Direct Field Ionisation

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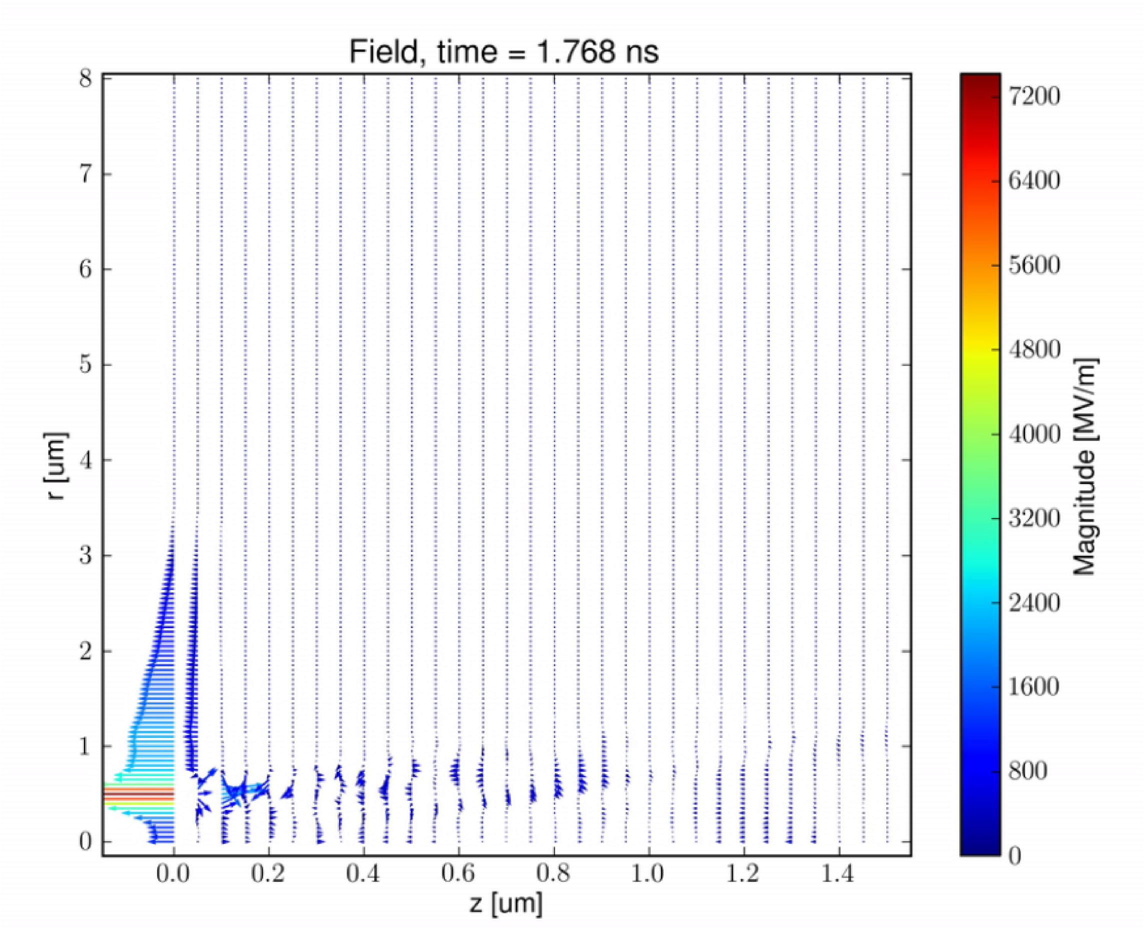
Abstract

Direct field ionisation of neutral atoms is a tunnelling phenomenon which may happen when atoms are exposed to an external electric field of magnitude comparable to the atomic electric field seen by the outer electron shells. The resulting ionisation probability may have a magnitude comparable to the usual electron impact ionisation probability, and thus this process should not be neglected in plasma simulations codes. In particular direct field ionisation may play an important role in the first triggering phase of a breakdown.
This poster presents the basic underlying physics and formulas for the ADK model [1, 2], and some simple comparison with electron impact ionisation cross-sections.

The context

From ArcPIC plasma simulations: in the proximity of the field emitter tip we may have fields of the order of 6-8 GV/m. Strong field enhancement near field emitters may result in even higher fields (> 10 GV/m).

Is field ionization relevant for us?



...courtesy of Andreas Kyritsakis

Basic model

The probability for direct field ionisation from [4] is:

$$p = 1.52 \times 10^{15} \frac{4^n \xi}{n\Gamma(2n)} \left(20.5 \frac{\xi^{3/2}}{E}\right)^{2n-1} \exp\left(-6.83 \frac{\xi^{3/2}}{E}\right)$$

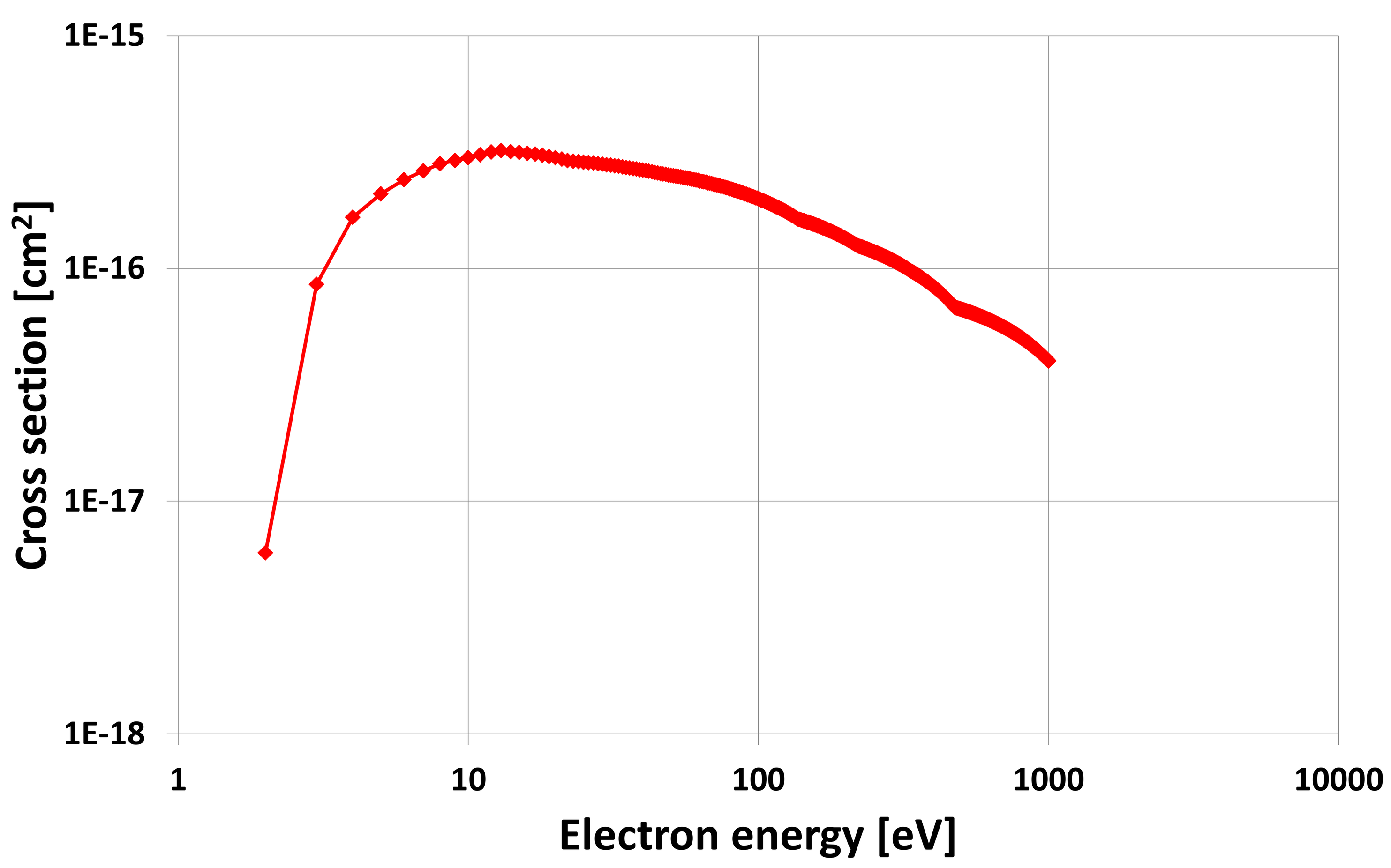
with: $n = 3.69 z \xi^{-1/2}$

And:

- p [s^{-1}]: probability of ionisation
- ξ [eV]: potential of ionisation of a given atom
- E [GV/m]: electric field
- z : charge number after ionisation

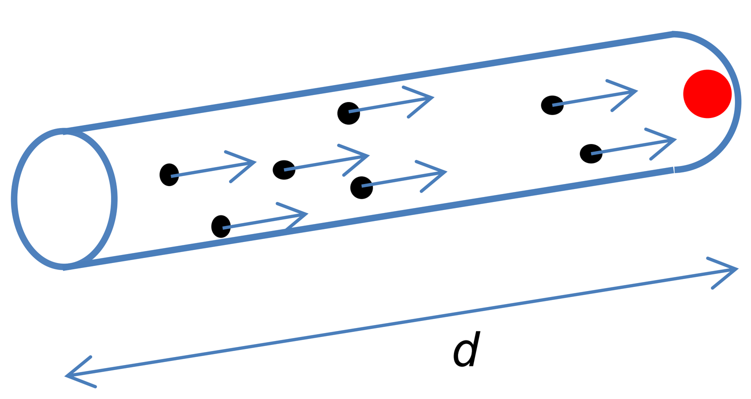
Limit of validity up to $E_{crit} = 1.5\xi^{3/2}$ (barrier suppression).

Electron impact ionisation



Values used in ArcPIC (courtesy of H. Timkó) [3].

To compare with field ionisation:

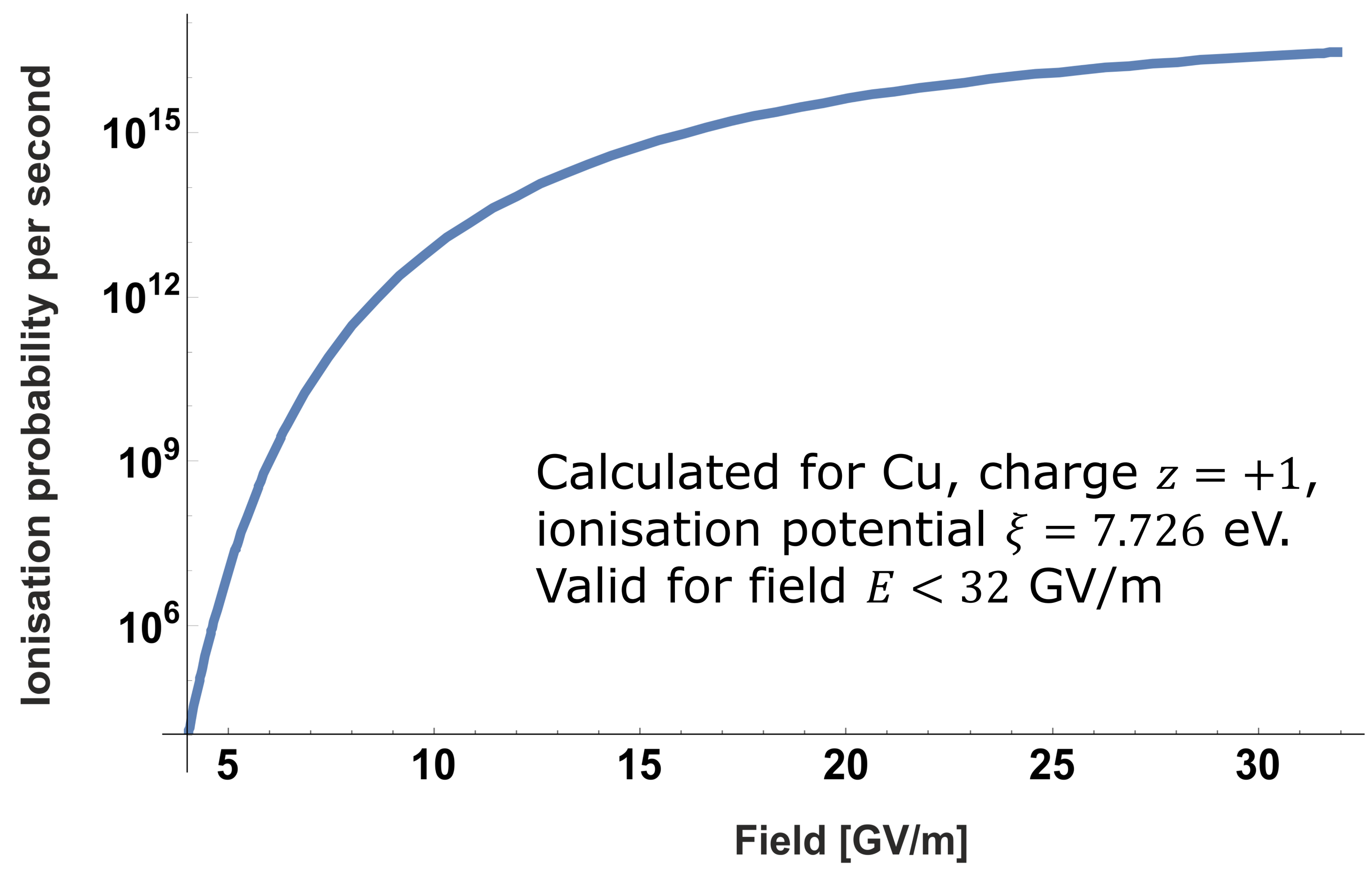


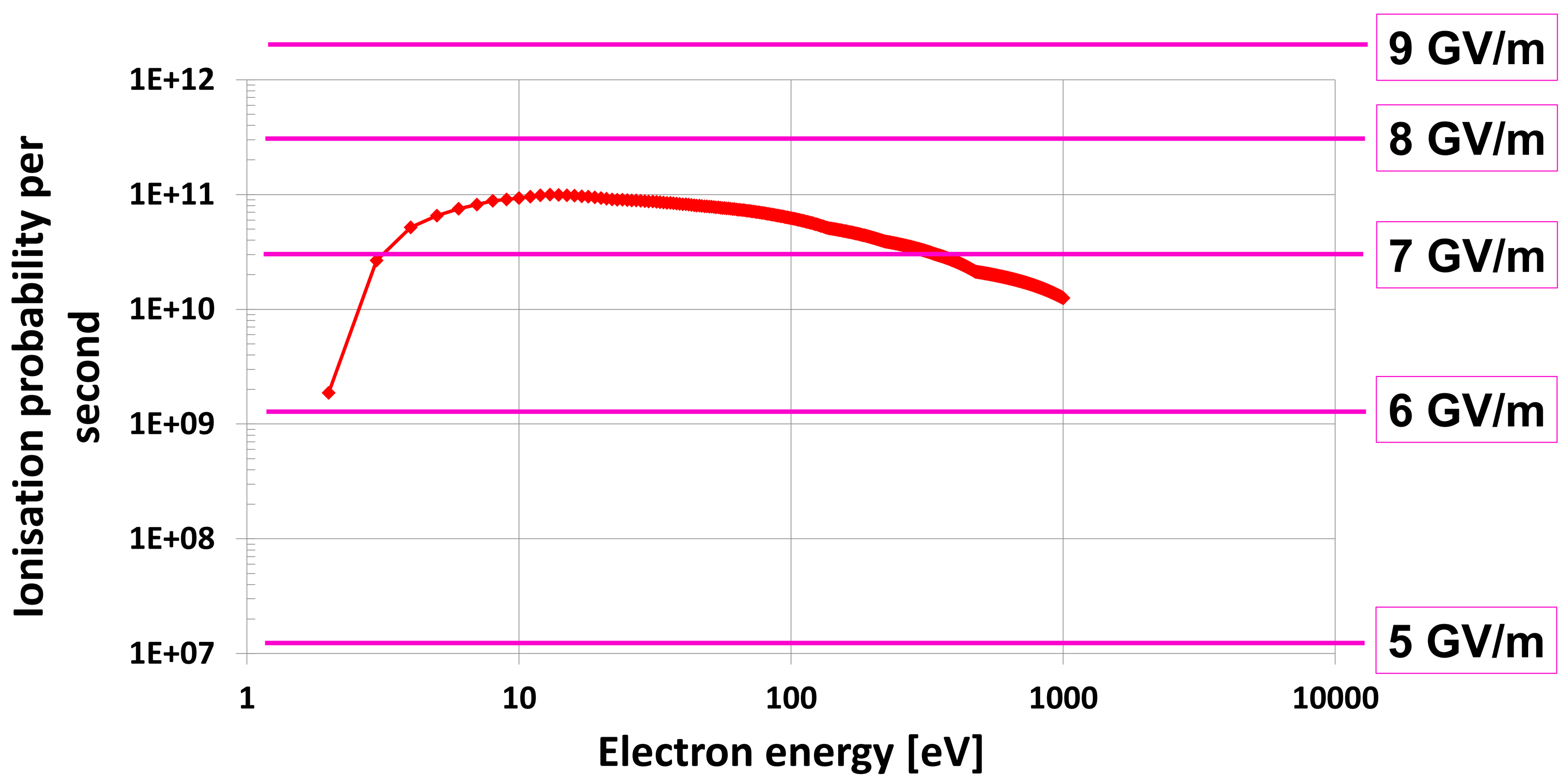
Copper atom intercepting a stream of **electrons** of velocity $v_e = d/t$, having a current of density $J_e = n_e v_e$.
Probability for one Cu atom of being ionised in unit time:

$$P = \sigma \frac{d}{t} n_e = \sigma_e \, n_e v_e = \sigma J_e$$

Where σ is the electron impact cross section and $J_e = 0.5$ A/μm² as in PIC simulations (typical field emission - runaway current) [2].

Results





The purple lines are the direct field ionisation probabilities compared to impact ionisation.
In ArcPIC, we need 0.015 electrons/neutral copper atom in order to trigger runaway. Including field ionisation in the simulations may lead to relaxing this requirement.

Conclusion

Direct field ionisation may be relevant in:
Ionisation in the plasma sheath (competition with other mechanisms).
Ionisation in vicinity of the field emitter tip (influence on the breakdown triggering process).

References

1. M.V.Ammosov, N.B.Delone, and V.P.Krainov, Sov. Phys. JETP 64, (1986) 1191.
2. D.Bauer and P.Mulser, Phys. Rev. A 59, (1999) 569.
3. M.A.Bolorizadeh, C.J.Patton, M.B.Shah, and H.B.Gilbody, J. Phys. B: At. Mol. Opt. Phys. 27 (1994) 175.
4. D.L.Bruhwiler et al., Physics of Plasmas 10 (2003) 2022.

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