Fabrication and application of shielded probes for conductive AFM measurements

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Motivation

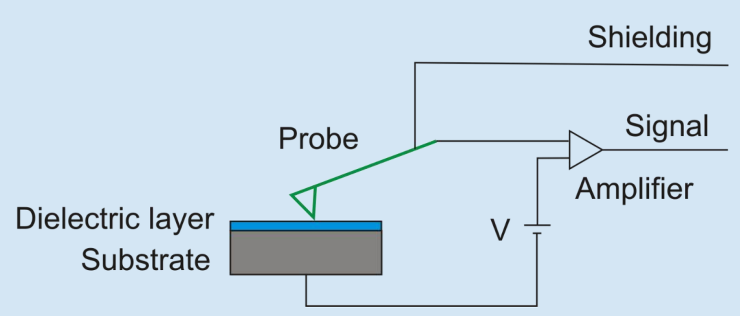
Trends in semiconductor technology

- Continuously shrinking dimensions lead to nanoscaled electronic devices
- Necessity for novel materials (e.g., nanocrystalline high-k materials)
- Metrology with nanometer spatial resolution required

Associated challenges for electrical measurements grow

- Reduced amounts of charge carriers and doping atoms in new devices
- Very small currents have to be measured
- Very small capacitances determine device characteristics

→ Electrical Scanning Probe Microscopy (SPM) is a highly preferred solution



Issues - cAFM

Conductive atomic force microscopy (cAFM) used for measurements of very small local currents

- Characterization of novel materials and dielectric layers (e.g., nanocrystalline high-k layers)
- Investigation of local current conduction mechanisms (e.g., along grain boundaries and through grains)
- Investigation of local defects
- Breakdown characteristics
- Degradation effects

Technique

- Tip in direct contact with dielectric
- Tip of probe, dielectric and semiconductor form a local metal-insulator-semiconductor (MIS) capacitor
- Voltage is applied between sample stage and conductive probe
- Voltage is swept for local I-V-measurements (mapping is performed in constant voltage mode)
- Local I-V-spectroscopy curves are recorded

Drawbacks

- Additional displacement current - Increasing with sweep rate
- Transient effects - Increasing with sweep rate
- Displacement current originates from relatively high parasitic capacitances
- High capacitance between sample and cantilever, chip-body of the probe, as well as holder
- Displacement current can easily exceed interesting leakage or tunneling current of device under test
- Effective parasitic capacitance is strongly dependent on position of probe in relation to sample - This can obstruct comparability of results measured at different positions

→ Displacement current has to be reduced for accurate measurements
→ Just using lower sweep rates, however, generates more electrical stress for samples and possible alterations during testing for recording I-V-curves

Preparation

Approach: Reducing parasitic interaction by the use of shielded probes

Fabrication of probes

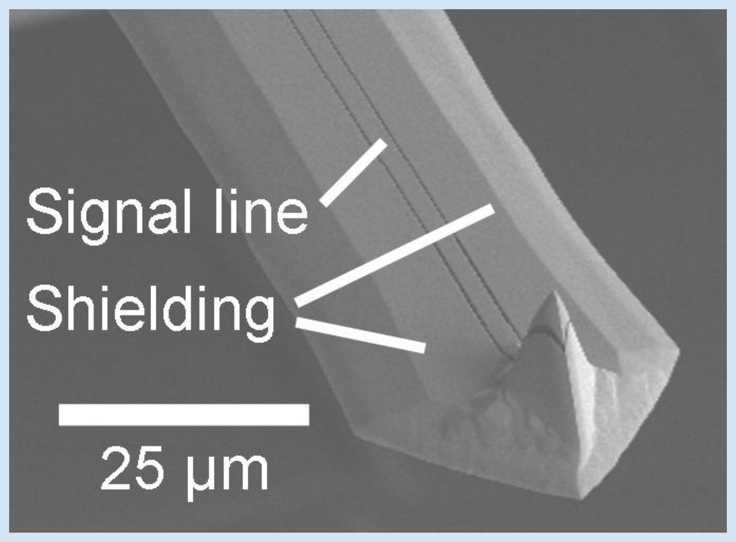
- Starting from commercially available Si probes (NanoWorld Pointprobe® FM)
- Coated with SiO_2 layer, 1000 nm
- Coated with Cr layer, 3 nm
- Coated with metal layer Pt/Ir, 100 nm

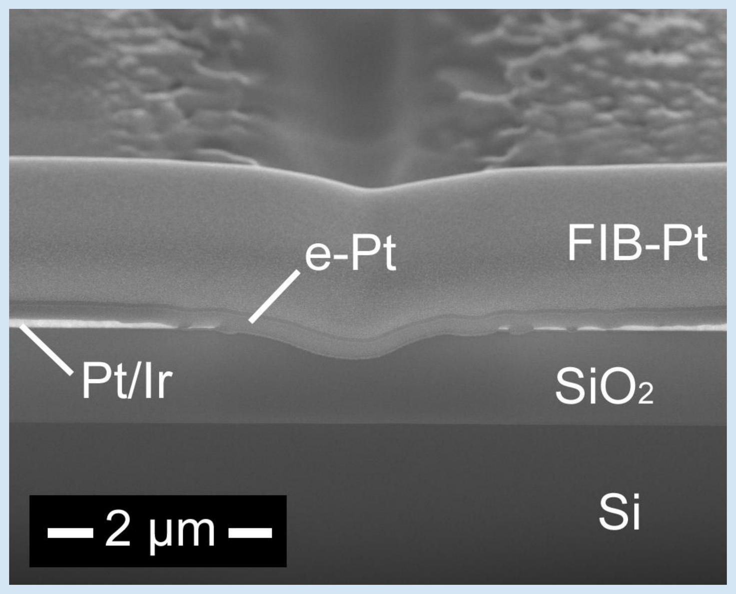
Structuring of probes

- Focused ion beam (FIB) processing
- Adaption of parameters for ion energy and beam current
- Adaption of parameters for FIB line patterns
- Semi-automated processing
- Coplanar lines

Packaging and connection

- Specially modified holders, based on the MPA-NP holder (Bruker)
- Aligned and mounted on special holders
- Electrical connection between probes and holders by using gold wires and silver paint
- Signal line of probes connected to TUNA jack
- Shielding connected to grounding jack of Extended TUNA module (Bruker)



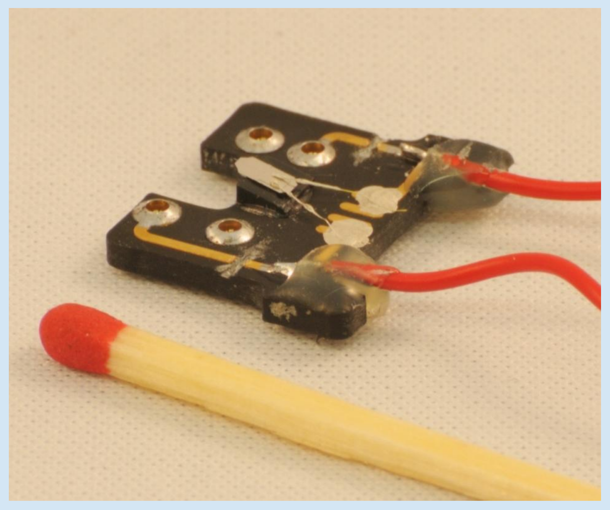


Application for cAFM

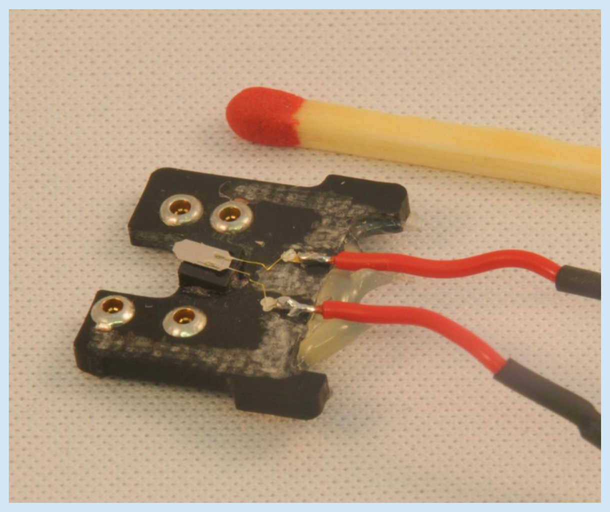
- Local I-V-spectroscopy curves of silicon dioxide layers
- Recorded in sub-breakdown voltage regime

- Standard probes (NANOSENSORS™ PPP-EFM100) on standard shielded holder (DTRCH-AM, Bruker)
- Shielded probes on special medium capacitance holder (unshielded)
- Shielded probes on special low capacitance holder (unshielded, additional metal removed compared to medium capacitance holder)

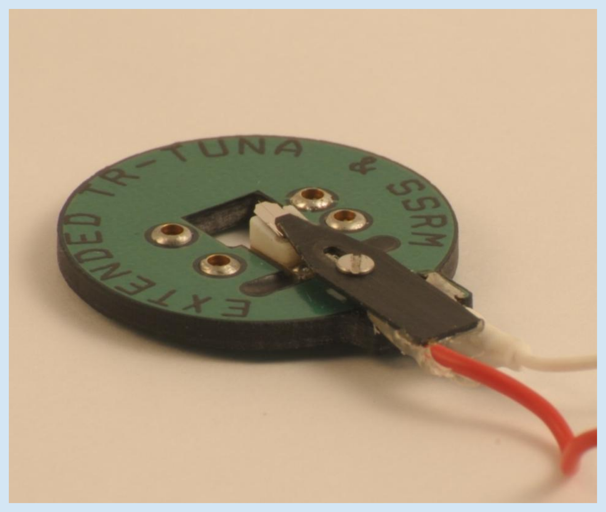
→ Although special holders used for shielded probes are not shielded, shielded probes show significantly lower displacement currents
→ Reduction of up to 70 % for sweep rates of 10.2 V/s compared to standard probes on commercial shielded holders
→ Reduced transient effects, i.e. more linear and constant curves in sub-breakdown regime for shielded probes



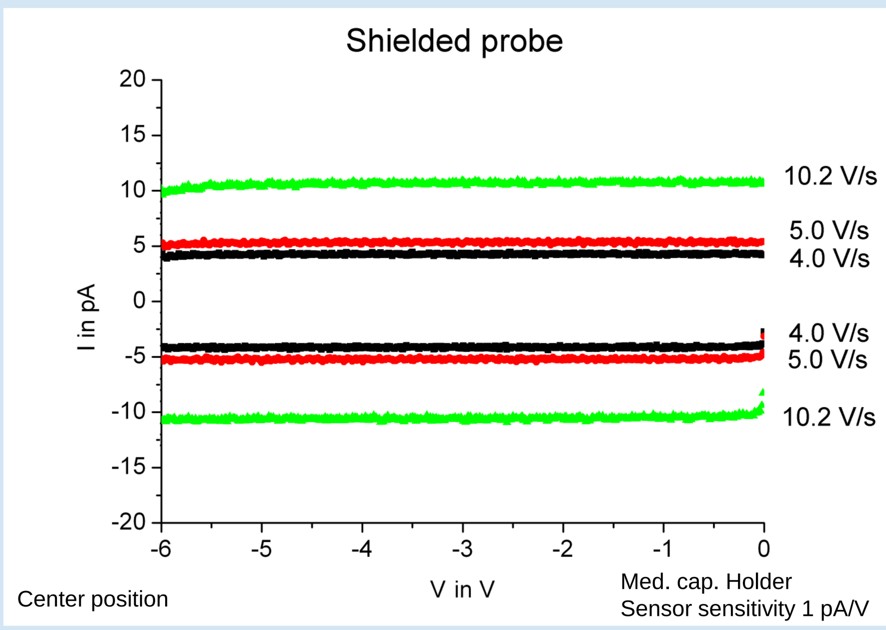
Shielded probe on medium-capacitance holder

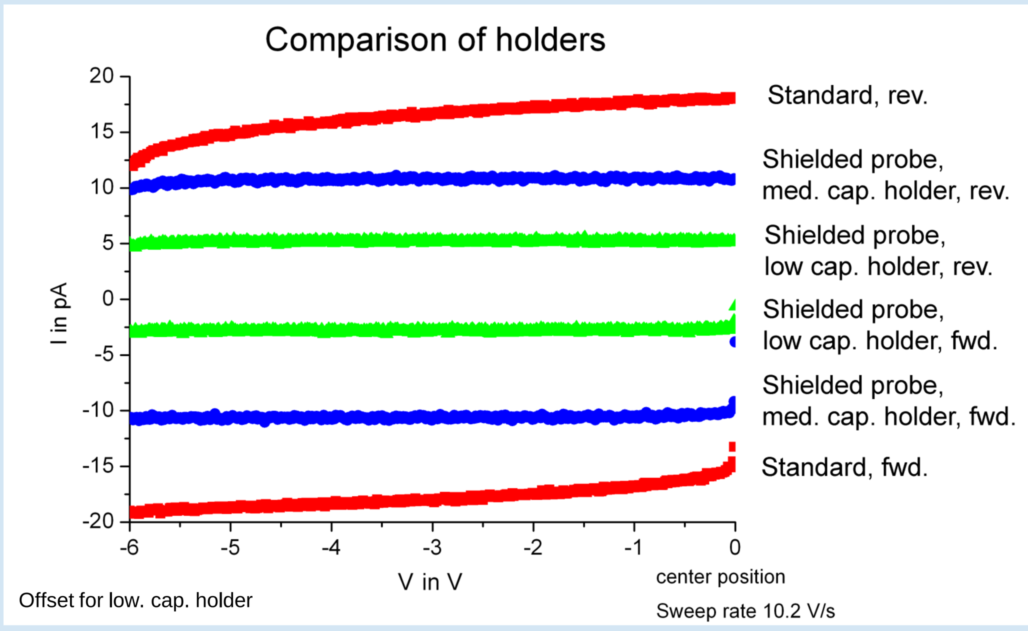


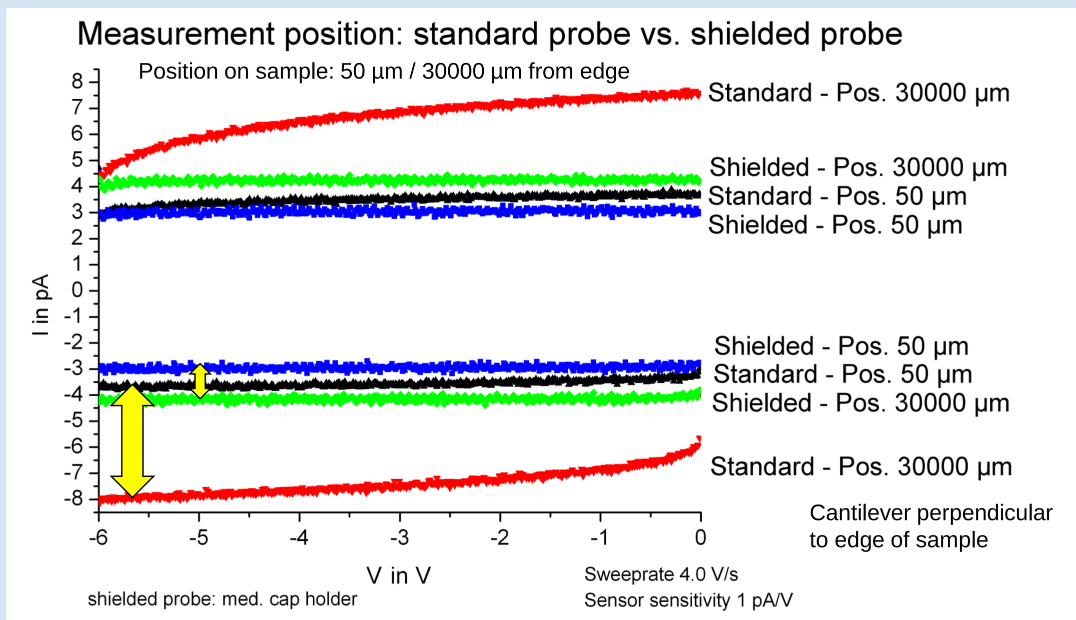
Shielded probe on low-capacitance holder



Standard probe on shielded holder







Summary and conclusions

- Shielded probes, special holders, and special processing developed
- Advantages of shielded probes on special holders compared to standard probes on standard holders:
  - Reduced displacement currents
  - Reduced transient effects
  - Reduced dependence on measurement position
  - Enabling higher sweep rates
  - Lower stressing of samples
- Even better effect expected for shielded probes on shielded holder

→ Improvements for cAFM / TUNA measurements
→ Also improvements for other electrical AFM techniques expected

Further work

Application for higher voltages presented at 17th Workshop on Dielectrics in Micro-electronics, June 25-27 2012, Dresden, Germany, "Approaches for the reduction of the influence of parasitic capacitances on local IV characteristics for conductive AFM", M. Rommel, J.D. Jambreck, K. Murakami, M. Lemberger, C. Richter, P. Weinzierl, A.J. Bauer, L. Frey, to be published in JVST B.

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