Modification of field emitters by electromigration

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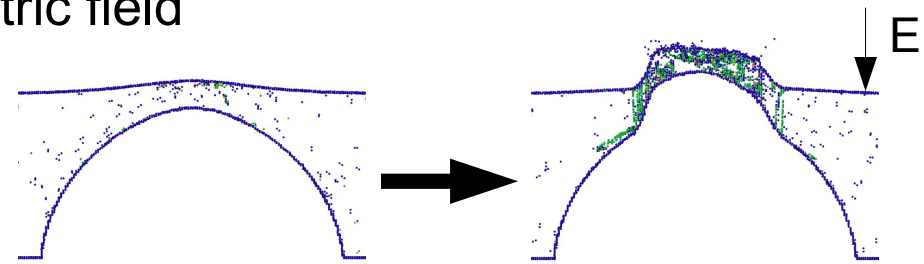
Background

- Field emission is measured prior to vacuum breakdown in CLIC structures
- Measured current is “suspiciously” high, corresponds to a surface feature with high aspect ratio (β = ~50-100)
  - Not 100% clear if β is from geometry or not
- These features have not been definitely identified with SEM. Where are they???
  - See the presentation by P. Serbun

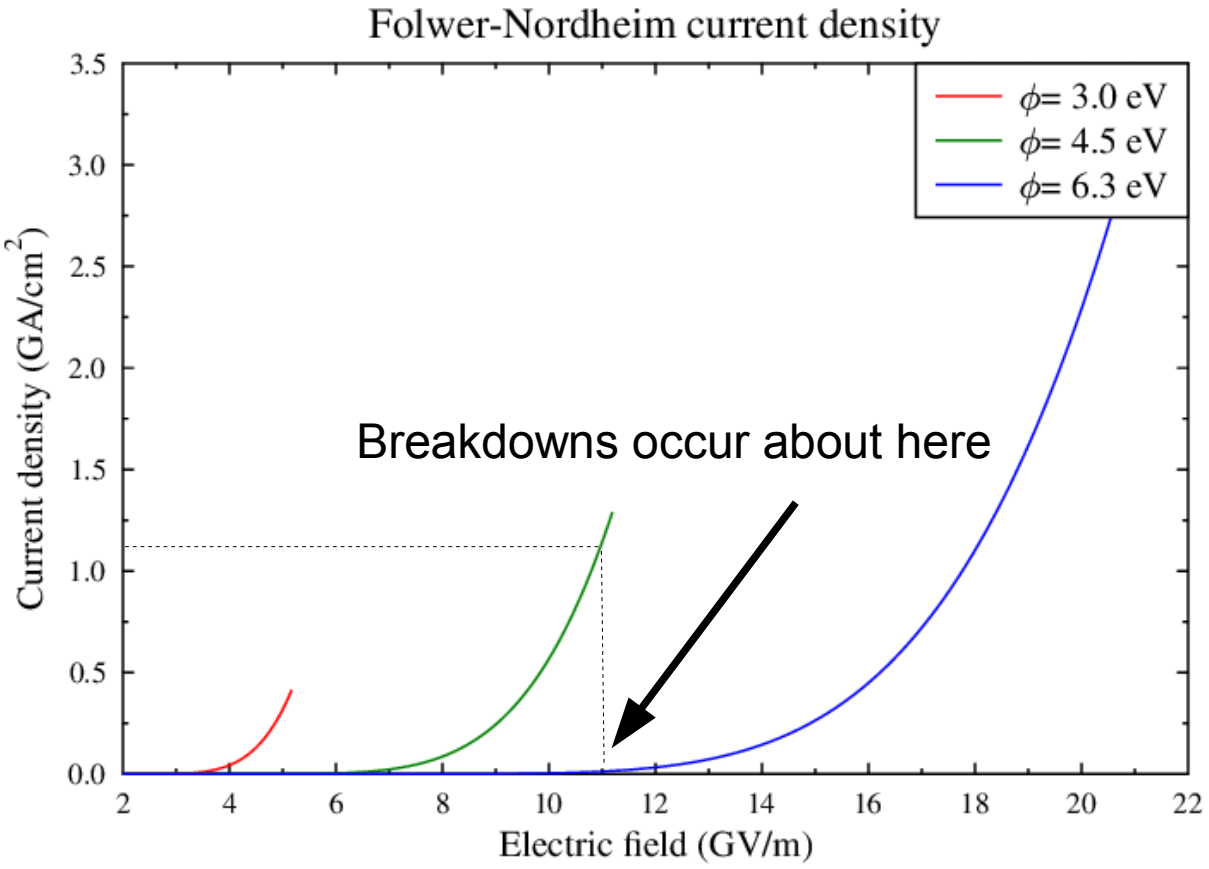
Where are the field emitters

- Our theory:
  - Field emitters may grow spontaneously under an electric field

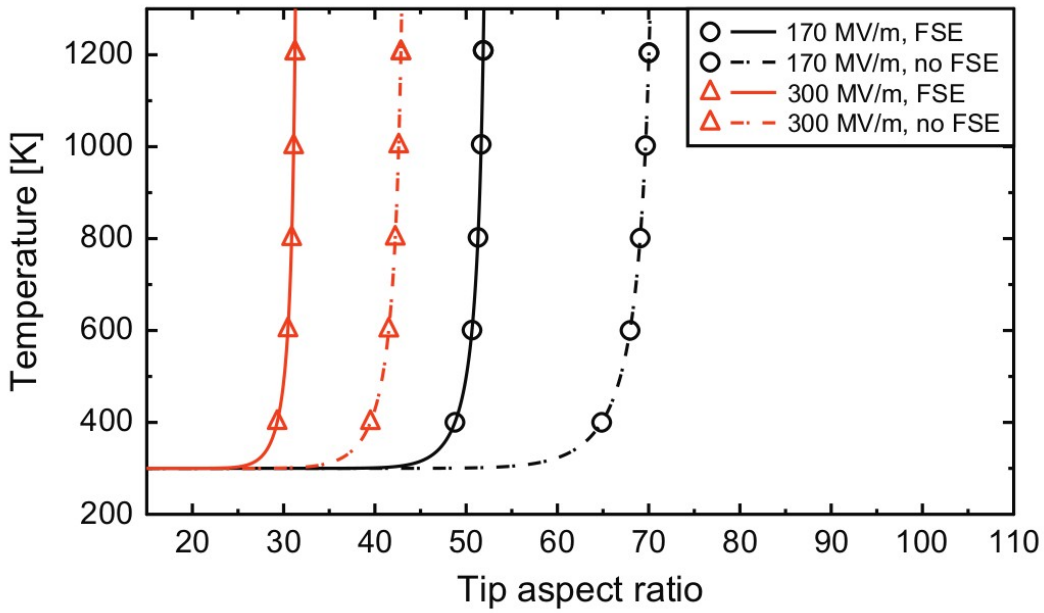


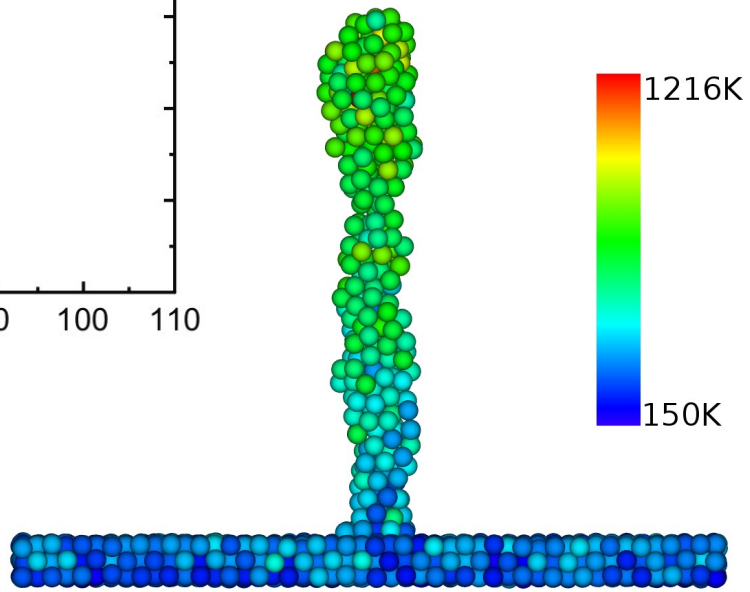
  - Some emitters are destroyed during the field emission process
    - Partial melting due to resistive heating?
    - Field evaporation due to high field?
    - High internal forces from the field emission current? (this work)
  - Remaining emitters flatten once the field is removed
    - See talk by V. Jansson

Current densities in an emitter

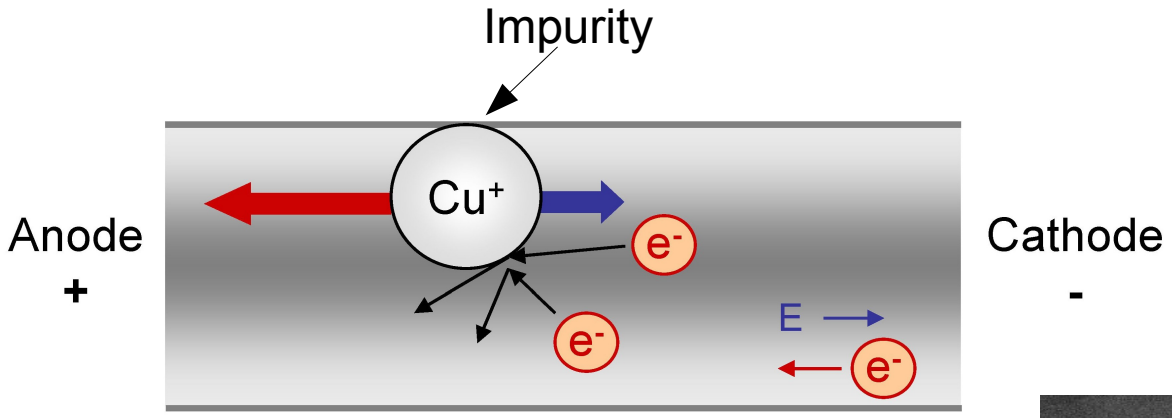


Temperature reached in emitter





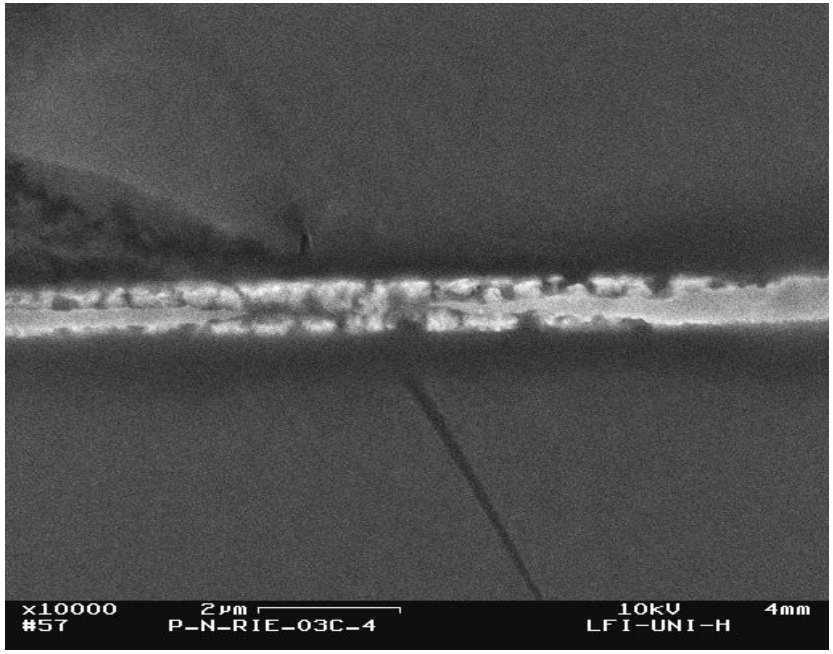
Electromigration



Linear77/Wikipedia

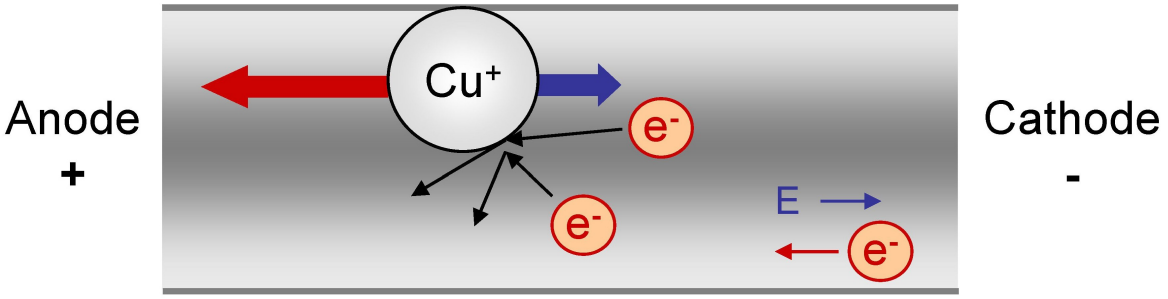
Electron wind force:

$$\boldsymbol{F} = \boldsymbol{E}_{\mathbf{int}}\left(Z_{\mathrm{d}} + Z_{\mathrm{w}}\right)$$



P. Zörner

Effective charge



$$F = E_{\text{int}}\left(Z_d + Z_w\right) = E_{\text{int}} Z^*$$

Direct Ion valence

Wind valence

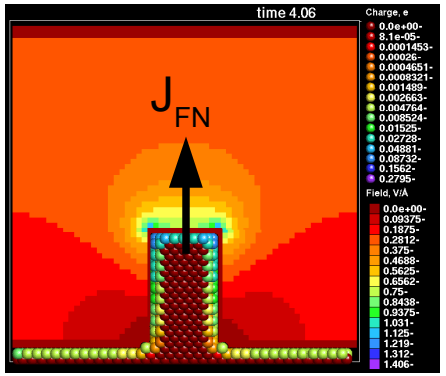
Effective valence

- Both Z_d and Z_w are difficult to determine precisly
- Z_d is affected by screening in a metal
- Z_w depends on the electron transport corss section
  - Difficult to calculate (Possible project coming)

“Electromigration” in HELMOD

- We want to include this effect in our HELMOD code
  - Classical electromigration is a diffusion process: not suitable for study with MD
  - But other interesting effects appear
  - Electromigration proper will be probably be included in the KMC model by V. Jansson et al.

HELMOD quick recap



- Hybrid electrodynamics - molecular dynamics code with support for various electronic effects, e.g.
  - Dynamic field calculation
  - Induced surface charge and Lorentz force on atoms
  - Calculation of field emission current and resulting resistive heating

“Electromigration” in HELMOD

- Implemented as additional ”electron wind force” acting on atoms in protrusion
- Force proportional to the internal electric field and effective valence of surface copper atoms as seen by current

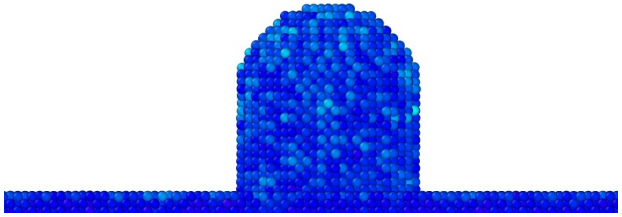
$$\boldsymbol{F} = \boldsymbol{E}_{\mathbf{int}} Z^{*} \qquad \boldsymbol{E}_{\mathbf{int}} = \boldsymbol{J}_{FN} / \sigma$$

$$Z^{*} \approx 10..100$$

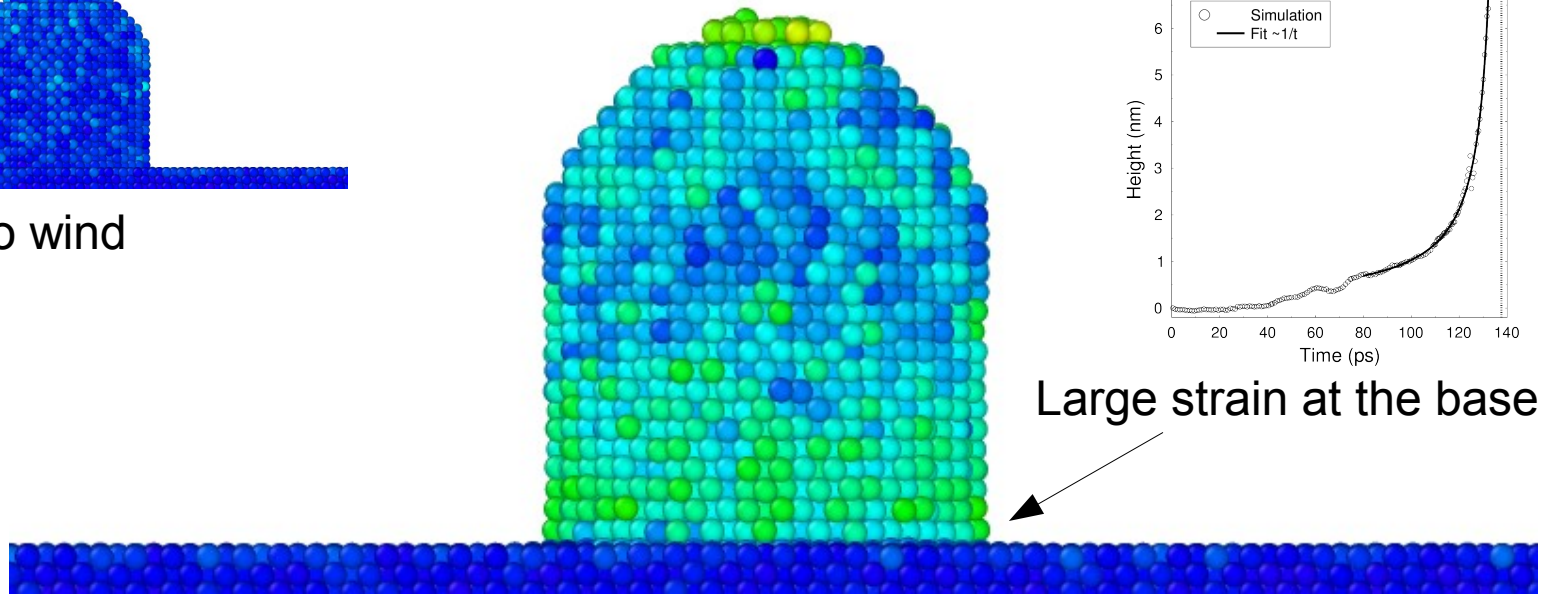
- Assume current (and force) is going straight upwards
  - actually follows surface geometry
- Apply on surface atoms (impurities), assume effective charge Z^{*} is constant

Stretching of emitter

- Whole emitter is stretched out by the electron wind force
- Large strain is seen at the base of the structure



No wind

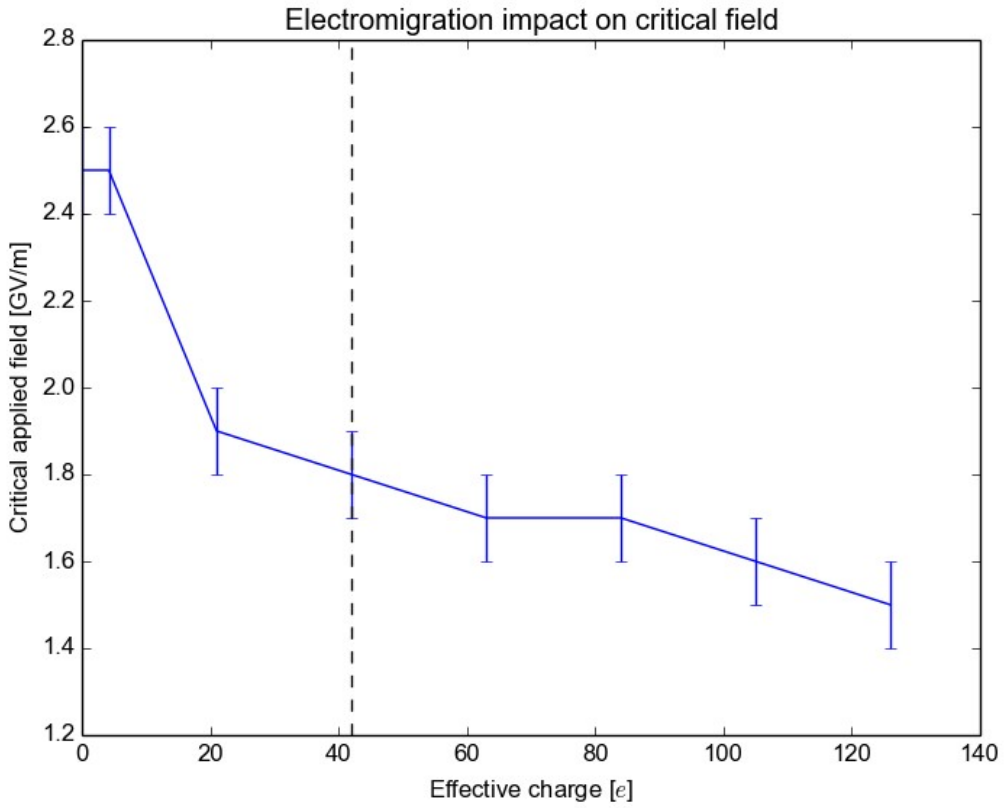


Large strain at the base

(Color indicates strain)

Reduction in critical field

- Protrusion with height 6.5nm, diameter 2nm, 300K



Conclusions

- We have large current densities in our field emitters
  - Electromigration should become an issue
  - MD is too slow to handle proper electromigration (diffusion process)
  - Electron wind force implemented into HELMOD
  - The wind force is sufficient to stretch emitters, reducing the critical field for their destruction

My current work contract is ending this year ...