奈米國家型科技計畫研究重要成果表

（以下資料請中、英文並呈）

1. 計畫背景：

計畫主持人及共同主持人（PI and Co-PIs）：

計畫主持人 PI： 李建平 Chien-Ping Lee

共同主持人 Co-PIs： 孫允武 Y.W. Suen　孫建文 K.W. Sun　林聖迪 S.D. Li
李柏璁 P. T. Lee
霍斯科 Oleksandr Voskoboynikov

研究題目（Project Title）：

奈米結構超物質之新穎特性研究

Metamaterials Built from Semiconductor Nanostructures

主持人執行機構（Organization）：

國立交通大學

National Chiao Tung University

全程計畫執行期限（Project period）：3 年 (Three Years)

分年經費（Budget per year）：

96 年(2007)： 20,000,000

97 年(2008)： 20,000,000

98 年(2009)： 20,000,000

2. 計畫目標：

- 演驛砷化銦、銻化銦和銻化鎵結構的量子點和量子環崁入到各式不同的主材料中。
- 針對由半導體奈米物件所製成的人工超物質做多角化的研究。
- 了解並控制半導體奈米物件結合於半導體奈米結構超物質系統之電、磁和磁光特性。
- 對於由半導體奈米物件所製成之新的超物質發展包括量子和光學非局化效應的量化描述。
- 發展並完成橢圓儀量測、直接的磁性量測和利用近場顯微鏡在低溫高磁系統中針對超物質的光學研究。
- 發展積體雷射和利用於慢速光元件的光子晶體結構。
- 藉由半導體奈米結構研發可見光範圍之左手物質(left handed material)。

- Demonstration of growth of InAs, InSb and GaSb quantum structures like quantum dots and quantum rings embedded in various kinds of host materials
- Perform a multilateral study of artificial metamaterials made from semiconductor nano-objects
- Understand and control electrical, magnetic and magneto-optical properties of systems of semiconductor nano-objects combined in semiconductor nano-structured metamaterials
- Develop quantitative description of new metamaterials built from semiconductor nano-objects including quantum and optical non-locality effects
- Perform and develop ellipsometry measurement, direct magnetism measurement

and optical study with SNOM for the metamaterials in the cryogenic system

- Development of integrated QD laser and photonic crystal structure for slow light devices
- A team of researchers who have substantial research experience in their respective fields and have a demonstrated commitment to collaborative research
- Strong support and commitment from the Center of Nano Science and Technology at the National Chiao Tung University to support the research needs of this program

3. 參與計畫單位及人數：

國立交通大學（NCTU）

- 電子工程學系(Dept. of Electronics Engineering) / 13人
- 應用化學系(Dept. of Applied Chemistry) / 3人
- 光電工程系(Dept. of Photonics) / 2人
- 奈米科技中心 (Center for Nano Science and Technology) / 1人

國立中興大學 (NCHU)

- 物理系(Dept. of Physics) / 3人

國立台灣大學 (NTU)

- 電機工程學系 (Dept. of Electrical Engineering) / 2人

4. 限本奈米國家型計畫產生之研究成果統計表

篇數 / 統計類別	2005	2006	2007	2008
國外期刊論文				7
國內期刊論文				

5. 請列出最具代表性之論文或專利至多 6 篇：

1.“High quantum efficiency dots-in-a-well quantum dot infrared photodetectors with AlGaAs confinement enhancing layer”, Applied Physics Letters 92, 193506, 2008

2.“Magneto-optics of layers of triple quantum dot molecules”, physica status solidi C (2008)

3.“Ballistic Aharonov-Bohm quantum bits and quantum gates”, Solid State Communications 145, 447 (2008)

4.” Ordering of stacked InAs/GaAs quantum-wires in InAlAs/InGaAs matrix on (100) InP substrates”, Physica E (2008)

5. “A Simple Model for Cavity Enhanced Slow Lights in Vertical Cavity Surface Emission Lasers”, Journal of Optics A : Pure And Applied Optics (2008)

6. “Unusual diamagnetism in vertical asymmetrical quantum dot molecule”, Physical Review B (2008)

6. 計畫已獲得之主要成就與成果（請列出相關文獻及圖表，**內容以整體計畫呈現，500 字為限，請勿以分項成果條列說明**）：

延續上半年之計畫研究成果，我們於利用結合量子點及量子井結構製作高效率紅外線偵測器方面，及結合彈道電子與耦合量子環執行量子運算之架構兩方面皆有重大之突破。

首先，我們於所設計的 dot-in-a-well (DWELL) 結構紅外線偵測器中置入一薄 AlGaAs 層於量子點層上，該置入層具有增加侷限效應之功效，使得吸收量子效率及載子逃離機率均獲得有效提升。如 Fig. 1 所示，比起傳統之 DWELL 偵測器結構，我們所設計的侷限加強 DWELL 結構(CE-DWELL)之峰值響應度在整個偏壓範圍均大幅度提高超過一個數量級。除此之外，偵測頻譜仍落在長波長大氣穿透窗口(8~12 μm)，這對於遠距離天文應用是非常有利的。

第二方面，我們提出了一量子計算架構，利用彈道電子作為量子位元及以耦合量子環作為量子邏輯閘。藉由仔細設計因 Aharonov-Bohm 效應對彈道電子的波函數產生的相位調變，我們使所提出的量子邏輯閘可重程式化及被動態控制。

Continuing our earlier success, we have two great breakthroughs in this year; one in the design and fabrication of dot-in a-well QDIP detectors with unprecedented performance, the other is design of an architecture to perform quantum computation.

A thin AlGaAs layer was inserted on top of InAs QDs as a confinement enhancing layer. This enhanced confinement effect greatly increase both the absorption quantum efficiency and the escape probability. As shown in Fig. 1, the peak responsivity of the confinement enhanced (CE-DWELL) sample is then elevated by over 10 times in the whole bias region. Besides, the spectral response is still located at long-wave infrared atmospheric transmission window. Our design is thus a promising result for the implication on long distance sensing.

We proposed an architecture to perform quantum computation, using ballistic electrons as qubits and coupled quantum rings as quantum gates. The phase modulation of the wave function of the ballistic electrons under the Aharonov-Bohm effect is carefully designed to facilitate reprogrammable and dynamically controllable quantum gates.

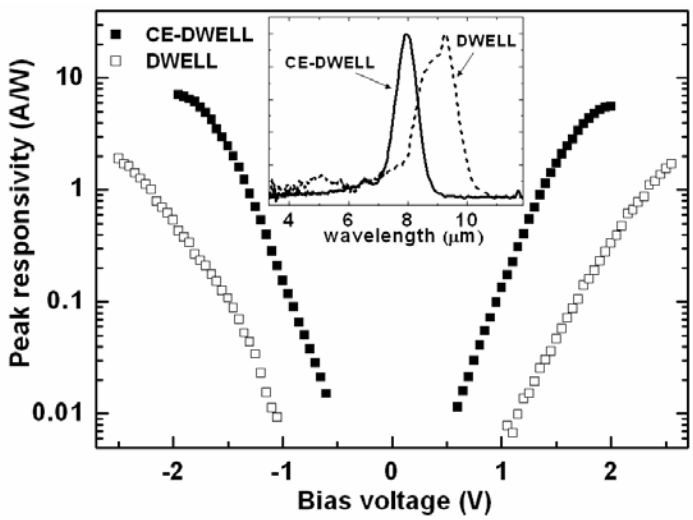

Fig.1 The voltage dependence of the peak responsivity of the CE-DWELL sample and the conventional DWELL sample at 77K. The inset shows the responsivity spectra of the two samples at -1V and 77K.

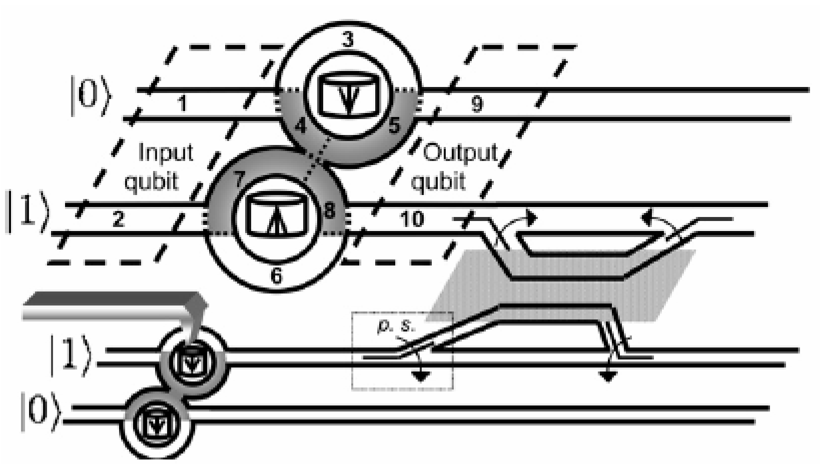

Fig. 2 Schematic diagram of the proposed architecture for quantum computation. Two pairs of parallel 1D quantum wires represent two qubits connected to two pairs of quantum rings, each of which stands for a single-qubit quantum gate. The upper pair demonstrates segments of the 1D quantum wave guides. The tablets in the rings are single-domain nano-sized magnets (the arrows indicate their magnetization), and the cantilever (for clarity reasons only one is shown) is used as a read-write head to monitor/control the magnetization.

7. 上述重大研究突破，與國際上類似領域之比較（**內容以整體計畫呈現，500 字為限，請勿以分項式條列說明**）：

上述研究成果皆已發表於頂尖國際期刊上，研發及製作之具 DWELL 結構之紅外線偵測器其效能已超越國際上類似領域成果水準。與一般 DWELL 結構之紅外線偵測器相較，我們製作出之元件在低溫下具有超過其二十倍的量子效率及增加一個數量級的偵測度。這是目前世界上最好的結果。
Aharonov-Bohm 量子邏輯閘的多功能性使我們在完成製程後，仍能重設各量子邏輯閘的功能。我們所設計之架構可忠實的建立任意單一量子位元的量子邏輯閘。使用了奈米尺度磁鐵提供外加磁通量，我們的架構展示了在量子邏輯線路中包含入磁通量作為額外可調項的潛力。

Some of the research results have been published in top international journals. The performance of our DWELL QDIP devices has surpassed those designed by the other leading research groups in the world. Compare with the conventional DWELL QDIP, the quantum efficiency of our devices have increased more than 20 times and its detectivity is about an order of magnitude higher at 77 K.
The universality of the Aharonov-Bohm quantum gates allows for post-fabrication reassignment of gate functionality, contrary to those previous proposals using ballistic electrons as qubits. Arbitrary single-qubit quantum gates with high fidelity can be constructed on the basis of our proposed architecture. Flux-providing nano-sized magnets in our architecture serve as a demonstration of the potential to incorporate external magnetic fluxes as additional dynamic factors in the design of quantum logic circuitry.

8. 評估主要成果之價值與貢獻度：(請從學、技術創新、經濟效益、社會衝擊等影響面，內容以 300 字為限)：

一、學術面分析

提供紅外線偵測器、量子計算、人工超物質及積體光學方面學者研究所需，刺激研究課題。建立相關領域研究水準，促進國際上的學術交流。

Providing information for researchers in the infrared detector, quantum computation, metamaterials and integrated optics and stimulate related research topics. Building research standards and improve academic exchange with the international community.

二、技術創新面分析

應用半導體奈米結構於紅外線偵測器及量子計算元件設計上，以製做、改良現有元件之功能及開發新穎量子計算元件。

Appling semiconductor nanostructures on QDIP and quantum computing devices to fabricate and improve the device performance and to develop novel quantum computing elements.

三、經濟效益面分析

培養相關研究領域之人力資源，促進技術之發展，跨領域整合及提昇國際上競爭力。

Incubating human resources in the related research area. Promoting technology development and multi-disciplinary integration to become international competitive.

四、社會衝擊等影響面

刺激相關光電、材料產業的開發、系統整合及技術提升。相關先進奈米光電技術如量子點光偵測器。提供相關產業進行研發創意提昇。

Stimulating the related optoelectronics, material industry development, the system integration and improving the technology.