Interaction of slow highly charged ions with surfaces

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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
- 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

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 Au⁺ 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:
    - Electronic and kinetic energy can be clearly separated from each other
    - Tunneling yield increases linearly with the potential energy with a factor of \( 10^{-4} \) 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

Model: Local Electronic Temperature
(Work in collaboration with D. Kovacs, D. Diesing, A. Golczewski, P. Aumayr; see Peters et al., Hot electrons induced by slow multiply charged ions, New J. Phys. 10 (2008) 073019)
- 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 film tunnel junctions, PRB 77 (2008) 245432)

Outlook: Sputtering
Central Idea
- Excitation & ionization of emitted particles is not understood very well
- Theoretical ionisation models:
  - Substrate excitation models
  - Significant parameter:
    - Electron temperature \( T_e \)
    - Variation of \( T_e \) by chaining projectile charge state at constant kinetic energy
- Total sputtering yield depends on \( E_{kin} \) and \( q \) respectively
  - Particle dynamics unaffected
  - Electron emission depends strongly on \( q \)
  - Local excitations strongly influenced

Experiment
Time-of-Flight mass spectrometry with laser post ionization
- Secondary ions only (laser off)
- Neutral particles and ions (laser on)

1) M.L. Yu et al. in “Sputtering by Particle Bombardment Vol III, 81
2) Z. Šroubek et al., Vacuum 56 (2000) 263