2D Arc-PIC Simulating arc ignition

THE PHYSICS

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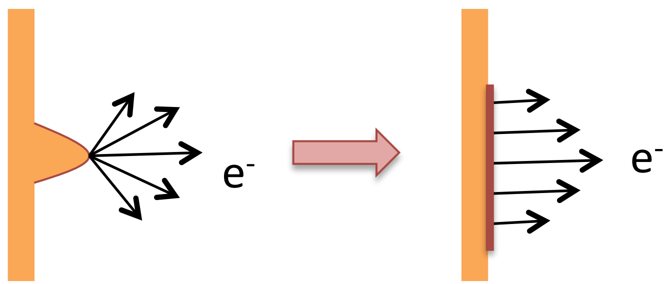
Input
Output
Discussion

Modelling the ignition of a vacuum arc

- Due to limited simulation range we cannot cover entire dynamic range of vacuum arc
  - Focus on the early stage of plasma ignition from a single field emitter ("tip") with enhanced electric field
- Tip not simulated explicitly
  - Modelled as area with large field enhancement factor β_0

- Aim to link different stages of vacuum arcs
- Capture transition from nano-scale to macroscopic properties



Emission model

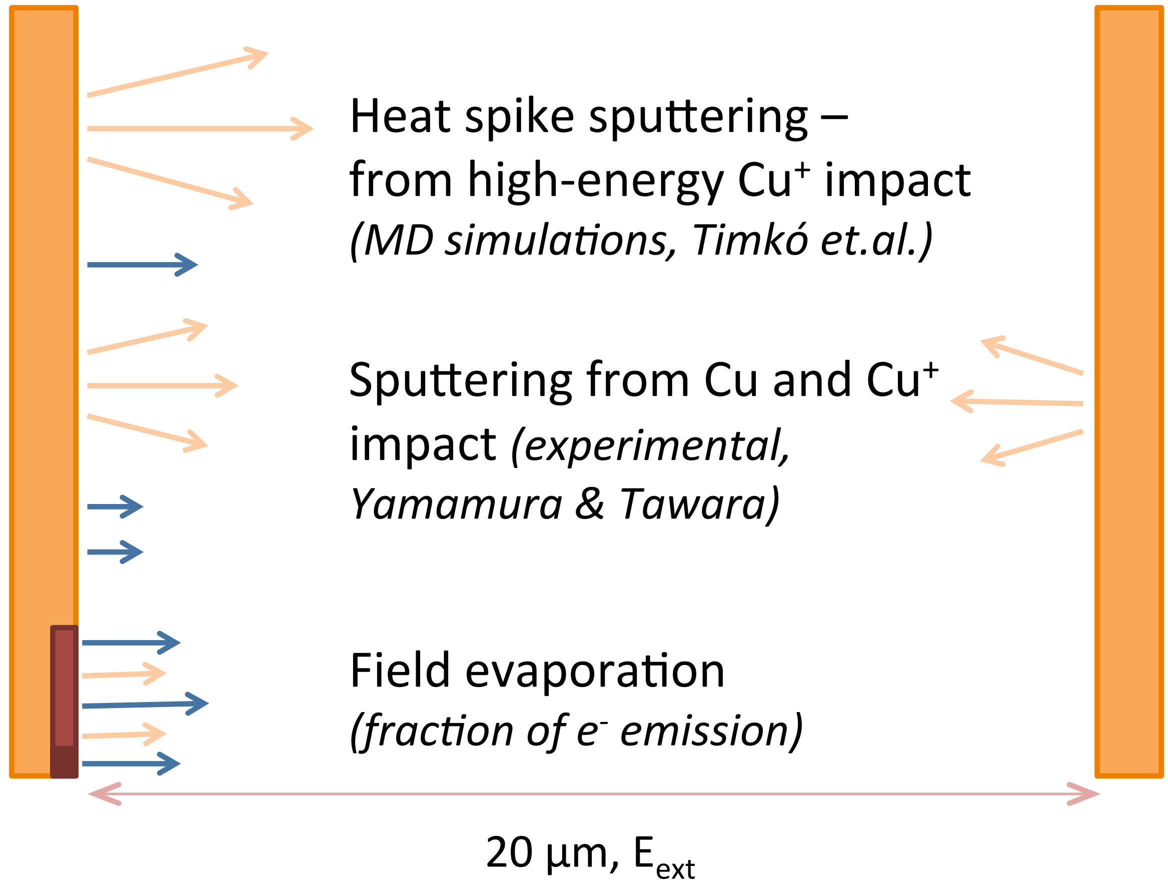
Electrons

SEY from Cu impact
(constant)

Injection from “flat” surface with β_f

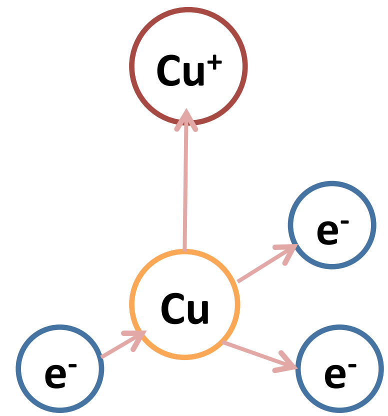
Injection over R_{em}
(calculated from J_{FN} through R_{tip} with β_0)

Neutrals



Monte Carlo collisions

- Coulomb collisions
  - (e^-, e^-) , (Cu^+, Cu^+) , (e^-, Cu^+)
- Elastic collisions
  - (e^-, Cu), (Cu, Cu)
- Charge exchange and momentum transfer
  - (Cu, Cu^+)
- Impact ionization
  - e^- + Cu --> 2e^- + Cu^+



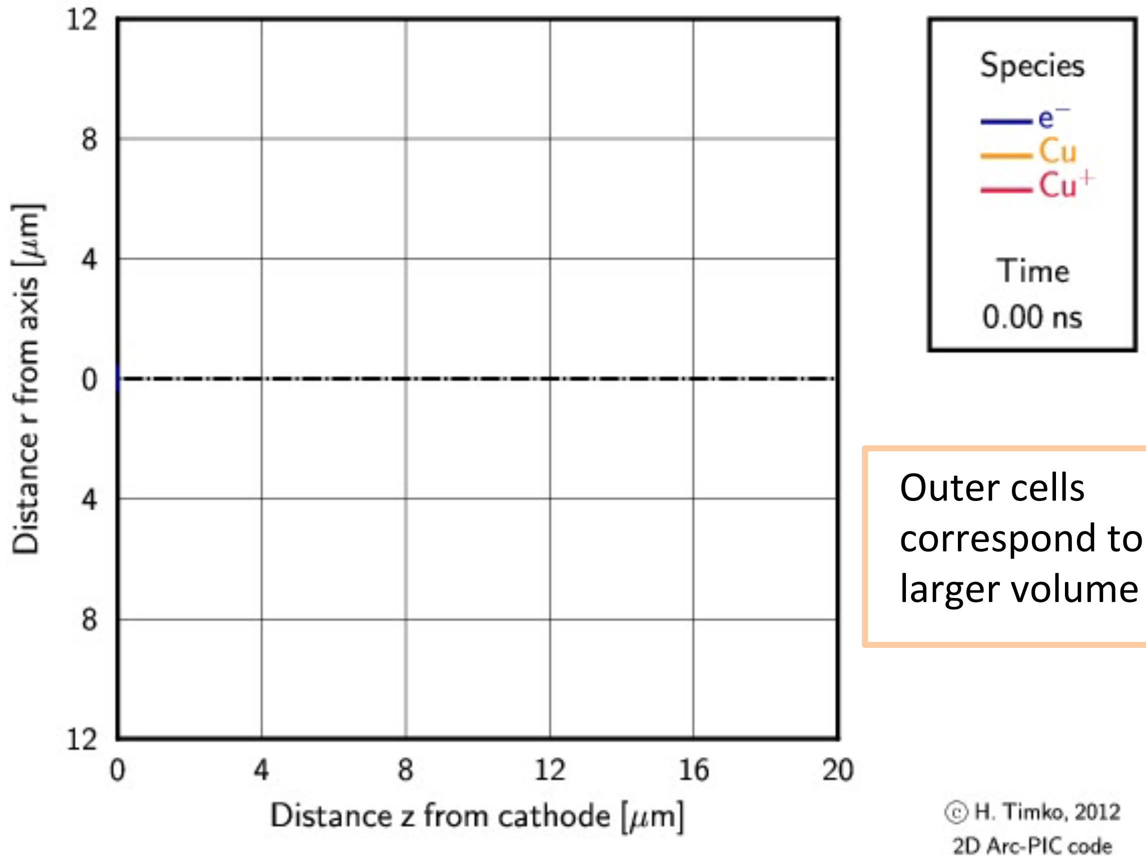
- No recombination

Only source of ions!

From field emission to plasma

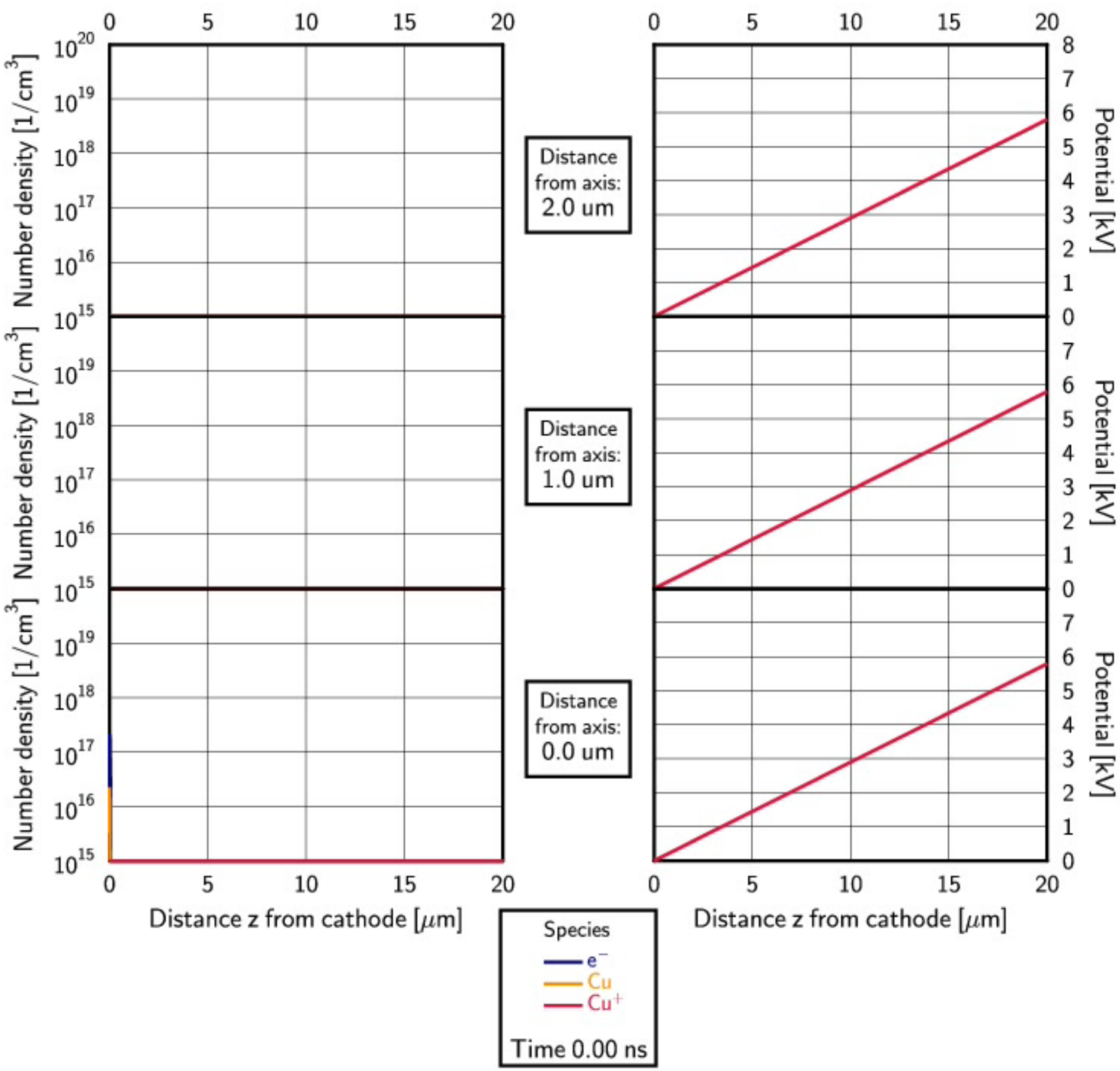
$\beta_0 = 35$, $\beta_f = 2$
$E_{ext} = 290$ MV/m
$R_{tip} = 0.1$ µm
$R_{em} = 0.4$ µm
$r_{Cu/e} = 0.015$
SEY = 0.5

Grid 240 × 400
dZ = 50 nm
$N_{sp} = 5.34$
dt = 1.78 fs
dt_ion = 5dt
dt_coll = 5dt



Outer cells correspond to larger volume

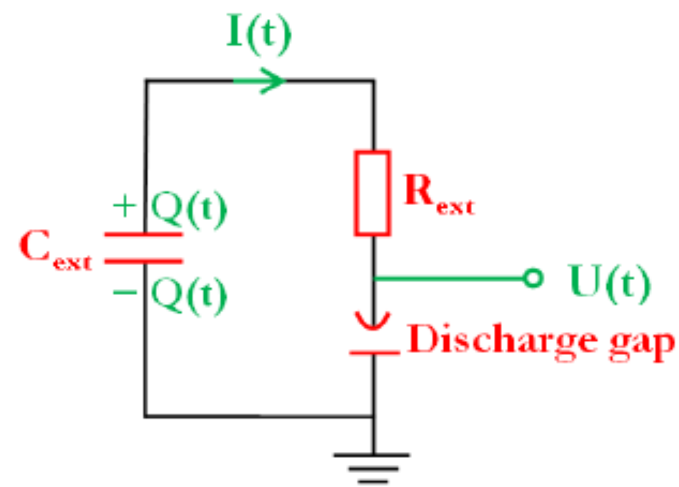
Number densities & potential

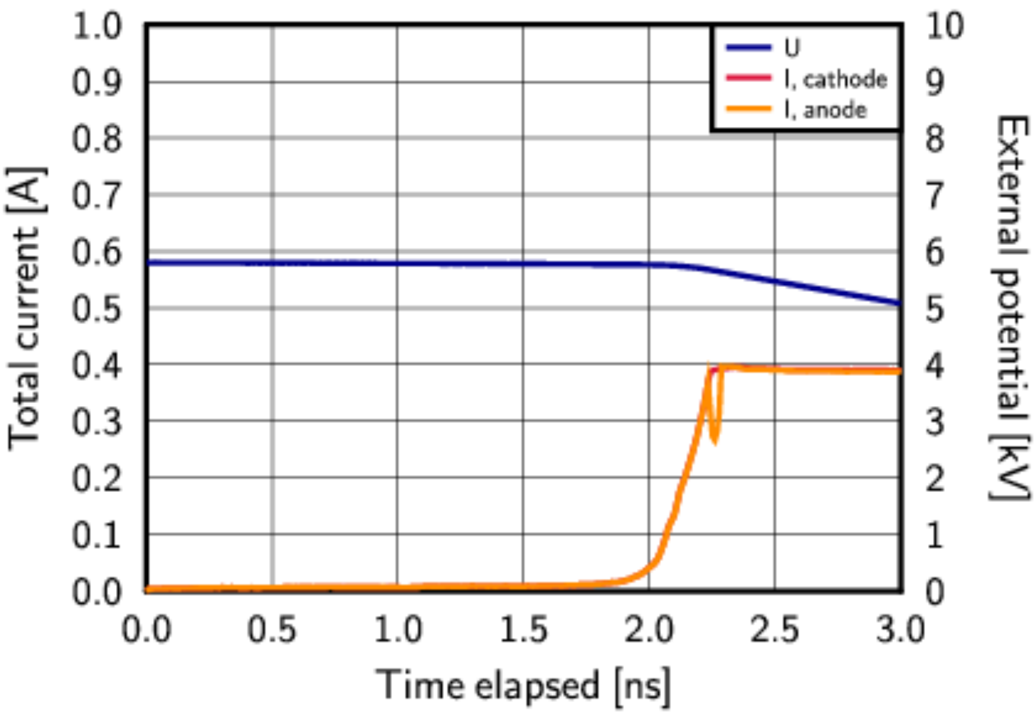


- Critical neutral density 10^{18} cm^{-3}
  - Runaway ionization
  - Breakdown!
- Formation of sheath + quasi-neutral plasma
- Sheath + plasma can be seen in potential
- No proper burning voltage

Current-voltage characteristics

- Current reaches maximum value ≈ 0.4 A
- Voltage decreases as capacitor is drained
- Plasma self-maintaining as long as energy is available





$$Q(t_{i+1}) = Q(t_i) - I(t_i)\Delta t$$

$$U(t_{i+1}) = Q(t_{i+1})\ /C_{ext} - R_{ext}I(t_i)$$

Here $R_{ext} = 0$

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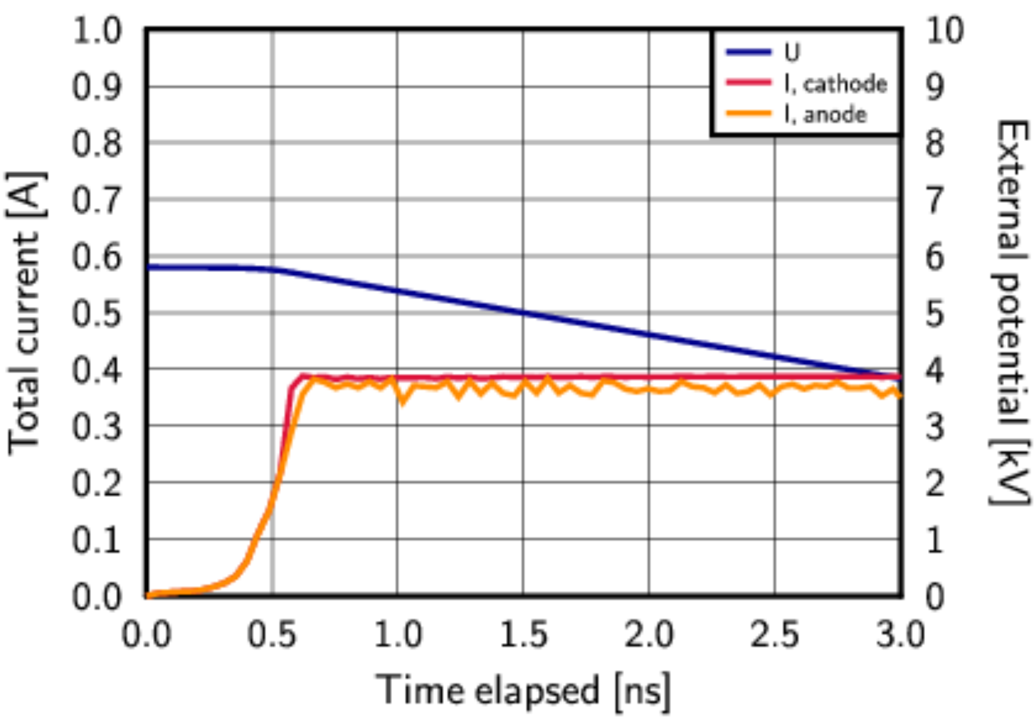

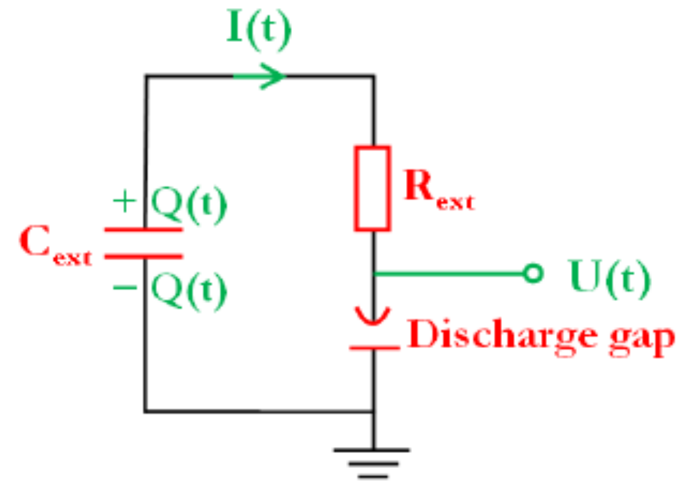

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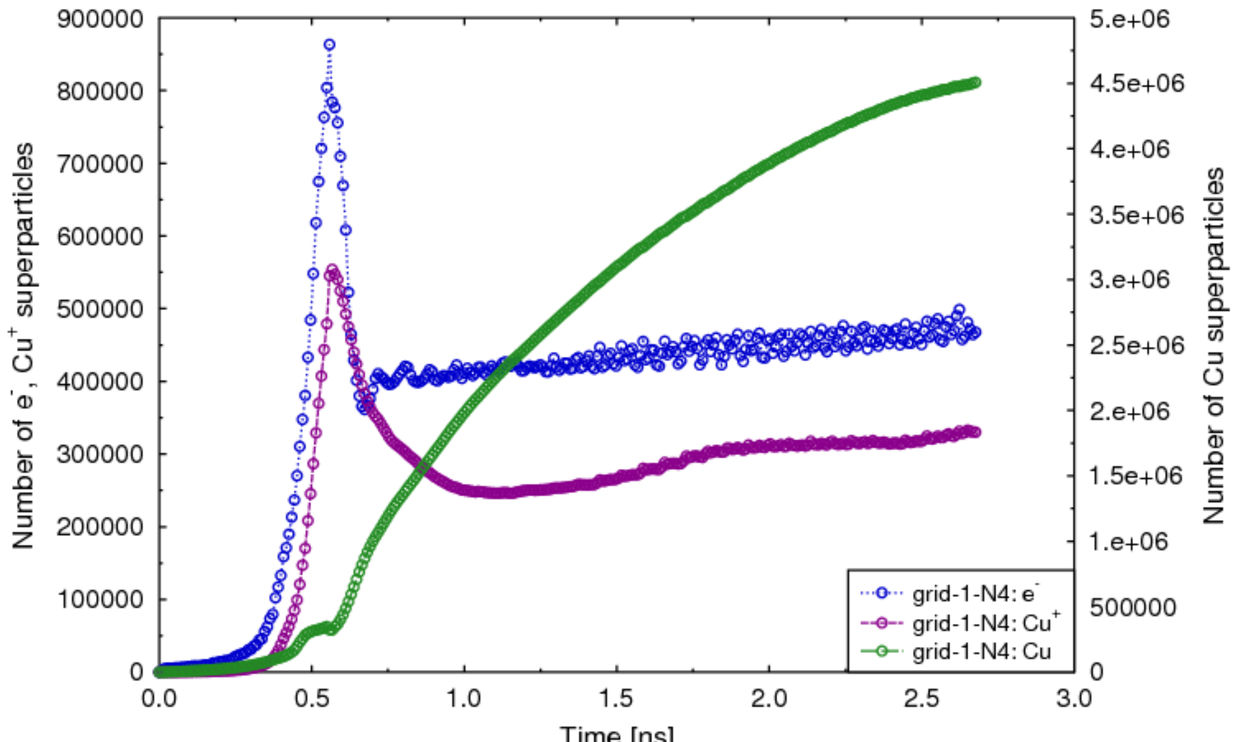
Why is the plasma current so low?

- Experimentally measured currents ≈ 10 -100 A
- Because of the field emission model
  – FN emission set to cut-off at 12 GV/m (≈ end of validity range)

- Need to improve emission model

- How?
  Thermionic effects?
  – How define T?
  – Shape of tip?



What else may be wrong?

- Neutral evaporation model
  - Current scheme compromise between simulation constraints
    - Much smaller value gives too long run times
    - Much larger too steep density gradients
- Field emitter and injection radii
  - Choice based loosely on experimental data
  - Makes a big difference quantitatively
- Charge states
  - Currently only first Cu charge state implemented
  - Average charge state ≥ 2
  - Optical spectroscopy at CERN

Conclusion & Outlook

- We model the development from a single field emitter to a stable vacuum arc
- Want to go from qualitative to quantitative description, model steady state…
  - Improve emission & circuit models
    - requires more knowledge/assumptions on tip properties?
  - Understand which effects are fundamental properties of the arc, what follows from our specific assumptions and/or limitations of the simulation method
- Use the code as a test lab
- Long term goals