

行政院國家科學委員會專題研究計畫 期中進度報告

量子奈米導線之新穎物理性質之研究(2/3)

計畫類別：個別型計畫

計畫編號：NSC94-2120-M-009-010-

執行期間：94 年 08 月 01 日至 95 年 07 月 31 日

執行單位：國立交通大學電子物理學系(所)

計畫主持人：林志忠

共同主持人：簡紋濱，開執中，陳福榮，吳玉書

計畫參與人員：李麗君、林永翰、邱劭斌、歐逸青、魏銘顏、葉佳唯、廖泰慶、
林彥甫、楊肇嘉、劉伊郎、吳忠義、林奎君、莊惠芳

報告類型：精簡報告

報告附件：出席國際會議研究心得報告及發表論文

處理方式：本計畫可公開查詢

中 華 民 國 95 年 5 月 30 日

行政院國家科學委員會補助專題研究計畫 ☐ 成果報告
☒ 期中進度報告

量子奈米導線之新穎物理性質之研究
Novel Physical Properties of Quantum Nanowires

計畫類別：☒ 個別型計畫 ☐ 整合型計畫

計畫編號：NSC 94 — 2120 — M — 009 — 010 —

執行期間：93 年 8 月 1 日至 96 年 7 月 31 日

計畫主持人：林志忠

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成果報告類型(依經費核定清單規定繳交)：☒ 精簡報告 ☐ 完整報告

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中 華 民 國 95 年 5 月 20 日

Novel Physical Properties of Quantum Nanowires

量子奈米導線之新穎物理性質之研究

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1. 計畫背景

計畫主持人及共同主持人：

主持人：林志忠教授（交通大學物理研究所及電子物理系）

共同主持人：陳福榮教授、開執中教授（清華大學工程及系統科學系）

共同主持人：簡紋濱助理教授（交通大學電子物理系）

共同主持人：吳玉書教授（清華大學電子研究所）

PI: Prof. Juhn-Jong Lin (Inst. of Physics and Dept. of Electrophysics, NCTU)

Co-PI: Prof. Fu-Rong Chen (Dept. of Engineering and System Science, NTHU)

Co-PI: Prof. Ji-Jung Kai (Dept. of Engineering and System Science, NTHU)

Co-PI: Prof. Wen-Bin Jian (Department of Electrophysics, NCTU)

Co-PI: Prof. Yu-Shu Wu (Institute of Electronics Engineering, NTHU)

研究題目：量子奈米導線之新穎物理性質之研究

Novel Physical Properties of Quantum Nanowires

主持人執行機構：交通大學電子物理系

Department of Electrophysics, National Chiao Tung University

全程計畫執行期限：(民) 93 年 8 月 1 日至 96 年 7 月 31 日

Project Period: 8/1/2004-7/31/2007

分年經費： 第一年：11,320,000 元，外加博士後研究一名

第二年：15,000,000 元

第三年：(預核中)

Budget for the 1st year: NT\$ 11,320,000 plus one post-doctoral position

Budget for the 2nd year: NT\$ 15,000,000

Budget for the 3rd year: (to be determined by the NSC)

2. Goals of the Project

In this project, we propose to grow *conducting* metal oxide and diluted magnetic semiconductor (DMS) nanowires (NWs) using vapor phase deposition method. Our goals are to study the atomic and electronic structures as well as the physical (electrical, magnetic, etc.) properties of these materials, and the correlations between the structures and the physical properties. In structural characterization, our goals are to develop methodology for next-generation super high resolution transmission electron microscopy (HRTEM) for quantitative analysis of atomic structure with sub-angstrom resolution. Combination with high resolution electron energy loss spectroscopy (EELS) and *in-situ* scanning probe microscopy, we intend to map out the two-dimensional property and electronic density of states in NWs. In physical property measurements, our goals are to investigate the low temperature electronic and magnetic properties. Quantum electron

transport phenomena in *single* metal oxide NWs will be studied. We also plan to use electron spin-dependent transport as a sensitive probe for exploring the physical properties of *individual* DMS NWs. Since the nanoscience & nanotechnology is an extremely rich area of research, we expect, in the course of our project, not only to achieve in synthesizing new nanoscale materials but also to discover novel physical phenomenon in the nanoscale.

This project is a highly integrated and multi-discipline research project. Its goals are to move along a line from the fabrication of oxide NWs, the development of next-generation HRTEM/EELS methodology for their atomic/electronic structures, the measurements of their physical properties, to the comparison of experiments with theory. In addition, it plans to develop a novel low temperature scanning probe microscopy (LTSPM) technique to facilitate the studies of quantum size and many-body effects in the nanoscale. The PI and the Co-PIs are well established and have renowned expertise in their own field of research. With close collaborations among the team members, they expect to achieve significant results and make impacts in the nanoscale researches.

3. Participants

Prof. Juhn-Jong Lin (Institute of Physics and Department of Electrophysics, NCTU)
Prof. Fu-Rong Chen, Ji-Jung Kai (Dept. of Engineering and System Science, NTHU)
Prof. Wen-Bin Jian (Department of Electrophysics, NCTU)
Dr. Lijun Li (Department of Electrophysics, NCTU)
Graduate students: Yong-Han Lin, Shao-Pin Chiu, Yi-Ching Ou, Ming-Yen Wei, Jia-Wei Yeh, Tai-Chin Liao, Yen-Fu Lin, Chao-Chia Yang (NCTU)
Yee-Lang Liu, Zhong-Yi Wu, Kuei-Jiun Lin, Hui-Fang Chuang (NTHU)

4. Representative Publications

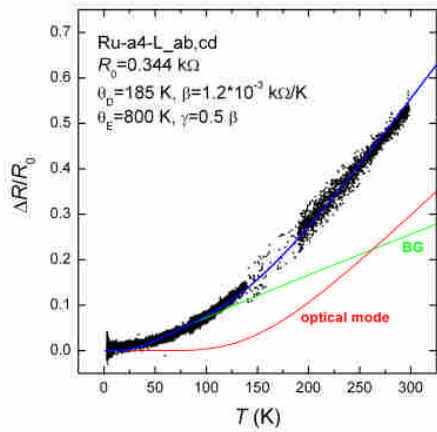
1. *Spontaneous magnetization and ferromagnetism in PbSe quantum dots*, W.B. Jian, W. Lu, J. Fang, M.D. Lan, and J.J. Lin, J. Appl. Phys. **99**, 08N708 (2006). (This article is selected for the May 8, 2006 issue of the Virtual Journal of Nanoscale Science & Technology.)
2. *Orbital susceptibility of PbSe quantum dots*, W.B. Jian, W. Lu, J. Fang, S.J. Chiang, M.D. Lan, C.Y. Wu, Z.Y. Wu, F.R. Chen, and J.J. Kai, J. Chem. Phys. **124**, 064711 (2006). (This article is selected for the February 27, 2006 issue of Virtual Journal of Nanoscale Science & Technology.)
3. *Valence state map of iron oxide thin film obtained from electron spectroscopy imaging series*, K.F. Chen, S.C. Lo, L. Chang, R. Egerton, J.J. Kai, J.J. Lin, and F.R. Chen, Micron, (accepted, 2006). (This article is an **invited paper** for the special issue *Nano-Characterization of Nano-Materials* in Micron.)
4. *Direct observation of structure effect on ferromagnetism in $Zn_{1-x}Co_xO$ nanowires*, W.B. Jian, Z.Y. Wu, R.T. Huang, F.R. Chen, J.J. Kai, C.Y. Wu, S.J. Chiang, M.D. Lan, and J.J. Lin, Phys. Rev. B, accepted (2006).
5. *Probing single RuO_2 nanowires by using high-precision electrical-transport measurements*, Y.H. Lin, S.S. Yeh, W.B. Jian, F.R. Chen, J.J. Kai, and J.J. Lin, to be published.
6. *Observation of size dependent Debye temperature in metal nanowires*, Y.H. Lin, W.B. Jian, F.R. Chen, J.J. Kai, and J.J. Lin, to be published.

5. Outstanding Results Achieved in This Project

A. Four-probe Electrical-transport Measurements on Individual Nanowires

One of the major efforts of this project is to study the electrical-transport properties of

individual NWs down to sub-Kelvin temperatures. In the past two years, we have managed to master the novel techniques of isolating single NWs, fabricating submicron electrodes onto a designated NW with electron-beam lithography, and detecting small signals over a wide range of temperatures. Both conducting metal oxide (RuO₂ and ITO) and semiconductor (ZnO) NWs have been investigated. In the former case, we have made an important finding: *the Debye temperature decreases significantly as the NW diameter reduces to several tens nm*. Further works are under way to clarify the size effect, and to extend the measurements to lower temperatures to explore quantum electron transport phenomena. In the case of semiconductor NWs, we have successfully carried out electrical measurements on individual ZnO NWs down to 0.3 K. Our work is likely the first low-temperature, four-probe measurements on single semiconductor NWs. We have also begun measurements on Co-implanted ZnO NWs (in magnetic fields). Experiments on individual DMS NWs are important for both fundamental researches and nanoelectronics.

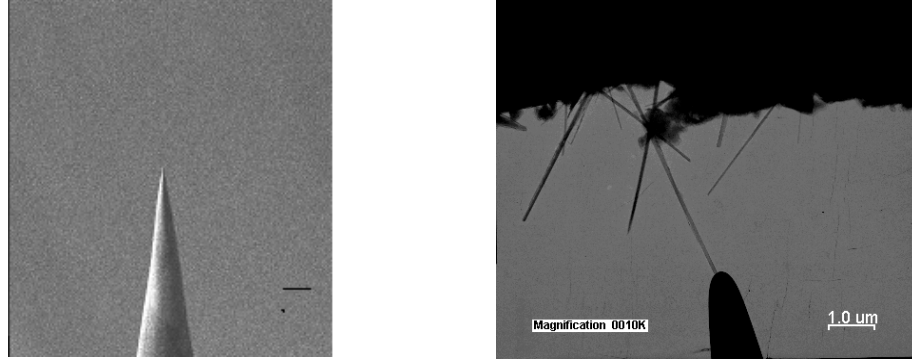


Normalized resistance as a function of temperature for a 40-nm diameter RuO₂ nanowire between 1 and 300 K. The measured resistance is well described by the Bloch-Grüneisen law (blue curve) taking into account both the electron—acoustic-phonon scattering (green curve) electron—optical-phonon scattering (red curve). The Debye temperature is then determined.

B. STM/TEM Studies of Electrical-transport Properties of Single Nanowires

We have recently developed a novel STM/TEM technique to *in-situ* characterize the electrical properties of *single* NWs at room temperature. In practice, the *I-V* curves of NWs are often nonlinear due to the “contact problem” between the STM tip and the NW. In this project, we have developed a novel procedure to produce ohmic contacts, thus obtaining linear *I-V* characteristics. The contact resistances and the resistances of individual RuO₂ and ITO NWs have then been determined. We found that the resistivities thus obtained are within a factor 3–4 to the values measured from the four-probe technique discussed above. This result establishes that the STM/TEM technique can serve as a reliable, quick probe for measuring the resistivity of a single NW. Taken together, the four-probe measurement and the STM/TEM method are powerful and complimentary: the former provides information for the *intrinsic* electrical property while the latter provides an *in situ*, handy check of the as-grown NWs. Our combined approach to the

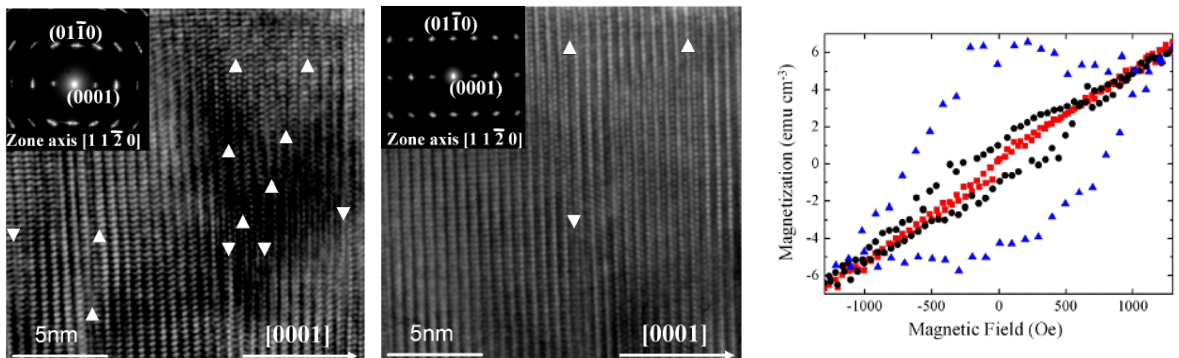
electrical properties of single NWs is rather unique in the nanoscience community worldwide.



(left) SEM image for a TEM/STM Au tip fabricated by focused-ion beam technique. (right) The TEM/SEM Au tip touching a RuO₂ nanowire grown on substrate.

C. Ferromagnetic Ordering in Co-implanted ZnO Nanowires

DMS NWs comprise an important class of building blocks for nanoelectronic devices. Their magnetic properties need to be understood and controlled. In this case, we have recently established a direct correlation between the structural order and the occurrence of ferromagnetism in Co-implanted ZnO NWs. We found that the as-implanted Zn_{1-x}Co_xO ($x \leq 0.11$) NWs contained large amounts of structural defects and exhibited paramagnetic behavior. After thermal annealing, the structural defects largely disappeared and noticeable hystereses in the magnetization loops were observed, indicating the presence of apparent ferromagnetic ordering. EELS and HRTEM studies had been performed to determine the valence state of the Co element, and to confirm that there was no Co clustering. Our result is the first to establish the structural effect on the ferromagnetism in DMS NWs.

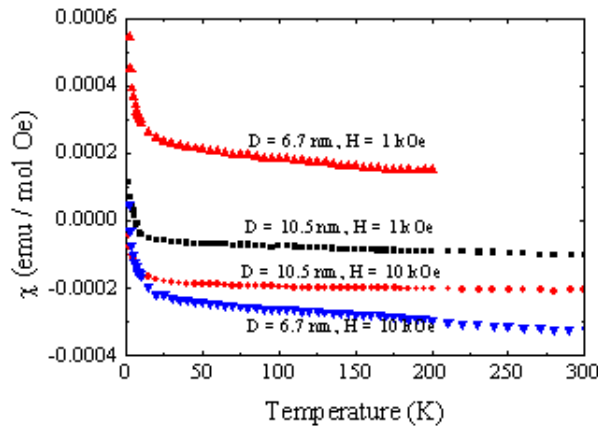


(left) SEM image of the lattice structure for a as-implanted Zn_{1-x}Co_xO nanowire. A good number of structural defects are indicated by the small white triangles. (center) SEM image of the lattice structure for an annealed Zn_{1-x}Co_xO nanowire. The number of defects is greatly reduced. (right) The magnetization for the

as-implanted nanowires revealed paramagnetism (red circles) while the magnetization for annealed nanowires revealed large hysteresis loop, indicating the occurrence of ferromagnetic ordering.

D. Magnetic Properties of Mn-doped CdSe Quantum Dots

To understand the magnetism resulting from the interplay between orbital electrons and doped magnetic impurities, we have studied the size effect on the orbital magnetism of PbSe, CdSe, and Mn-doped CdSe semiconductor quantum dots. Our results on PbSe dots have been published. As for the case of Mn-CdSe quantum dots, we found that the magnetic susceptibilities displayed noticeable size effects on the orbital susceptibility. We also discovered that the orbital susceptibility is quenched in those quantum dots with Mn ion inclusions. Moreover, our observation indicates that the low temperature magnetizations increased profoundly for Mn-doped CdSe quantum dots, which might originate from enhanced magnetic interaction between Mn ions through orbital electrons.



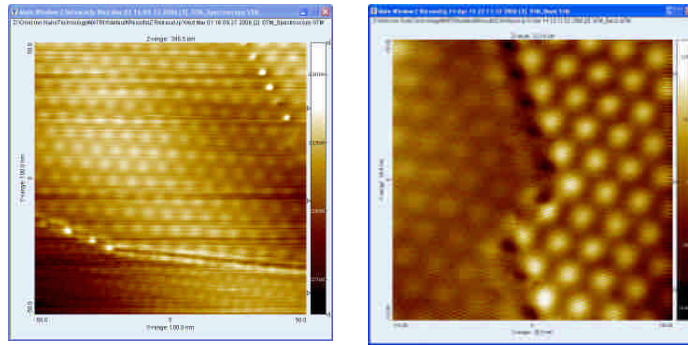
Temperature dependence of magnetic susceptibility of PbSe quantum dots. D labels the diameter of the quantum dots. At low temperatures and in low magnetic fields, the quantum dots revealed paramagnetism, while at high temperatures and in high magnetic fields, the quantum dots revealed diamagnetism. The paramagnetic response is stronger as the dot decreases in size.

E. Size effect on Electronic Structure in nanowires: Spatial Resolved EELS studies

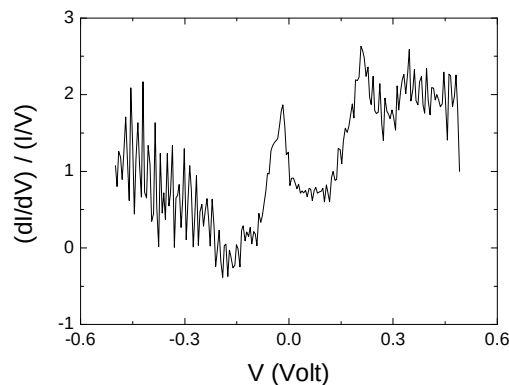
We have carried out studies of EELS spectra on RuO₂ NWs covering a wide range of diameter from 20 to 120 nm. We found a size dependent blue shift and broadening of the bulk plasmon. Similar blue shift has previously been reported in several nano-materials systems. However, the EELS spectrum from nano-materials is complicated by the “aloof” effect and “Bregrenzung” effect. The EELS may also be complicated due to geometric effect in nano-materials. In order to quantify the size dependent properties of the NWs, the contributions from these factors have to be decoupled. In this project, we continue to develop the algorithm and methodology for decoupling these contributions to fully understand the EELS response in nano-materials systems. (Figures not shown)

F. Low-Temperature Scanning Probe Microscopy:

We have recently set up a Low Temperature Scanning Probe Microscope and optimized the operation conditions down to liquid-nitrogen as well as liquid-helium temperatures. We have successfully measured the local density of states in the Moire patterns formed on graphite surfaces. In addition, we have found additional density of states across step edges, which might be the origin for the paramagnetism in graphite.



Constant-current STM images of Moire patterns revealing atomic resolution.



The local density of states in a Moire pattern as measured from the current image tunneling spectroscopy (CITS) at 6.0 K.

6. Invited talks at International Conferences and Workshops

1. **Juhn-Jong Lin**, *International Seminar and Workshop on Quantum Coherence, Noise and Decoherence in Nanostructures*, 15-26 May 2006, Dresden, Germany.
2. **Juhn-Jong Lin**, *2005 CCAST Mesoscopic Physics Workshop, China Center of Advanced Science and Technology—World Laboratory*, 28 March-1 April 2005, Beijing.
3. **Fu-Rong Chen**, *The 16th International Congress on Microscopy (IMC16)*, September 3-8, 2006, Sapporo, Japan, 2006.
4. **Fu-Rong Chen**, *Symposium on “Structure-Property Relationships of Transition Oxide Interfaces” at Material Science & Technology 2006 (MS&T2006)*, Cincinnati, OH, USA, Oct. 15-19, 2006.
5. **Fu-Rong Chen**, *Annual Meeting of Microscopy Society of American*, July 31-August 4, 2005, Hawaii, USA, 2005.