the center gate was fixed at $0.2\ \mu\text{m}$.

Fig. 4-14. Schematic drawing in comparison of ball bonds (a) and wedge bonds (b). The upper part shows the difference of the bonding tools (capillary and wedge). The lower part shows the bonds formed on 1st pad and 2nd pad, respectively.

Fig. 4-15. Schematic top view of the chip carrier and the sample with the gold wires soldered to the carrier's leads.

Fig. 4-16. Schematic cross-sectional drawing of the 1.5 K ^4He cryostat system (Oxford).

Fig. 4-17. Schematic cross-sectional drawing of the 0.3 K ^3He cryostat system (Oxford).

Fig. 4-18. Schematic circuit diagram of a four-terminal current bias measurement set-up. The first lock-in amplifier sources an ac voltage, $V_{\text{rms}} = 0.1\ \text{V}$, which is converted into a constant ac current, $I_{\text{rms}} = 1\ \text{nA}$, via a $100\ \text{M}\Omega$ resistor. The gate voltages are all computer controlled by virtual equipment of LabVIEW automatically.

Fig. 4-19. Schematic circuit diagram of a four-terminal voltage bias measurement set-up. The ac + dc adder box combines and divides the two voltage components; the box has a 100,000 : 1 divider for the ac voltage and a

1000 :1 divider for the dc voltage at 77 Hz.

Fig. 4-20. Schematic circuit diagram of a four-terminal voltage bias measurement set-up used for DQW sample.

Fig. 4-21. Conductance G measured at 1.5 K as a function of split gate voltage V_{SG} of devices with (thick line) and without (thin line) center gate. The two devices have the same split-gate geometry, $L = 0.2$ and $W = 0.6$ μm .

Fig. 4-22. Pinch-off voltage V_P of devices with different channel width W , plotted as a function of channel length L . Solid (open) symbols indicate devices with (without) center gate. For those with center gate, the center-gate bias is kept at $V_{CG} = 0$ V. Three curves represent the pinch-off voltages calculated as a function of L for different W using eq.(4-1).

Fig. 4-23. G of a device with $L = 0.4$ μm and $W = 0.6$ μm measured at 1.5 K as a function of V_{SG} . From left to right, the center gate voltage V_{CG} is varied from 0.9 to -0.45 V in 0.05 V step. The thick line corresponds to $V_{CG} = 0$ V.

Fig. 4-24. Gray-scale plots of transconductance dG/dV_{SG} measured at $T = 0.24$ K as a function of V_{SG} and source-drain bias (V_{SD}) for $V_{CG} = 0$ (upper panel) and 0.8 V (lower panel). Bright features indicate peaks in dG/dV_{SG} . The sample is the same as in Fig. 4-23 ($L = 0.4$ μm and $W = 0.6$ μm).

Fig. 4-25. Energy separation ΔE of adjacent subbands deduced from the transconductance data in Fig. 4-24, plotted as a function of V_{SG} for various V_{CG} varied from 0 to 0.8 V in 0.2 V step. The leftmost data point for each V_{CG} corresponds to the lowest subband energy separation $\Delta E_{1,2}$. Solid squares represent $\Delta E_{1,2}$ calculated for each set of V_{SG} and V_{CG} . The sample is the same as in Fig. 4-23 ($L = 0.4$ μm and $W = 0.6$ μm).

Fig. 4-26. G vs. V_{SG} for different combinations of V_{CG} and V_{BG} at 1.5 K. From bottom to top, V_{CG} is increased from 0 to 0.6 V in 0.2 V step while V_{BG} is decreased from 0 to -1.5 V in 0.5 V step to keep the same pinch-off voltage. The sample is the same as in Fig. 4-23 ($L = 0.4 \mu\text{m}$ and $W = 0.6 \mu\text{m}$).

Fig. 4-27. $\Delta E_{1,2}$ for each set of V_{CG} and V_{BG} , in Fig. 4-26, plotted as a function of V_{CG} . Open and closed symbols represent results of simulation and experiment, respectively.

Fig. 4-28. G vs. V_{SG} of a device with $L = 1 \mu\text{m}$ and $W = 0.6 \mu\text{m}$ ($T = 1.4$ K). From right to left, V_{CG} is increased from 0 to 0.8 V in 0.05 V step. Inset: G vs. V_{SG} of the same device for a different cool down.

Fig. 4-29. G vs. V_{SG} of the same device as in Fig.4-28 ($L = 1 \mu\text{m}$ and $W = 0.6 \mu\text{m}$), measured at 1.4 K (upper panel) and 0.24 K (lower panel). From right to left, V_{CG} is increased from 0 to 0.8 V in steps of 0.01 V. Here, positive back-gate bias of $V_{BG} = 1$ V is applied to enhance ballistic transport. Two horizontal lines indicate the positions of $0.7 \times 2e^2/h$ and $0.5 \times 2e^2/h$.

Fig. 4-30. Depletion characteristics of the DQW sample as a function of V_{IG} with V_{BG} varied from 0 to 4 V at 4.2 K. A constant 10 mV is fed to small contact and the current is measured by another small contact.

Fig. 4-31. Depletion characteristics of DQW sample as a function of V_{IG} with V_{BG} varied from 0 to 4 V at 4.2 K. A constant 10 mV is fed to small contact and the current is measured by another big ohmic contact.

Fig. 4-32. Interlayer leakage current measurement of the DQW device. The V_{IG} is varied from -0.3 to -0.4 V. The V_{BG} is kept at 3 V to make lower layer conducting. Inset: the interlayer bias of 20 mV with leakage current smaller than 1 nA.

Fig. 4-33. G plots of the DQW device with $L = 0.2 \mu\text{m}$ and $W = 0.6 \mu\text{m}$ measured at 1.4 K as a function of V_{SG} . From left to right, the V_{CG} is varied from 0.4 to -0.2 V. The blue curve presents the measured G of the front layer while the red one shows the G for the back layer.

Fig. 4-34. Gray-scale plot of transconductance dG/dV_{SG} measured at $T = 1.4$ K as a function of V_{SG} for $V_{\text{CG}} = -0.2$ to 0.4 V. Bright features indicate peaks in dG/dV_{SG} . V_{BG} is kept at 3 V. Two layers are simultaneously pinch-off at $V_{\text{CG}} = 0.1$ V. The sample is the same as in Fig. 4-33 ($L = 0.2 \mu\text{m}$ and $W = 0.6 \mu\text{m}$).

Fig. 4-35. Gray-scale plots of transconductance dG/dV_{SG} measured at $T = 1.4$ K as a function of V_{SG} for $V_{\text{CG}} = 0$ to 0.4 V. Bright features in the upper plot indicate peaks in dG/dV_{SG} . The upper plot shows the transconductance of one quantum well while the lower one exhibits the drag signal on the adjacent well. The negative resistance occurs at the cross point of the bilayer region as indicated in Fig. 4-34.