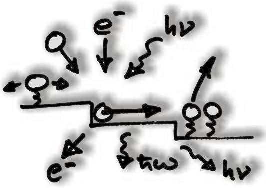
UNIVERSITÄT DUISBURG ESSEN

SFB 616

Interaction of slow highly charged ions with surfaces



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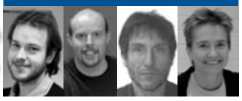

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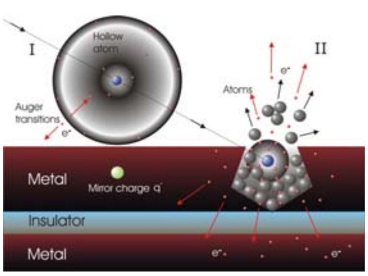
Goals

- Investigation of electronic excitations at and below the surface due to energy dissipation of highly charged ions
- Measurement of characteristic parameters of emitted particles with respect to localized electronic excitations
- Possible interaction between kinetic and potential effects
- Characterization of energy transfer processes by different kinds of energy dissipation

Scenario of Ion Impact at Surfaces

- Approach of the ion with well defined charge state, mass, kinetic and potential energy
- Development of a mirror charge below the surface and transition of electrons from the surface to highly excited states - "hollow atoms" (figure part I)
- Partial deexcitation of the projectile - electron emission ("pumping") by Auger transitions
- Impact of the ion; sputtering of electrons, ions and neutrals; complete deexcitation below the surface (figure part II)

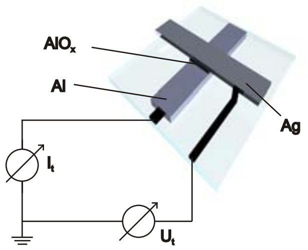


Experiment

Detection of Hot Electrons

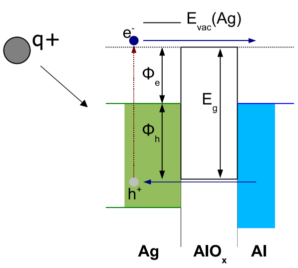
with thin film metal-insulator-metal junctions

- **Measurement of hot electrons:** excited electrons will move through the insulator and can be measured in the bottom electrode
- **Energy dependence:** investigation of electron energy by application of a bias voltage between the two electrodes



Energy Scheme

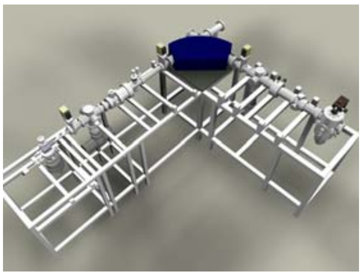
- Electron hole pair creation by dissipation of kinetic and potential energy
- "Tunneling" current over and through the oxide barrier into the bottom Al electrode



Typical values of the MIM:

- work function of Ag: 4.3 eV
- barrier height Φ_e : approx. 3 eV
- band gap E_g of the oxide: approx. 7 eV
- thickness of Ag film: 25 nm
- thickness of oxide film: 3 nm

The Beamline in Duisburg



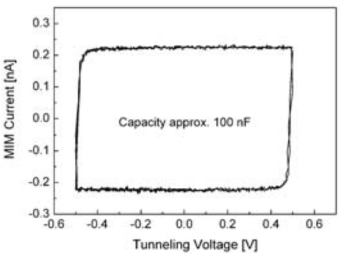
The EBIT beamline will offer:

- **Highly charged ions:** various kinds of noble gases can be ionized up to the highest charge states with a Dresden Electron Beam Ion Trap
- **Charge separation:** a bending sector magnet separates the emitted charge states
- **Deceleration:** slowing down of the ions to kinetic energy < q · 50 eV
- **SIMS/SNMS:** detection of secondary ions and neutral particles (laser post ionization) and emitted electrons (PIPS)

Stability of MIM devices

Measurement of resistance and capacity of the MIM

- MIM remains stable under several hundred shots
- Sputtering does not influence the measurement of subsequent shots



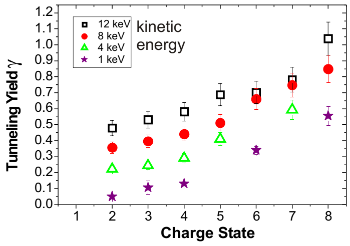
Internal Electron Emission

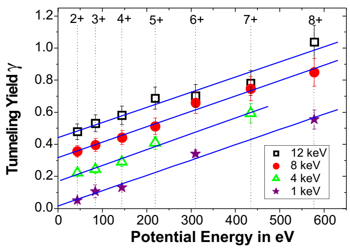
Measurements

MIM under irradiation with Ar^{q+} of different q, but with constant kinetic energy

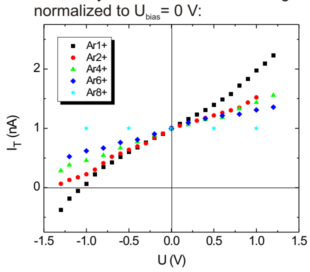
single shots (t = 150 ms, I approx. 1 nA):

- Tunneling yield (e^- per projectile) at U_{bias} = 0 V:





- Effect of kinetic and potential projectile energy can be clearly separated from each other
- Tunneling yield increases linearly with the potential energy with a factor of 10^{-3}/eV
- Yield increases linearly with the kinetic energy with $0.4 \cdot 10^{-4}$/eV
- Relative yield at different bias voltages normalized to U_{bias} = 0 V:



- Decreasing influence of bias voltage with increasing charge state
- Indication of higher electronic excitation

Work in collaboration with D. Kovacs, D. Diesing, A. Golczewzky, F. Aumayr; see Peters et al., *Hot electrons induced by slow multiply charged ions*, New J. Phys. **10** (2008) 073019

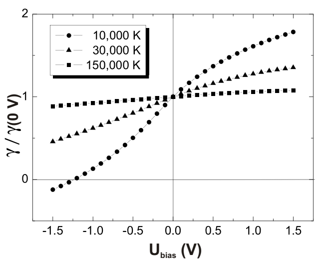
Model: Local Electronic Temperature

(Cooperation with A3: D. Kovacs and D. Diesing)

Yield can be explained by a locally heated electronic system:

- Electrons excited by Auger transitions scatter with other electrons
- Energy distribution of excited electrons and holes reaching the barrier can be described by a Fermi-Dirac-function
- Current density of electrons and holes overcoming the barrier can be calculated by an assumption that local heating of a free electron gas in the top metal film causes internal electron emission (see Kovacs et al., *Potential electron emission induced by multiply charged ions in thin fim tunnel junctions*, PRB **77** (2008) 245432)

- Calculated normalized tunneling yield of a hot electronic system in the top electrode:



Outlook: Sputtering

Central Idea

- Excitation & ionization of emitted particles is not understood very well
- Theoretical ionisation models:

$\alpha^+ \propto \exp\left[-\frac{v_0}{v}\right]$	$\alpha^+ \propto \exp\left[-\frac{I-\Phi}{kT_e}\right]$
Non-adiabatic models [1]	substrate excitation models[2]

- Significant parameter:

  Electron temperature T_e

  → Variation of T_e by chaning projectile charge state at constant kinetic energy

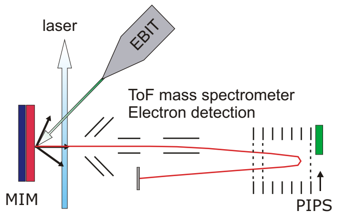
- Total sputtering yield depends on E_{kin}, not on E_{pot} (and q, respectively)[3]
  → Particle dynamics unaffected!
- Electron emission depends strongly on q
  → local excitations strongly influenced

1) M.L. Yu et al. in "Sputtering by Particle Bombardment Vol III, 91
2) Z. Šroubek et al., Vacuum **56** (2000) 263
3) Aumayr et al., Phil. Trans. Royal Soc. London A,362 (2004) 77

Experiment

Time-of-Flight mass spectrometry with laser post ionization

→ secondary ions only (laser off)
→ neutral particles and ions (laser on)



- Local excitation by potential energy of the projectile
- Measurement of excitation and ionization probabilities of sputtered particles in dependence of q (T_e)

  → Proof of ionization model

- Measurement of external and internal electron emission with PIPS and MIM