Investigation of the work function fluctuations for high precision experiments

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Why?

In high precision experiments the electric potentials have to be known precisely!

*a*SPECT 10 mV | KATRIN 20 mV

Electrodes, defining the potentials for charged particles, can show spatial fluctuations of the work function up to several 100 mV!

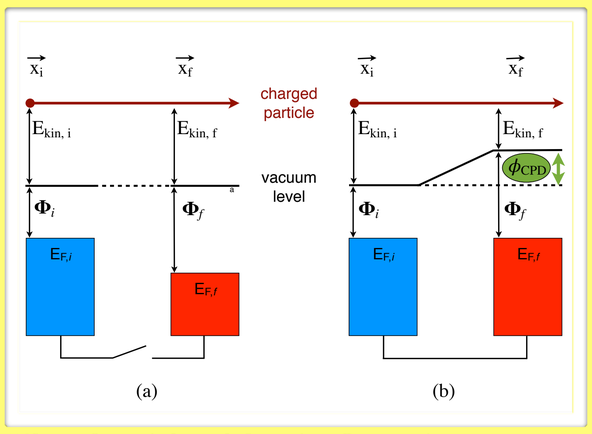
E.g. the crystal orientations of gold lead to 160 mV pk-pk difference!

What's the problem?

Spatial work function fluctuations $\Phi(\vec{x})$ corresponds to local Fermi levels $E_F(\vec{x})$. Due to balancing of electrically connected Fermi levels, there will be a shift of the vacuum level by the

contact potential difference

$$\phi_{\mathrm{CPD}} = \Phi(\vec{x}_f) - \Phi(\vec{x}_i)$$



Effect of spatial work function fluctuations.

A charged particle moving from $\vec{x}_i$ to $\vec{x}_f$ and thus $E_{\mathrm{F},i}$ to $E_{\mathrm{F},f}$. Balancing of the Fermi levels lead to an electric field, which shifts the final kinetic energy by $q\phi_{\mathrm{CPD}}$. In experiments utilizing an electrostatic filter like *a*SPECT and KATRIN (MAC-E type), this effect has to be taken into account.

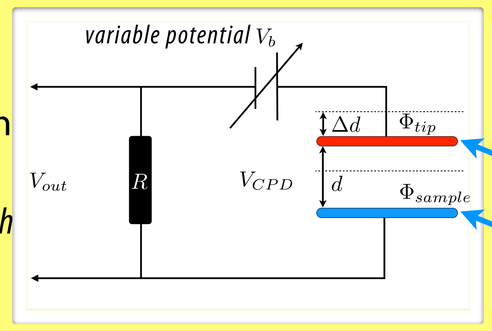
How to measure? - *Kelvin probe!*

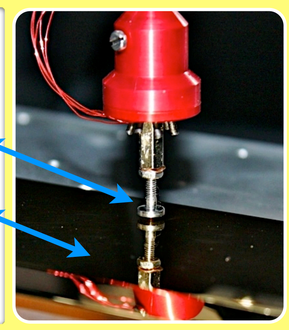
Simplified Kelvin probe circuit

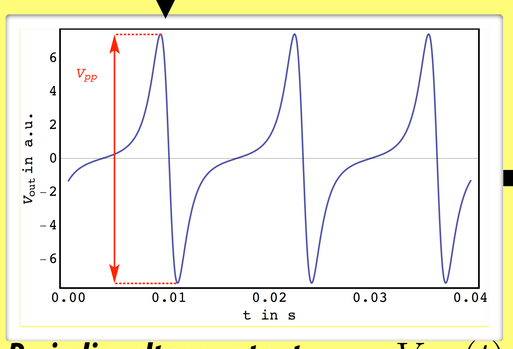
Tip with Φ_{tip} vibrates above sample surface with Φ_{sample}.

vibrating capacitor with voltage drop

$V_{\mathrm{CPD}} = \phi_{\mathrm{CPD}}/q$



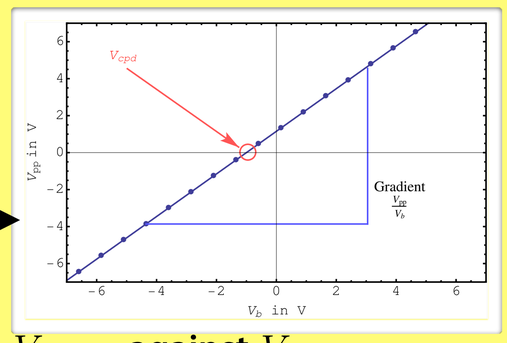




Periodic voltage output $V_{\mathrm{out}}(t)$

... easy to show ...

$$V_{\mathrm{out}}(t) = (V_{\mathrm{CPD}} + V_{\mathrm{b}})R\frac{\mathrm{d}\,C(t)}{\mathrm{d}\,t}$$



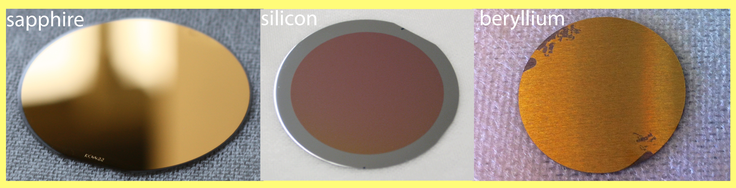
$V_{\text{pk-pk}}$ **against** V_{b}

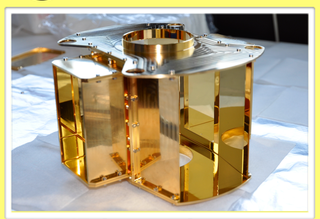
Determination of V_{CPD} by variation of V_{b}

$V_{\text{pk-pk}} \propto (V_{\mathrm{CPD}} + V_{\mathrm{b}})$

Samples being investigated

- Au electroplated on copper (*a*SPECT)
- Au(111) epitaxially grown on sapphire
- Au sputtered on silicium/beryllium, . . .





aSPECT decay volume electrode

Made in Mainz

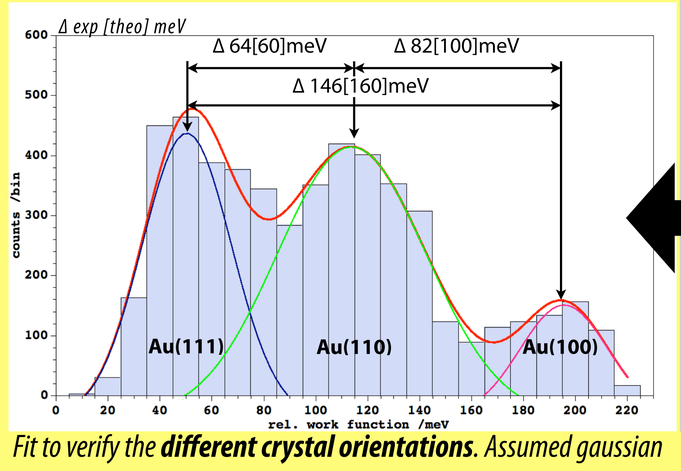
Systematic investigations

Observation of the patch effect

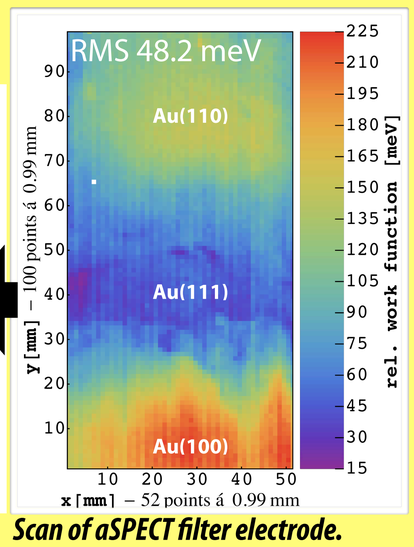
Electroplating

... leads to areas with different crystal orientations of Au. The work function depends on the crystal orientation. This leads to the so called patch effect.

orientation	phi /eV
Au(100)	5.31
Au(110)	5.41
Au(111)	5.47



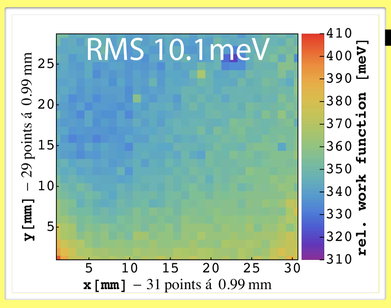
Fit to verify the ***different crystal orientations****. Assumed gaussian fits agrees with the theoretical values in some extent.*



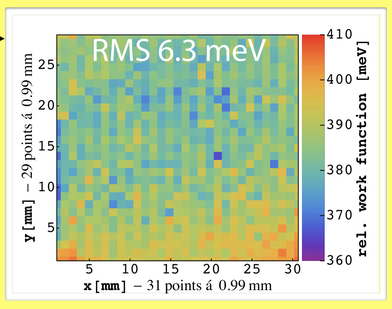
Scan of aSPECT filter electrode.

Different crystal orientations are visible!

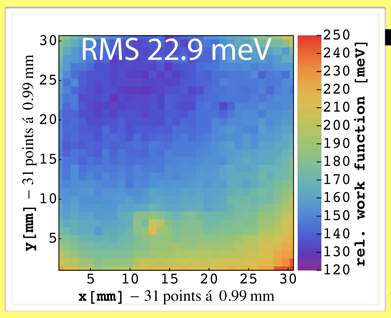
Effect of bake out



10 hours @ 150°C in UHV chamber (~10^{-8} mbar)

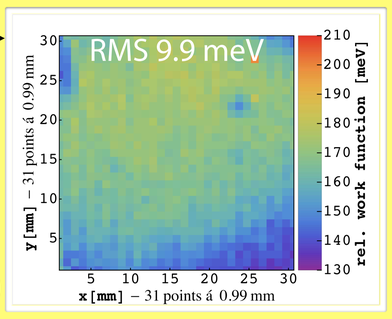


Effect of vacuum cleaning procedure



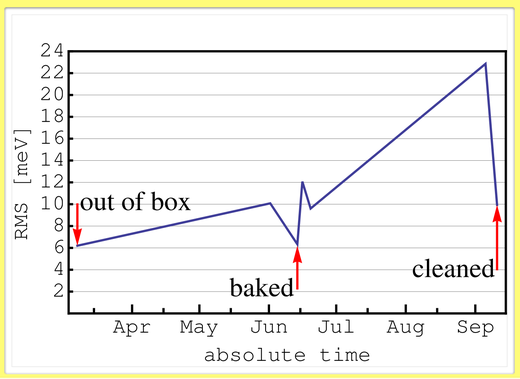
15 min bath of
- isopropanol
- destilled water

drying in ambient air (dust protected)



Temporal stability of Au(111) on sapphire

... shows that the inital RMS fluctuation „out of box" can be nearly recovered by a vacuum cleaning procedure or/and a bake out.



Conclusion and Outlook

- Studied and commissioned a scanning Kelvin probe system
  - Now stable at 3 $\mathrm{meV_{RMS}}$
- Electroplated samples >$\mathrm{cm^2}$ are patched, thus show high $\mathrm{meV_{RMS}}$, e.g. Au on silicon showed fluctuations down to 4.5 $\mathrm{meV_{RMS}}$

Further investigations:

- ***Measure filter electrode and decay volume electrode used in aSPECT beamtime 2013 as input for simulations!***
- ***Measure under beamtime conditions:***
  - Influence of adsorbed layers on fluctuations
  - Influence of cryogenic temperature
    - Therefore a UHV Kelvin probe will be commissioned!

The Mainz Kelvin probe is a reliable system to investigate work function fluctuations, which can cause systematic errors in your experiment! Check and ask for support!

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