專題研究計畫成果報告

一、背景與目的

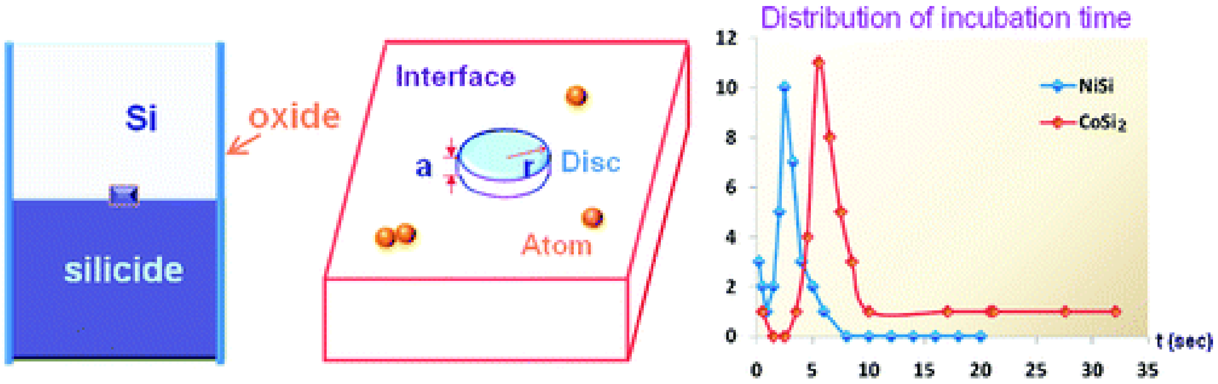
近年來電子元件微小化的發展,使得具奈米尺度之功能性材料結構及其光電特性益受重視。在新世代奈米元件中,奈米點可望應用於單電子電晶體、高密度記憶體、半導體雷射。而一維奈米結構則被看好應用於導線及具發光特性之奈米元件。尤其以矽奈米線為基礎,應用於微電子奈米元件之研究,一直是各個相關領域相當重視的研究方向。在矽晶上,自動對準低電阻率金屬矽化物仍為下一世代電子元件所需之重要材料。近年來許多矽化物奈米線之研究亦由於在新世代奈米元件中可望取代金屬導線而成為重要焦點。在此趨勢下,更發展出利用矽奈米線製作奈米尺度之電晶體,使其具有取代積體電路上金氧半電晶體之潛力,並對微電子工程及高敏度的生物檢測器帶來新的契機。為了達成此目標,矽化物/矽奈米線異質結構(heterostructure)成為重要的研究課題。在相關金屬矽化物奈米線之研究領域中,近年來有許多重要的成果刊登於知名頂尖期刊,顯見其重要性。而近期,本研究團隊亦在此領域發表幾項重要研究成果,也在世界上居於領先的地位,並且持續往更深入與重要的主題進行研究。另一方面,對於矽化物與矽鍺合金以及碳化矽的反應研究也有深入探討。

二、結果與討論

本研究計畫針對上述研究主題,至今已有成果產出,且部分成果都發表在知名國際期刊上。本研究主要分兩大部分,一是金屬矽化物的奈米結構成長、特性、及動力學研究。另一部分為矽鍺薄膜上之成長及金屬化研究。兩部分都有極佳的成果,其摘要及主要成果分別描述如下:

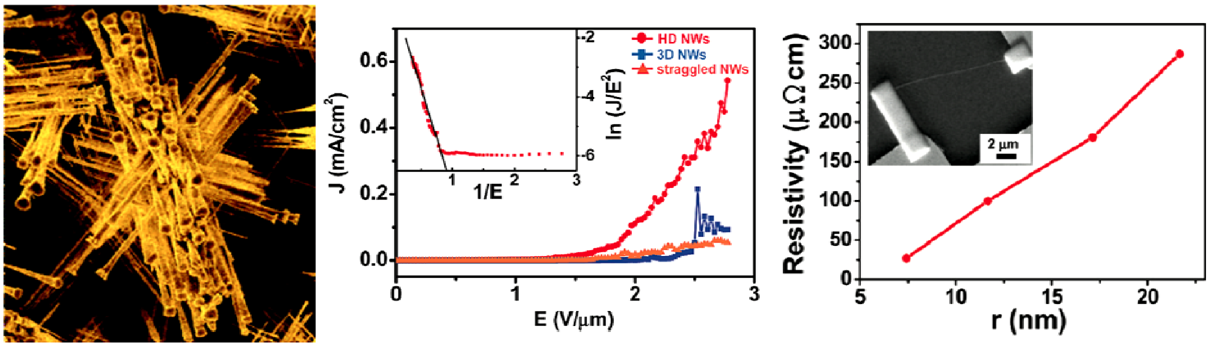
1. Y.C. Chou, **W.W. Wu**, L.J. Chen, and K.N. Tu, “Homogeneous Nucleation of

Epitaxial $CoSi_2$ and NiSi in Si Nanowires," *Nano Lett.* **9**, 2337-2342 (2009).



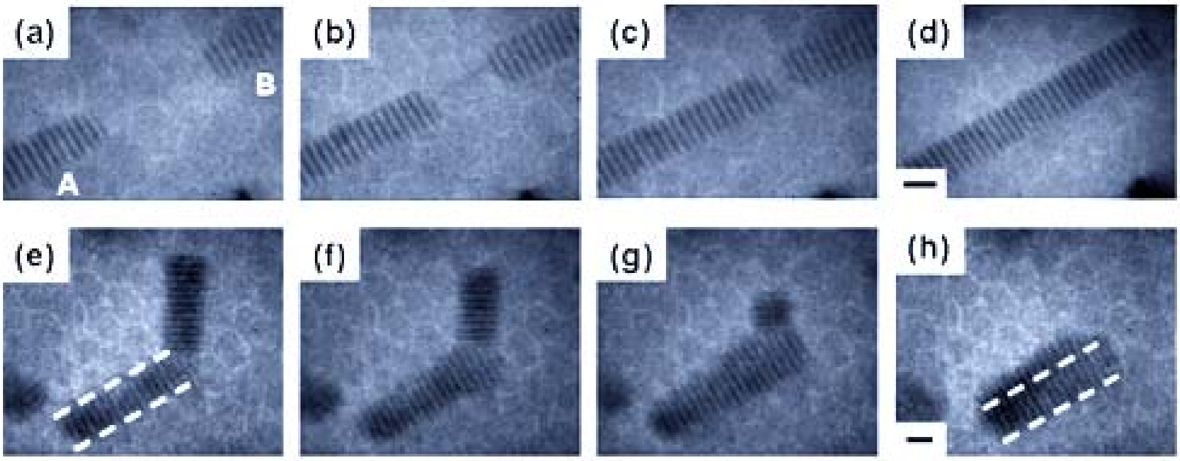
Homogeneous nucleation is rare except in theory. We observed repeating events of homogeneous nucleation in epitaxial growth of $CoSi_2$ and NiSi silicides in nanowires of silicon by using high resolution TEM. The growth of every single atomic layer requires nucleation. Heterogeneous nucleation is prevented because of non-microreversibility between the oxide/Si and oxide/silicide interfaces. We determined the incubation time of homogeneous nucleation. The calculated and the measured nucleation rates are in good agreement. We used Zeldovich factor to estimate the number of molecules in the critical nucleus; it is about 10 and reasonable. A very high supersaturation is found for the homogeneous nucleation.

2. C.I. Tsai, P.H. Yeh, C.Y. Wang, H.W. Wu, U.S. Chen, M.Y. Lu, **W.W. Wu**, L.J. Chen, and Z.L. Wang, "Cobalt Silicide Nanostructures: Synthesis, Electron Transport and Field Emission Properties," *Cryst. Growth Des.* **9**, 4514-4518 (2009).



Cobalt silicide nanostructures have been synthesized by a spontaneous chemical vapor transport and reaction method. The temperature and the vapor flow rate were shown to critically influence the growth of nanostructures. The effects of two main parameters on the growth of nanostructures were discussed. The phases formed were determined by the Gibbs free energy changes in the reactions. Various phases (CoSi, Co_2Si) and morphologies, such as single-stem nanowires, three-dimensional (3D) nanowire networks, and aloelike nanostructures, have been synthesized. Very low turn-on field (1.42 V/μm) and good conductance obtained from field-emission and electrical property measurements, respectively, indicate that CoSi nanowires are potentially useful for electronic devices.

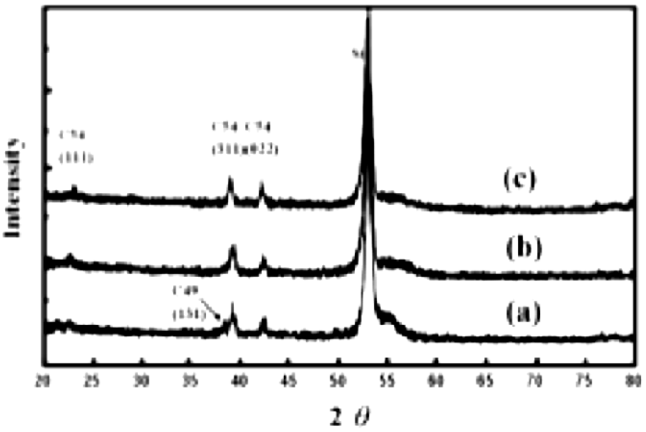
3. L.J. Chen, and **W.W. Wu**, "In situ TEM Investigations of Dynamical Changes in Nanostructures," *Mater. Sci. Eng. R* (in press, 2010).

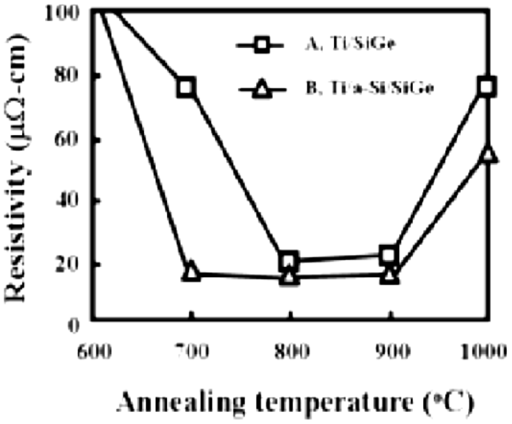


In situ investigation of the temperature induced phase transformation, structural and chemical evolution of nanocrystals is important for understanding the structure and stability of nanomaterials. Transmission electron microscopy (TEM), one of the most powerful tools for characterizing nanostructured materials, is essential for the development of nanotechnology. In situ TEM is a technique that allows a direct observation of dynamic properties in nanoscale. Recent development of ultra high vacuum TEM (UHV-TEM) further enables the investigation on atomic-scale materials systems in a clean environment. The appropriate utilization of the UHV-TEM will be beneficial in studying the fundamental mechanisms of dynamic reactions, formation of transient phase, solid-state amorphization, epitaxial growth, growth kinetics and evolution of defects. In this paper, we present the most recent progress in observing dynamic processes in nanoscale by in situ UHV-TEM.

4. **W.W. Wu**, C.W. Wang, K.N. Chen, S.L. Cheng, and S.W. Lee, "Enhanced growth of low-resistivity titanium silicides on epitaxial $Si_{0.7}Ge_{0.3}$ on (001)Si with a sacrificial amorphous Si interlayer," *Thin Solid Films*

doi:10.1016/j.tsf.2010.04.090 (in press, 2010).





Enhanced growth of low-resistivity self-aligned titanium silicides on epitaxial $Si_{0.7}Ge_{0.3}$ with a sacrificial amorphous Si (a-Si) interlayer has been achieved. The a-Si layer with appropriate thickness was found to prevent Ge segregation, decrease the growth temperature, as well as maintain the interface flatness and morphological stability in forming low-resistivity C54-$TiSi_2$ on $Si_{0.7}Ge_{0.3}$ grown by molecular beam epitaxy. The process promises to be applicable to the fabrication of high-speed Si-Ge devices.

5. S. W. Lee, S. H. Huang, S. L. Cheng, P. S. Chen, **W. W. Wu**, “Ni silicide formation on epitaxial Si1-yCy/(001) layers,” *Thin Solid Films* doi:10.1016/j.tsf.2010.05.015 (in press, 2010).

The formation of Ni silicides on $Si_{1-y}C_y$ (y = 0.01 and 0.018) epilayers grown on Si(001) has been investigated. The presence of C atoms was found to significantly retard the growth kinetics of NiSi and enhances the thermal stability of thin NiSi films. For Ni(11 nm)/$Si_{0.982}C_{0.018}$ samples, the process window of NiSi was shifted and extended to 450–700 °C. Moreover, there was an additional strain introduced into the $Si_{1-y}C_y$ epilayers during Ni silicidation. This work shows the potential of Ni silicidation on $Si_{1-y}C_y$ for device applications.

三、參考文獻

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4. W. W. Wu, C. W. Wang, K. N. Chen, S. L. Cheng, and S. W. Lee, “Enhanced growth of low-resistivity titanium silicides on epitaxial $Si_{0.7}Ge_{0.3}$ on (001)Si with a sacrificial amorphous Si interlayer,” *Thin Solid Films* doi:10.1016/j.tsf.2010.04.090 (in press, 2010).
5. S. W. Lee, S. H. Huang, S. L. Cheng, P. S. Chen, **W. W. Wu**, “Ni silicide formation on epitaxial Si1-yCy/(001) layers,” *Thin Solid Films* doi:10.1016/j.tsf.2010.05.015 (in press, 2010).

四、計畫成果自評

本計畫承蒙國科會微電子學門給予大力支持，特此感謝。近一年來之研究成果也所幸能發表於部分優質期刊，希望貴會能繼續支持我們新人，也期許後續相關的研究能持續能拿出更好的科研成績。另外在材料與半導體領域，材料分析仍是相當關鍵且重要的一環，因此電子顯微鏡扮演著舉足輕重的角色，陳力俊教授的臨場超高真空穿透式電子顯微鏡提供了重要的實驗平台，對於新穎材料的熱、電行為目前已正在積極研究且有相當好的成果，預計在一年內將會陸續發表。