1D nanolines and single atom chains on Si(001)

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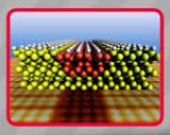
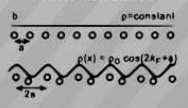
Motivations



Why 1D chains on Si(001)?

- Explore 1D experimentally
- Probe the Tomanaga-Luttinger liquid theory
- More versatile than systems on vicinal surfaces
- Implement the infinite length limit condition addressed by theory
- Interconnects for novel electronics

Peirels instabilities

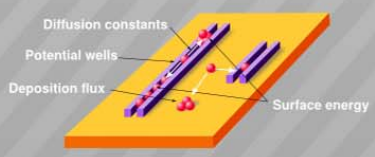


Spinon and holons

Nanolines templating

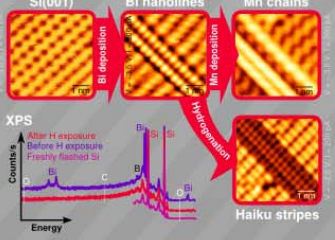
Possible metalic chains on Si(001) and Bi-nanolines :

- Au, Ag atomic chains
  J. Phys. Cond. Mat. 19, 226315 (2007)
  Mat. Sci. and Eng. 140, 160 (2007)
- Fe interstitial atomic chains
  Appl. Phys. Lett. 89, 093115 (2006)
  Appl. Surf. Sci. 254, 98 (2007)
- Nearby Mn atomic chains
  Surf. Sci. 602, 986 (2008)



Synthesis

- Bi nanolines grow on Si(001) at 570°C
- Mn chains forms between Bi nanolines
- Haiku stripes form by exposing Bi nanolines to hydrogen:
  - Bi dimers are stripped by H, exact mechanism not yet understood
  - No trace of contaminations after hydrogenation in XPS



Properties & Interests

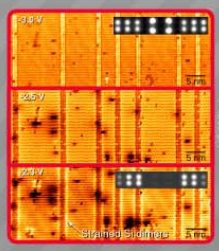
- Straight, no kinks
- Nearly defect free
- Tunable line density
- Length limited by defects and terraces
- ⊥ Si dimers
- Self-assembled
- No vicinal surface
- Independent of step edges
- Gapped substrate
- Industrially relevant surface

Bismuth nanolines

J. Owen, et al. J. Mater. Sci. 41, 4568 (2006)

Haiku structure

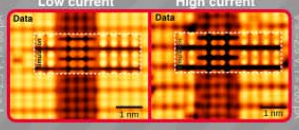
- 4 Si dimers wide, 1.54 nm
- Double chain of Bi dimers
- Si reconstruction (Haiku structure) below the Bi nanolines
- Composed of 5- and 7- fold rings of Si extending 5 layers below the surface
- Bias dependant contrast in filled state reproduced by STM simulation



Haiku stripes

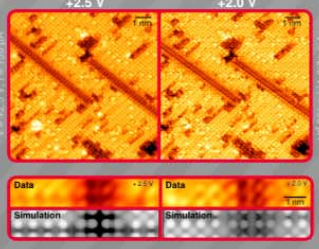
F. Bianco, Phys. Rev. B, 84, 035328 (2011)

Filled state



- Very good matching between STM simulation (integrated DFT) and experimental data
- Electronic effects : both central atoms are rised at high current

Empty state

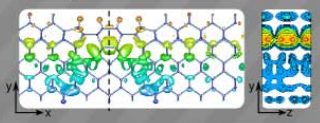


- 1D delocalized state close to the Si band gap
- Purely electronic effect
- Run along the nanolines
- Does not correspond to any atom position in the structure

Model

Hydrogen covered Haiku structure, no Bi

Charge densities simulations



- Reproduce the 1D central state...
- ... and predict it as delocalized along the nanoline

Perfect 1D electronic model system ?

Manganese chains

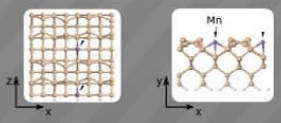
S. A. Köster, in prep. (2012)

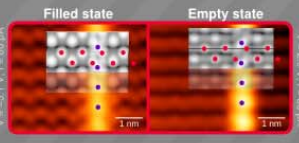
Mn chains near Bi nanolines

- Up to 40 atoms chains (self-assembled)
- Unusual zig-zag chain structure
- Structure still under investigation together with DFT modelling
- Bi nanolines promote growth of long Mn chains

Proposed model

- C-type chains
- Mn between Si dimers in first layer

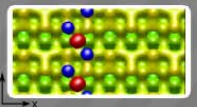




- Fairly good matching between STM simulation (integrated DFT) and experimental data

Spin densities simulations

- Interesting magnetic structure predicted by spin polarized DFT



Sena, Bowler, J. Phys.: Cond. Matt. 23 (2011) 305003
Liu et al. Surf. Sci. 602 (2008) 986

Perfect 1D spin chain model system ?

Interests for 1D

Haiku stripes

- Stable up to 400°C in UHV
- Inert in air
- Stable in real life's lab !

- Huge aspect ratio (length/width) achievable
- Promising 1D templates for atom chain assembly
- Mn chains are good candidate for 1D spin system

Outlook

- Look for metallic properties...
- .... and contacting for transport measurements
- Optical measurements

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