Plasma Efficiency and Losses for pulsed Xe Excimer DBDs at high Power Densities

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Dielectric Barrier Discharges

- Non-equilibrium plasma
- Xenon excimer
- Radiation around 172 nm
- Plasma efficiency up to 65 % [1]

- Phosphor coated lamps for
  - UV water disinfection
  - Advanced oxidation processes

Experimental setup
Lamp overview

barrier: fused silica
gas gap: 4.5 - 5.5 mm
xenon: 210 - 400 mbar
frequency: 20 - 200 kHz

Investigation:
- radiation flux
- optical losses
- plasma efficiency estimation

barrier: glass
gas gap: 2 mm
xenon: 50 - 350 mbar
frequency: 20 - 200 kHz

Investigation:
- luminance
- inner electrical values
- NIR (823 nm, 828 nm)
Experimental setup
VUV goniometer

- wavelength range from $115 \text{ nm} < \lambda < 1700 \text{ nm}$
- absolute calibration from VUV to NIR
- photometric distance = 120 cm (max lamp size = 12cm)
- ability to measure angular distribution of radiant intensity
Results for silica lamps: angular distribution and spectra

- Angular distribution of radiant intensity (ARI) shows optical thin plasma
- \( \text{Xe}_2^* \) spectra is overlapped with transmission edge of fused silica (~155 nm)
Results for silica lamps:
Calculation of plasma efficiency

- light flux:
  \[
  \Phi = \int_{\lambda_1}^{\lambda_2} \int_{\phi_1}^{\phi_2} \int_{\gamma_1}^{\gamma_2} I(\lambda, \phi, \gamma) \sin(\gamma) d\lambda d\gamma d\phi
  \]
  \[
  \Phi = 4\pi \cdot ARI \cdot \Delta \lambda \cdot \sum_{i=1}^{n_j} I(\lambda_i, \phi_{j=\phi_{\text{Max}}})
  \]

- extraction efficiency $T_{\text{eff}}$:
  - transmission of silica
  - net-shaped electrode
  - absorption of inner barrier

- plasma efficiency:
  - isotropic emission of $\text{Xe}_2^*$ ($4\pi$)
  \[
  \eta_{\text{Plasma}} = \frac{\Phi}{ARI \cdot T_{\text{eff}} \cdot P}
  \]
Results for silica lamps: efficiency

- Variation of repetition rate:

- Maximum optical power density:
  \[ P_{\text{VUV}} = 0.12 \text{ W/cm}^2 \text{ at } p_{\text{Xe}} = 300 \text{ mbar} \]

- Power density rises with pressure, but ...

- Transition of homogeneous into filamented discharge (pressure depended)
Results for silica lamps: efficiency

- maximum plasma efficiency ~ 52 % (at $P_{el} = 0.07$ W/cm²)
- plasma efficiency declines to ~ 34 % (at $P_{el} = 0.8$ W/cm²)
- why is the efficiency declining?
Results for flat lamp: power and efficiency

- comparable results for flat lamp as for silica lamps
- above $p = 200$ mbar slight pressure dependency when repetition rate is adjusted
Results for flat lamp: voltage and IR

- Pulse shape matched for double ignition
- For f = 200 kHz no ignition in first positive half-wave, despite voltage excite ignition voltage
Due to high frequency increasing plasma current density before ignition, that separates the remaining charges and lowers the gas gap voltage.

Plasma becomes a glow discharge.
Summary

- VUV goniometer to measure the total radiance of a lamp between 115 nm and 1700 nm

- Measurements of power density and efficiency for high power $\text{Xe}_2^*$ DBDs

- Limiting factors:
  - Transition into filamented discharge
  - Remaining charges and plasma current density
Thank you for your attention.
Experimental setup

**ECG**

![Diagram of ECG setup]

**Electrical excitation / measurement**

- resonant pulse ECG as current source
- measurement of plasma current $i_{\text{plasma}}$
- measurement of gap voltage $u_{\text{gap}}$