UNIVERSITY OF DUISBURG ESSEN

SFB 616
surface science group Prof. R. Möller

Scanning Tunneling Potentiometry on the Au/Ge(001) Surface

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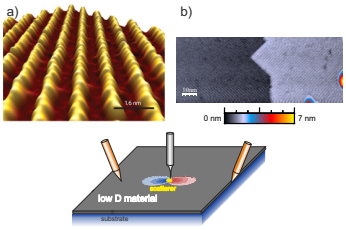
Transport in the Au/Ge(001) surface

- Au/Ge(001) surface, wires separated by 1.6nm
- Au/Ge(001): 1D conducting system (Tomonaga Luttinger Liquid) [1]
- two perpendicular oriented wire domains
- transport through the atomic wires
- scattering of conducting electrons at defects, e.g. step edges, domain boundaries



Au/Ge(001) Surface
(a) STM image from [1] and (b) from our multiprobe STM showing the atomic wire like structure

[1] C. Blumenstein et al., Nature Phys. **7**, 776 (2011)

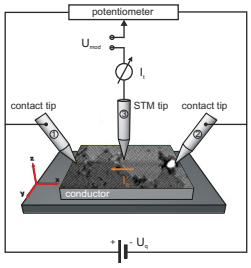
Scanning tunneling potentiometry (STP) [3]

- using scanning tunneling microscopy (STM) and potentiometry (STP) to study surface transport
- adjusting the potentials of sample and tunneling tip

  → mean value of tunneling current vanishes:

  $\langle I_{tunnel} \rangle = 0$
- controlling of the tunneling distance using the AC component of I_{tunnel} by modulating the tunneling voltage by U_{mod}
- simultaneous measurement of topography and local electrochemical potential $\mu_{ec,STP}$ (with full STM resolution)

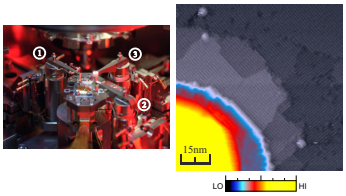
[3] P. Muralt and D. Pohl, Appl. Phys. Lett. **48**, 514, (1986)
[4] A. Bannani, C.A. Bobisch, R. Möller, Rev. Sci. Instrum. **79**, 083704, (2008)



scanning tunneling potentiometry scheme using a multiprobe system [4]

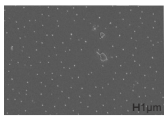
Sample preparation and contacting the surface

- Ge(001) substrate, undoped
- Ar^+ sputtering, 600eV for 30 min at T_{sample}=740°C
- cooling to T_{sample}=-145°C and deposition of about 6ML Au in 6 min
- annealing at T_{sample}=540°C
- excess Au condenses into 3D islands

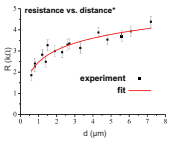


optimized Omicron Nanoprobe 4-Probe STM surface structure near Au island

Measuring resistance vs. distance using a three terminal STM setup



Au island distribution on Au/Ge(001) (SEM image*)



scheme to measure resistance vs. distance contacting individual Au islands

2D: $R \propto 2\ln(d) - \ln(r_2) - \ln(r_1)$

3D: $R \propto -\frac{2}{d} + \frac{1}{r_1} + \frac{1}{r_2}$

scaling laws for 2D and 3D electronic transport

*data courtsey of M. Wojtaszek, F. Krok, M. Szymonski

- *in situ* contacting procedure monitored by SEM (max. resolution 50 nm)
- each tip is carefully lowered using the z-piezo until an electrical contact is established
- Au tips are soft enough to only cause little damage to the surface while a good ohmic contact is provided
- if only Au islands are contacted, the resistance scales logarithmic vs. distance

  → 2 dimensional transport

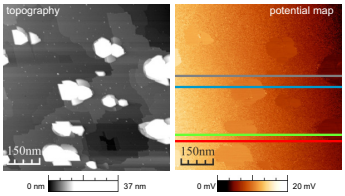
Potentiometry at the Au/Ge(001) surface

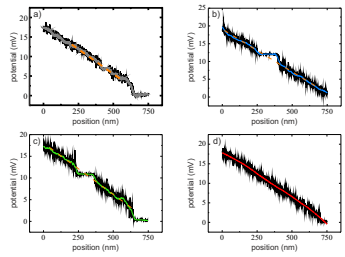
Experimental details

- large area STM scans show Au wire structure and Au islands
- applied lateral potential: U_q=10 V
- STP map shows featureless monotonous global gradient (room temperature)
- no features at step edges / domain boundaries
- better defined potential on the Au islands
- Au islands show different potential than surrounding area
- abrupt transition at the Au island / wire interface
- resistivity vs. temperature scales linearly

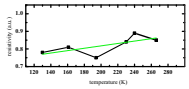
Tentative model

- islands couple to a 2D conducting layer / are decoupled from surrounding wires
- 2D conducting layer is buried below the surface?





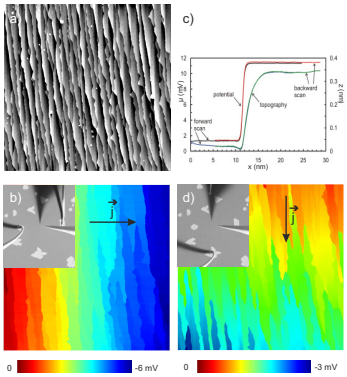
a)-d) line profiles of the potential map; the overall gradient and the smooth potential on the Au islands are visible



resistivity as function of the sample temperature evaluated from the potential gradients

Previous work [2]

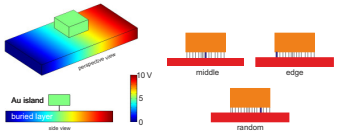
- lateral current applied perpendicular/parallel to the surface step edges
- analysis of the distribution of the electrochemical potential $\mu_{ec,STP}$ using STP
- current parallel to the step edges: reduced mean free path due to diffusive scattering at the rough step edges
- monotonous change of $\mu_{ec,STP}$ at the step edge
- potential shows most pronounced change right in front of step edge, biggest variation within 6 Å
- potential shows variations at domain boundaries
- anisotropic resistivity for both contact geometries due to different resistances of step edges and domain boundaries
- transmission across step edges depends on charge carrier´s angle of incidence relative to step edge



a) topography, ca. Δz = 1nm
b) simultaneously measured electrochemical potential for a current density of 0.4 A/m **perpendicular** to the step edges
c) line profiles at a monoatomic step
d) analog for a current density of 0.26 A/m **parallel** to the steps
insets show SEM images of the contact geometry.

[2] J. Homoth, M. Wenderoth, T. Druga, L. Winking, R.G. Ulbrich, C.A. Bobisch, B. Weyers, A. Bannani, E. Zubkov, A.M. Bernhart, M.R. Kaspers, R. Möller Nano Letters **9**, 1588, (2009)

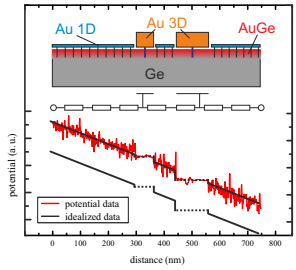
Discussion



Comsol simulation for single contact geometry

possible contact geometries for Au islands contacted to a buried 2D conductive layer

- Comsol Multiphysics simulation reproduces mapped potential
- assumptions: conductivity of the layer is much lower than for the Au island ($6\cdot10^{-7}$S/m vs. $6\cdot10^{-3}$S/m)
- single / few contact points between Au island and subsurface layer



sketch of Au islands contacted to a 2D conductive buried layer, raw data (red) and idealized potential variation.

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[5] I. Horcas et al., Rev. Sci. Instr. **78**, 013705, (2007)