Modelling of arc-electrode systems: preliminary results for high pressure xenon arc lamps

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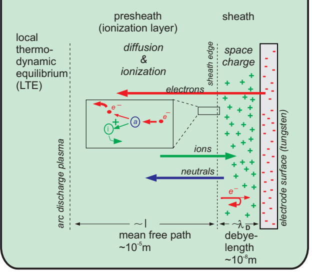
Objectives:

- development of quantitative high pressure discharge models applicable to a wide range of lamp configurations
- understanding of the arc electrode system, i.e. prediction of the cathode hot spot formation for thermionic cathodes
- validation of modelling software by quantitative comparison with experimental data

Solution method:

- iterative linking of numerical submodels:
  - description of the discharge plasma by conducting fluid models (2-D, LTE)
  - description of the electrode layers by local sub-models (1-D)
  - current and energy transport inside the electrodes (2-D)
- model validation and optimization for discharge configurations with reliable and accurate experimental data available:
  - free burning atmospheric argon arc (0.1 MPa, LTE)
  - high pressure xenon short arc lamp (4 MPa, LTE)

boundary layer models:



model of the arc column:

$$\frac{\partial}{\partial t}\rho + \vec{\nabla}\cdot(\rho\vec{v}) = 0 \quad \text{(mass)}$$

$$\rho\frac{D}{Dt}\vec{v} = -\vec{\nabla}p + \vec{\nabla}\cdot(\mu\vec{\vec{\pi}}) + \vec{j}\times\vec{B} \quad \text{(momentum)}$$

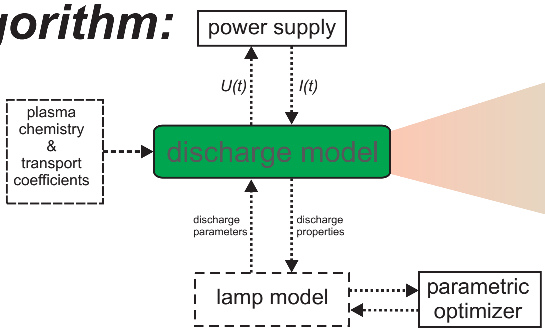
$$\rho\frac{D}{Dt}h = \vec{\nabla}\cdot\vec{q} + \vec{j}\cdot\vec{E} - S_R \quad \text{(energy)}$$

with $\vec{q} = \frac{\lambda}{c_p}\vec{\nabla}h + \frac{5k_b}{2e}\frac{\vec{j}}{c_p}h$

$$\vec{j} = \sigma\cdot\vec{E} \quad \text{(current)}$$

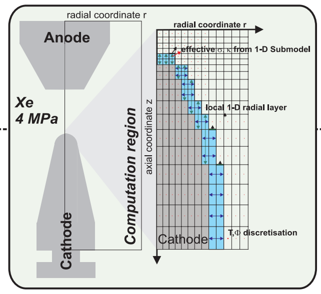
$$\vec{\nabla}\times\vec{B} = -\mu_0\mu_r\vec{j} \qquad \vec{\nabla}\cdot\vec{j} = 0 \quad \text{(Maxwell equations)}$$

Algorithm:



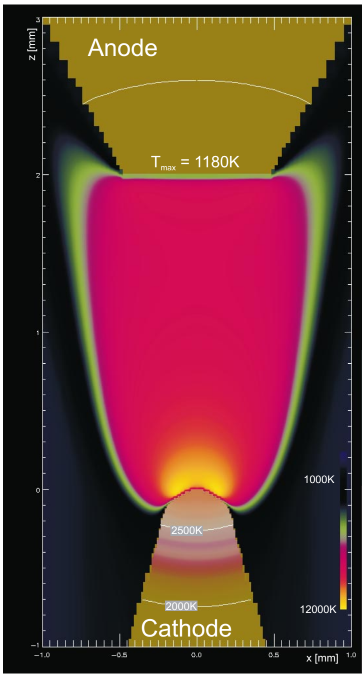
input	arc-model	output
discharge parameters: - total current & pressure - gas filling - geometry	cathode: - locally 1-D *non-LTE* *(space charge formation, temperture split, electron emission, diffusion)*	overall discharge: - voltage & temperature distribution - flow velocity distribution - global energy balance (e.g. heat loads)
electrodes: - temperature boundary conditions - effective work-function	anode: - locally 1-D *non-LTE*	electrodes: - temperature distribution - hot spot formation
material properties: - electrodes - plasma chemistry - transport coefficients	arc column: - 2-D LTE-plasma (hydrodynamic decription as a conducting fluid) - radiation as net emission & heat conductivity	electrode layers: - fall voltage - local current densities

internal iterations

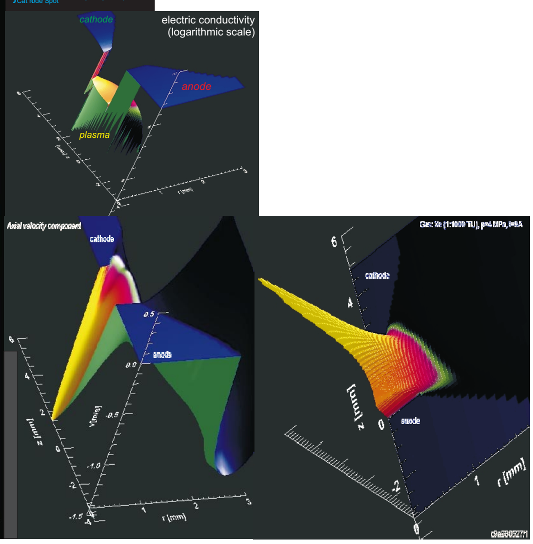


Results:

- comparison of different cathode layer models:
  - space charge formation may be collision-free
  - electron emission is the dominating physical effect
  - field enhanced thermionic emission decreases cathode spot temperature below 3000K
  - work function is the dominating material property
- model validation and optimization:
  - arc voltage is the critical validation parameter
  - mode transitions need large computing power
  - for the 4 MPa xenon test case, hydrodynamics do not dominate the cathode spot formation



4 MPa Xe + TlJ (1:1000)
12A, ~250W
$V_{Cathode\ Layer}$ ~ 7V
$j_{Cathode\ Spot}$ ~ 6·10^7 A/m^2



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Acknowledgement:
this work was supported by the german federal ministry for education and research under contract number 13N7105/9 (Forscherverbund Lampenkathoden).

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