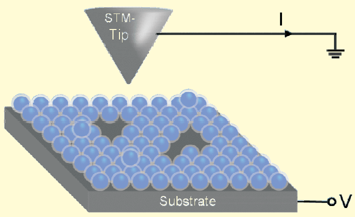
Electron Tunneling Through a Monolayer of Small Metal Clusters Investigated by Scanning Tunneling Spectroscopy

Huijing Zhang, Dirk Mautes and Uwe Hartmann
Institute of Experimental Physics, University of Saarbrücken, 66123 Saarbrücken, Germany

Introduction

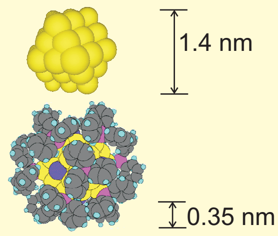
Quantum phenomena, such as electron tunneling, play an important role for devices with functional structures at the nanometer scale. We report investigations on monolayers of small metal clusters by means of scanning tunneling microscopy (STM) and spectroscopy (STS). Monte-Carlo simulations were carried out in accordance with the experimental situations.

Experimental setup

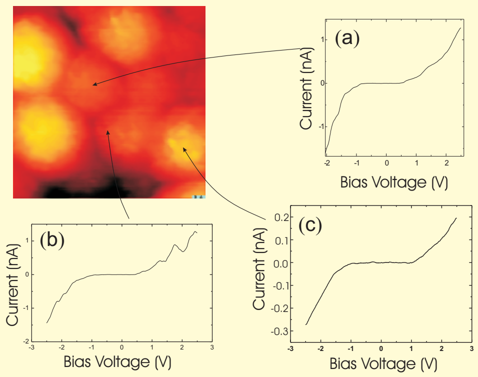


Cluster monolayer, STM
Substrate: HOPG, Au(111)

Cluster $Au_{55}[P(C_6H_5)_3]_{12}Cl_6$

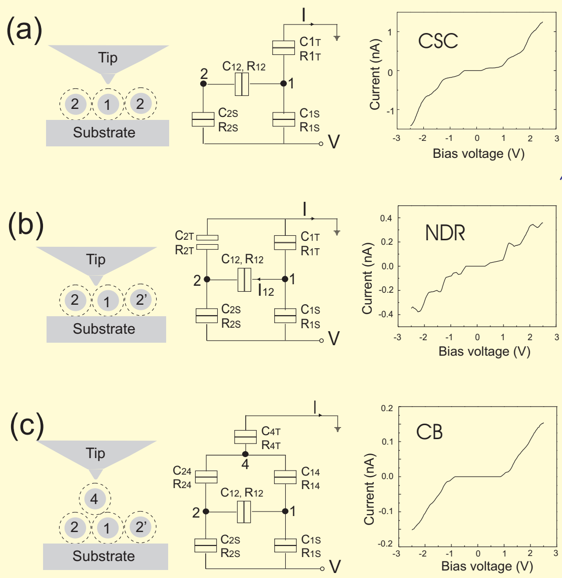


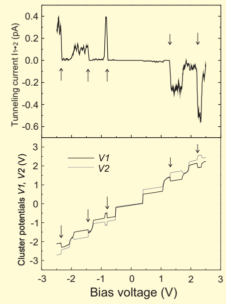
Experimental Results



STM image of deposited Au_{55} clusters, obtained at 7 K, scan range: 7 x 7 nm², and *I-V* curves acquired:
(a) above the center of a cluster, showing Coulomb staircase (CSC);
(b) away from the center and near a neighboring cluster, showing negative differential resistance (NDR);
(c) above a cluster which belongs to the second cluster layer, showing only Coulomb-Blockade (CB).

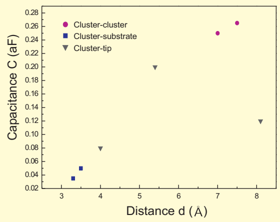
Monte-Carlo Simulation [1]





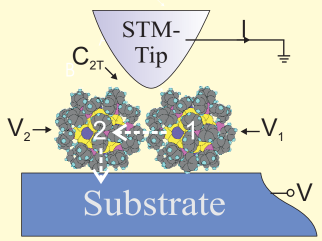
NDR occurs
wenn electrons tunnel
from cluster1 to cluster2

Nonclassical capacitive behavior



(a) C_{1T} = 0.2 aF, $C_{1S} = C_{2S}$ = 0.05 aF, C_{12} = 0.25 aF, R_{1T} = 5 GΩ, $R_{1S} = R_{2S}$ = 100 MΩ, R_{12} = 100 GΩ;
(b) C_{1T} = 0.08 aF, $C_{1S} = C_{2S}$ = 0.03 aF, C_{12} = 0.25 aF, C_{2T} = 0.12 aF, R_{1T} = 5 GΩ, $R_{1S} = R_{2S}$ = 100 MΩ, R_{12} = 100 GΩ, R_{2T} = 1200 GΩ;
(c) C_{4T} = 0.08 aF, $C_{1S} = C_{2S}$ = 0.05 aF, C_{12} = 0.25 aF, C_{14} = 0.25 aF, C_{24} = 0.27 aF, R_{4T} = 2 GΩ, $R_{1S} = R_{2S}$ = 200 MΩ, R_{12} = 100 GΩ, R_{14} = 8 GΩ, R_{24} = 80 GΩ.

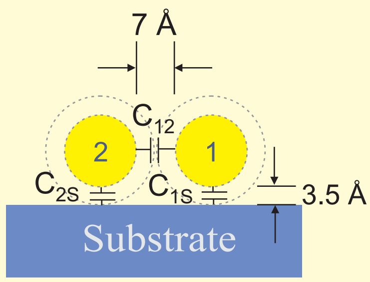
Discussion for case (b)



"Gate" effect
as reason for NDR

C_{2T} not negligible

If $|V-V_2| > e/2C_{2S}$
Tunneling 2→S, V_2↑
→ Tunneling 1→2, I↓



$d_{12} > d_{1S}, d_{2S}$

Classical physics:
$C_{12} < C_{1S}, C_{2S}$

Tunneling regime:
$C_{12} > C_{1S}, C_{2S}$ [2]

Conclusions

- *I-V* characteristics of monolayers of Au_{55} clusters were investigated with a low temperature STM.
- Apart from the usual charge-quantization phenomena, such as Coulomb blockade and staircase, negative differential resistance (NDR) was observed at well defined positions.
- NDR can be explained by a "gate" effect caused by neighboring clusters and involving a nonclassical behavior of the capacitances in the tunneling regime.

[1] U. E. Volmar, U. Weber, R. Houbertz, and U. Hartmann, Physica B **240**, 38 (1997).
[2] T. Christen and M. Büttiker, Phys. Rev. Lett. **77**, 143 (1996).

This work is supported by the Deutsche Forschungsgemeinschaft