# Instability and Fluctuations of Metallic Atomic Wires on Silicon Surfaces

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## Introduction

One dimensional (1D) forms of materials are intersting due to their exotic electronic properties such as density wave formation, non-Fermi liquid behaviors, and unconventional superconductivity. These tranditional interests has recently been revitalized by the possible realization of molecular-scale devices, where the new forms of 1D materials such as nanotubes and nanowires become crucial components.

In both such fundamental and technological aspects, the fabrication of 1D materials on silicon surfaces, the most industrially-important substrate, would be very exciting. Indeed, during the last decade, various 1D atomic chain strictures were found in the intial growth of metals on flat and stepped Si surfaces. In particular, some of these structures were found to have well-defined 1D metallic band structures; as the most famous examples, Si(111)4x1-In [1], Si(557)-Au [2], and Si(553)-Au surfaces [3]. The 1D (or quasi-1D) metallic bands of these surfaces with "atomic chains or wires" commonly have nearly half-filled bands, which can make the systems susceptible to electron-phonon interaction and density-wave formation.

## Methods and Materials

We have focussed especially on the stability of the metallic phases of the metallic atomic wires on silicon surfaces since the enhanced eletron-phonon interaction of the 1D metallic bands would make the metallic phase instable (so called the Peierls instability) to exhibit a metal-insulator transition. The metallic atomic chain systems of In or Au were prepared on silicon surfaces carefully and their atomic and electronic band structures were investigated *in situ* by electron diffraction, scanning tunneling miscroscopy/spectroscopy, and high-resolution photoelectron spectroscopy. In particular, for the photoelectron spectroscopy measurements, we used ultra-bright undulator radiation from Pohang Light Source (beamline 8, Korea) and Advanced Light Source (beamline 7, USA).

## Results

Through a series of experimental works, we found that all the above metallic atomic wire systems, Si(111)4x1-In [1], Si(557)-Au [2], and Si(553)-Au surfaces, exhibit reversible metal-insulator transition at a temperature range of 100-250 K. These transitions commonly exhibit periodic lattice distortions at low temperature [see Fig. 1 for the case of Si(553)-Au] and band gap openings (see Fig. 2). The size of band gaps as measured by photoelectron spectroscopy and scanning tunneling spectroscopy range from 60 to 300 meV for different systems and different bands.

## Discussion

In the present contribution, we would like to discuss the current debates on the above systems, most importantly, those on the origin of the transitions. In particular, the recent theoretical works tried to explain the transitions by order-disorder type phenomena, which is clearly contradictory with the idea of a Peierls transition. In addition, we introduce rich interesting phenomena of the phase transitions, as revealed by varible-temperature scanning tunneling microscopy, concerning the atomic scale fluctuations and excitations in real space. Finally, the future directions and challenges in this field of research, both for materials and physics, are suggested.

## Acknowledgements

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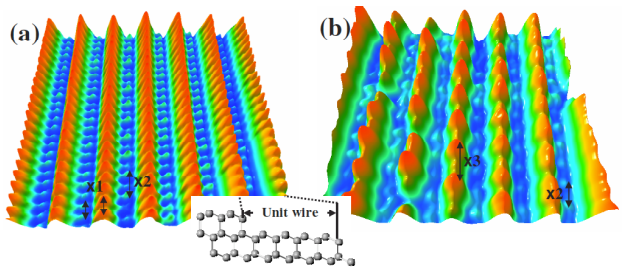


*Fig. 1. Scanning tunneling microscopy images of the Si(553)-Au atomic wire system at 300 (a) and 70 K (b). The periodic lattice distortions or the charge-density modulations are clear.*

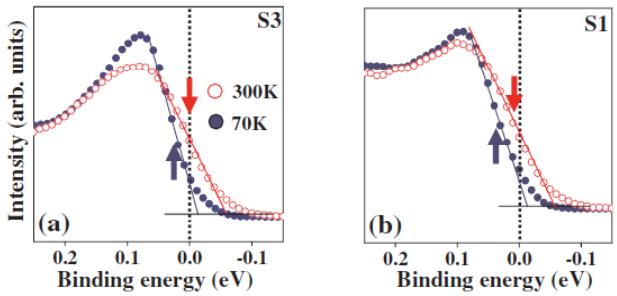


*Fig. 2. Angle-resolved photoelectron spectra for the Fermi-level crossings of the half-filled (a) and 1/3-filled (b) 1D metallic bands of the Si(553)-Au atomic wire system at 300 and 70 K. The gap-opening, metal-insulator, transition is apparent.*