NWO/RGC JOINT RESEARCH SCHEME
COMPLETION REPORT

Project Reference Number

D-HK008/11T-II

Project Title

Probing single functional molecules anchored at atomic chains

Particulars

	Hong Kong team	Dutch team
Name of Principal Investigator (with title)	English: Prof. Nian Lin Chinese: 林念	Prof. Harold J.W. Zandvliet
Name of Co-Investigator (if any)	English: Chinese:	
Institution or Institutional affiliation	[ ] CityU [ ] HKU [ ] CUHK [x] HKUST [ ] HKBU [ ] LU [ ] HKIEd [ ] PolyU	University of Twente
Other project team members (if any)	Lei Dong	Avijit Kumar

Funding Period

	1st year	2nd year (if applicable)
Start Date	01 Jul 2011	01 Jul 2012
Completion Date	30 Jun 2012	30 Jun 2013

Objective(s) as per original application

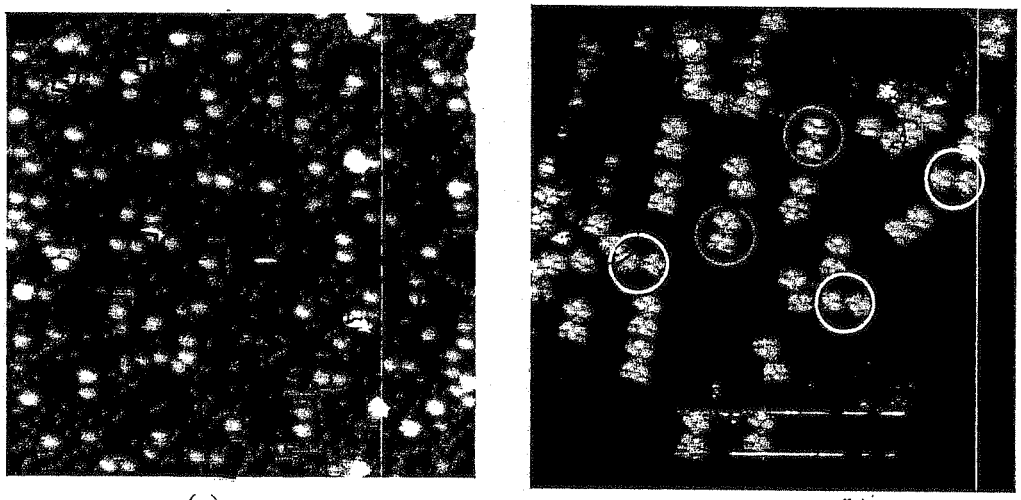
1. Fabricate Au/Pt nanowires on Ge(001) surface
2. Deposit functional molecules on the nanowire
3. Investigate the electronic transport of the anchored molecules.

[Please attach relevant document(s)]

i) Outline of proposed research and results obtained

In March 2012 Prof. Harold Zandvliet visited the Hong Kong University of Science and Technology within the framework of joint project entitled "Probing single functional molecules anchored at atomic chains". During this stay the Dutch PI has built an Au evaporator showed the Hong Kong colleagues how to clean germanium (001) oriented substrates in ultra high vacuum by Argon ion bombardment and annealing. During the visit (10/3 to 12/3) Harold Zandvliet cooperated with Prof. Nian Lin (PI HKUST) and Dr. Dong Lei (post doc at HKUST). From December 1-15 2012, a student, Avijit Kumar, from Prof. Harold Zandvliet visited the Hong Kong University of Science and Technology within the framework of joint project entitled "Probing single functional molecules anchored at atomic chains". During his visit, he has carried out experiments in collaboration with the Hong Kong team. He also presented his results obtained in Twente, exchanged ideas and discussed the on-going project. Prof. Nian Lin of the Hong Kong team visited the Dutch team from January 6 to 13 2013. He participated in the experiments of tunnelling spectroscopy measurements of Au nanowire grown on Ge(001). He also discussed extensively with the Dutch team members and gave a presentation reporting the results obtained in HKUST. During this visit, an interesting phenomenon of one-dimensional metallic states was discussed. The experiments was planned and conducted in both labs.

The experiments focused on studying the electronic properties of the molecules adsorbed on Au/Ge(001) surface. As shown in Figure 1a, dog-bone shape molecules (as highlighted by the red and blue rectangle frames) are adsorbed on Au nanowires. Primarily, the molecular axis is 45 degree titled with respect to the nanowire direction. The adsorbed molecules are in a bridging configuration which link the two adjacent nanowire rows. Figure 1b is a high-resolution image which reveals the intra-molecular features.



(a) (b)

Figure 1 (a) Scanning tunnelling microscopy image showing the molecules adsorbed in two orientations as marked by the red and blue frames, respectively. (b) High-resolution STM revealing the intra-molecular features.

We used differential tunnelling spectroscopy to probe the electronic properties of the adsorbed molecules. Figure 2 presents site-specific spectra acquired with the STM tip located at the end and the middle of a molecule, and an Au nanowire. We found that the intrinsic molecular states are absent, which indicates that the molecules strongly adsorbed at the Au nanowire. Nevertheless, the density of states at the end of the molecule is significantly high at 2.4 V than those at the middle of the molecule or the Au nanowire. This signature hints that the molecule behaves as a conducting board for charge transport.

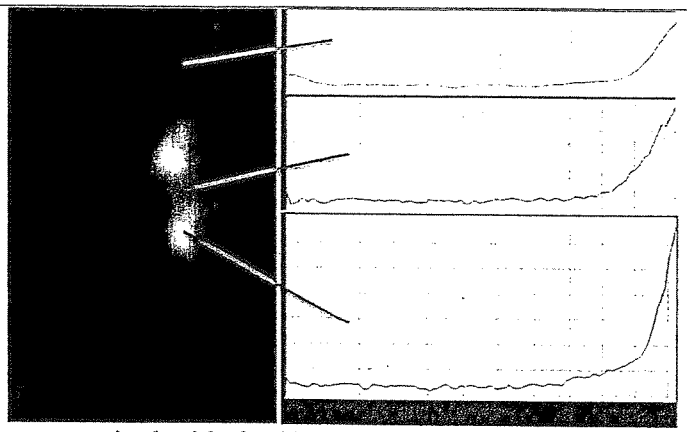


Figure 2 Site-specific spectra acquired with the STM tip located at the end and the middle of a molecule, and an Au nanowire.

Figure 3 shows Au atoms form three types of nanowires on Ge(001) surface with inter-wire separation of 1.59 nm (D1), 0.79 nm (D2) and 0.40 nm (D3), respectively. The D1 type is well-known, while D2 and D3 are not reported in literature. The formation of the two new nanowire structures is attributed to high Au dosage.

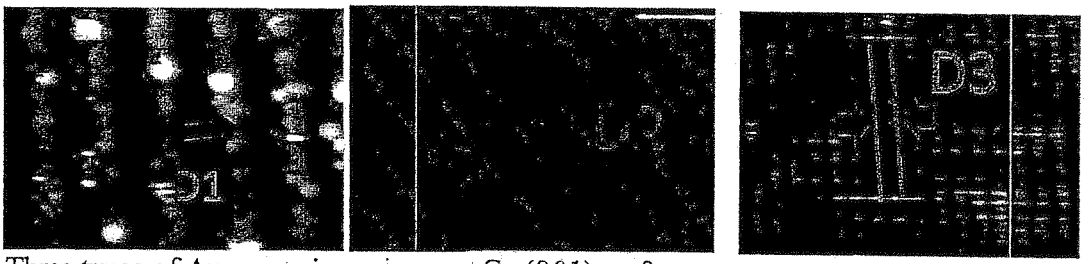
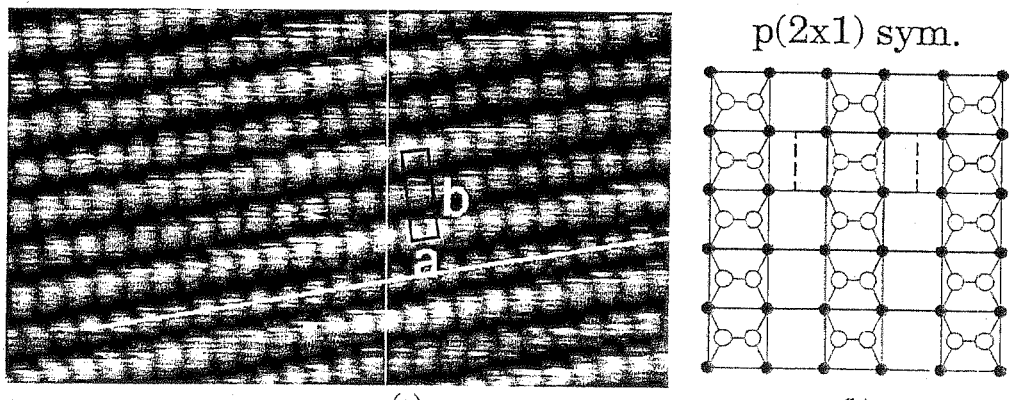


Figure 3. Three types of Au nanowires grown on Ge (001) surface.

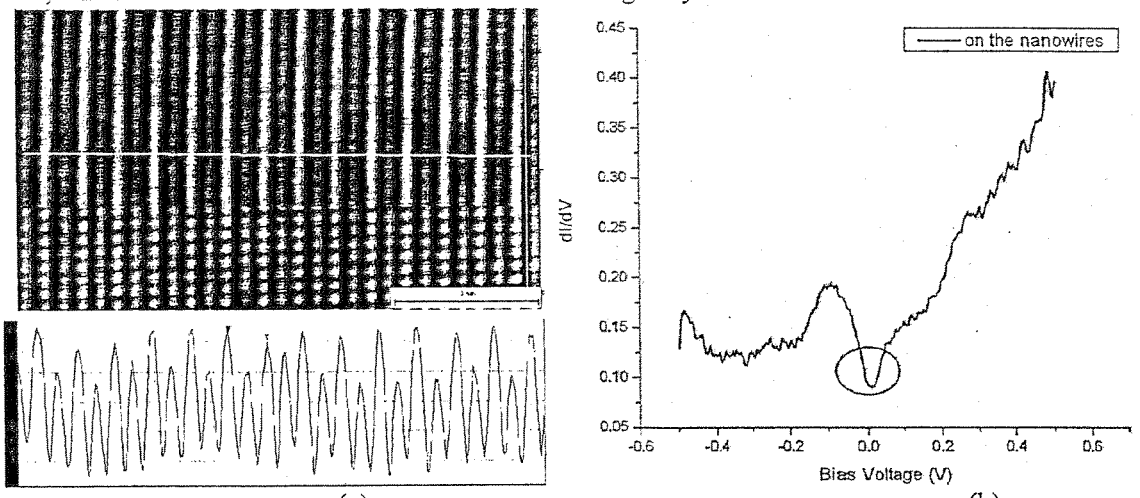
Figure 4a shows an atomic-resolution STM topograph of the D2 type nanowires. Each protrusion represents a single Au atom. One can see the Au atoms form dim and bright inter-spaced rows (nanowires) along ***a*** direction. The distance between two neighbouring bright rows (***b***) is 0.79 nm, which equals to two times of Ge substrate atomic lattice, or distance between adjacent dimer rows of Ge (001) p(2X1) reconstruction as luustrated in Figure 4(b). Along the row direction, the Au atoms are spaced by (***a***) 2.8 A, which corresponds to Au atom size. We propose a model of the D2 structure: Bright rows are Au atoms adsorbing on the dimer rows whereas the dim rows are Au atom adsorbing in the troughs; Along the row direction, Au atoms, which are closely packed according to Au atomic size, are incommensurate to the substrate lattice.



(a) (b)

Figure 4. (a) Atomic-resolution STM topograph of D2 nanowires. (b) p(2X1) dimer-row reconstruction of Ge (001) surface.

displays atomic-resolved D2 nanowires and a corss-section profile. Figure 5 (b) shows site-specific dI/dV spectrum acquired with the tip located at the bright rows. A striking feature is the V-shaped dip at the zero bias, which is a character of one-dimensional Luttinger system.



(a) (b)

Figure 5. (a) Atomic-resolution STM topograph of D2 nanowires and a cross-section profile. (b) Differential tunnelling conductance measured at a bright row showing a dip at zero bias, as highlighted by a red circle.

ii) Significance of research results

The collaboration has generated several interesting results. We have confirmed that the molecules are adsorbed on the Au nanowires in a bridging configuration. We also investigated the electronic properties of the adsorbed molecules and found the functional end groups of the molecules strongly interact with the Au nanowires. These findings confirm what we proposed in the proposal, demonstrating the feasibility of using functional organic molecules as single molecular conducting board.

iii) Research output

Conference presentation:

(1) **On-Surface Synthesis and Characterization of Conjugated Poly-Phenyl Systems**, International workshop, *Addressing, Transport and Storage of information by single atoms and molecules,* 13th to 18th, January 2013, Les Houches, France.

(2) **Modulating Single-molecule Electronic Structures via Metal Atoms**, Collaborative Conference on 3D & Materials Research (CC3DMR) 2013, 24 – 28 June, 2013 , Jeju, Korea

iv) Potential for or impact on further research collaboration

The collaboration has led to a new development. The un-expected results of the one-dimensional Luttinger character observed on D2 nanowire are extremely interesting and deserve more investigation. Both teams are planning to conduct systematic measurements on this topic.