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The Detection of Light Emitted from the Tunneling Junction of a Low Temperature-STM

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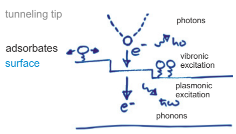
Motivation

Bottom up understandig of the electronic transport processes within organic molecules

- beside the elastic tunneling processes in an scanning tunneling microscopy (STM) experiment, also a fraction of inelastic processes take place
- e.g plasmonic or vibronic excitation of the sample may be induced by the injection of electrons

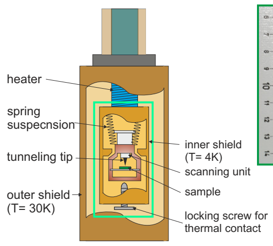
  → relaxation via light emission
- characterisation of individual molecules with submolecular spatial resolution

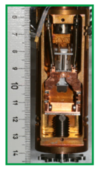


Low Temperature-STM

Compact design homebuilt system

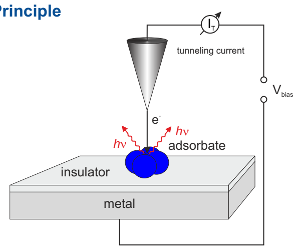
- entire scanning unit cooled to 7K (80K) with liquid He (N_2) using a continuous flow cryostat
- temperature stability is maintained for several days (He) / weeks (N_2)
- tips can easily be exchanged during the experiment
- transferable molecular evaporators allow for an evaporation of molecules onto the cooled sample within the STM (30K)

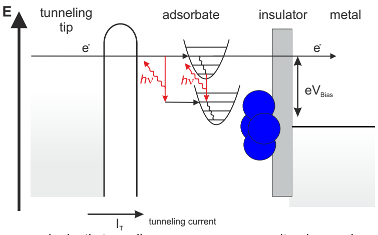




STM Induced Light Emission (STM-LE)

Principle





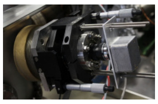
- hot electrons are injected into the adsorbate by the tunneling tip
- most electrons tunnel elastically, i.e. without loosing energy
- a small part of the electrons (approx. 10^{-7}-10^{-4}) tunnels inelastically

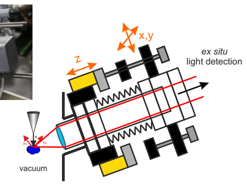
- inelastic tunneling processes may excite plasmonic or vibronic states at the surface
- the relaxation may follow different pathways, e.g. a radiative decay

  → emission of photons

X.H. Qui, G. V. Nazin,W. Ho, Science **299**, 542 (2003)
R. Berndt et al., Science **252**, 1425 (1993)

In situ light collection

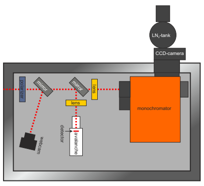


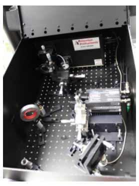


- the light is collected by a lens inside the vacuum system
- position of the lens can be adjusted in x,y- (commercial gimbal) and z- (homebuilt adjustment unit) direction
- detection table is parallel to the light path

  → no additional mirrors needed

Ex situ light detection



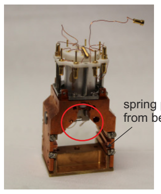


- light is detected outside the vacuum system
- the photons can be focused on either a webcam, an avalanche diode or a monochromator with an attached CCD-camera
- optionally, a polarising filter, etc. can be placed into the optical path

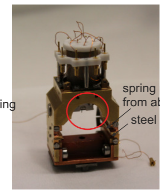
Latest Changes of the STM-LE

Scanning Unit

before

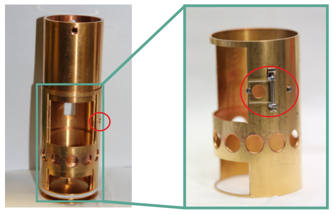


after



- to increase the photon count rate the aperture in the sample stage is enlarged
- three point support of sample holder on stainless steel balls
- springs are pushing onto the sample carrier from above to ensure a save fixation of the sample holder

Shields



- additional window was added to detect the photons when the shields are closed
- to reduce heating by thermal radiation during the experiment, an ITO coated glass sheet is placed in front of the window

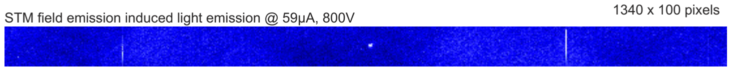
First Measurements

Photon detection using a CCD detector @ RT

LED coupled to STM junction for alignment

1340 x 100 pixels

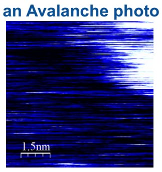
STM field emission induced light emission @ 59µA, 800V



1340 x 100 pixels

Photon detection using an Avalanche photo diode

Topography, 5nA, 3V

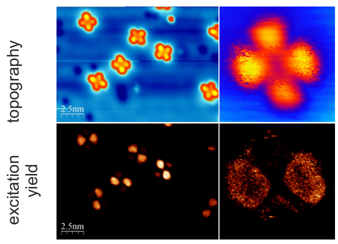


Photon image, 5nA, 3V, max 80c/s

- first experiments to calibrate the setup were conducted either using an LED focused on the tip-sample junction or during field emission
- first experiments under regular tunneling conditions show similarities between the topography and the photon image

Tunneling Current Induced Excitation of Individual Phthalocyanine and Porphyrin Molecules

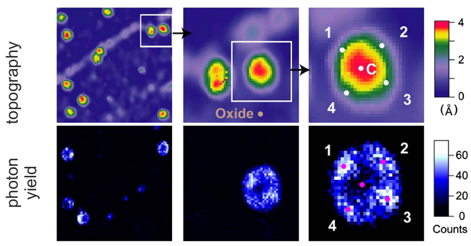
Möller Group: molecular switching



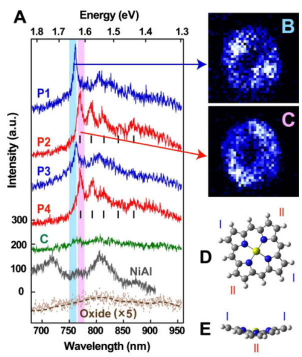
Individual copper phthalocyanine (CuPc) molecules on Cu(111). V_{bias}= 2V, I = 100pA. The individually adsorbed CuPc molecules show a tunneling current induced molecular switching.

J. Schaffert et al., Nature Materials **12**, 223 (2013)

Ho Group: STM-LE



Individual magnesium porphine (MgP) molecules on Al_2O_3/ NiAl(110). V_{bias}= 2.2V, I = 200pA. Scan size from left to right: 24nmx24nm, 6.8nmx6.8nm, 3.5nmx3.5nm. The individually adsorbed MgP molecules show a tunneling current induced photoemission.



(A) Vibronically resolved emission spectra taken at five positions inside the MgP molecule, on the oxidized substrate (AL_2O_3), and the metal substrate (NiAl).
(B), (C) Photon images of individual vibronic peaks. V_{bias}= 2.3V, I =400pA. Scan size for both images: 3.5nmx3.5nm.
(D), (E) Top and side view of the molecular structure of MgP.

Chi Chen, ..., C.A. Bobisch, W. Ho et al., PRL **105**, 217402 (2010)

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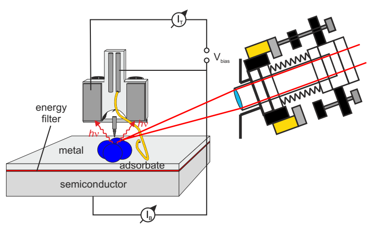
Outlook

Combined BEEM and STM-LE experiments at low temperatures



- ballistic electron emission microscopy (BEEM) experiments at low temperatures down to 7K
- combination of two complementary techniques

  → comprehensive characterization of individually adsorbed molecules and thin organic layers
- measurements with ultimate stability and spatial resolution
- bottom up approach to future electronic devices

Bell, L. D. and Kaiser, W. J., Physical Review Letters **61** (20), 2368 (1988)

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