

# **DEVELOPMENT OF MERCURY- FREE DBD LIGHT SOURCES**

PH.D. MAIN FINDINGS  
BOOKLET

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# Overview

Recently, concerns about environmental problems have received considerable attention in the field of lamps as well. The main driving force to move away from mercury-containing discharge light sources is connected to the environmentally unfriendly nature of mercury. In the lighting industry, however, any products still make use of mercury, for different reasons. The main reason is that mercury-containing products are, in most cases, more efficient than mercury-free products.

As recent research results indicate initiatives that may offer the most promising alternative for mercury-containing discharge light sources in respect of efficiency and production costs are based on rare gas discharges. Generating UV excimer radiation by means of dielectric barrier discharge (further called DBD) excitation of Xe represents a promising concept for novel types of excimer light sources.

Xe DBD excimer light sources exhibit various advantages over conventional light source designs since they are mercury-free, easily scalable, and possess simple construction geometry. DBDs significant disadvantage was that the UV radiation generation was characterized by a deplorable 10-15% efficiency. However it was found that using a well defined excitation procedure, using high voltage pulses makes it possible to achieve radiation efficiencies of more than 60% in xenon.

On the grounds of these findings a wide field of additional applications has been opened up. Due to the high efficiency, for the first time it became possible to take the chance for commercializing DBDs with the target of visible light generation.

## Scope of the work

The principal objectives of the Ph.D work are: (1) to create a framework of experimental and theoretical studies towards the optimization of discharge and photo conversion processes; (2) to determine the scientific basis of an efficient DBD excimer light source and how its efficiency can be optimized.

The work gives a detailed explanation of the underlying fundamental physical processes governing the operation of a DBD discharge fluorescent light sources by using a detailed fluid-dynamical computer simulation of the discharge plasma. The optimization work involves the characterization and optimization of parameters of the light source in order to achieve high luminous efficacy and high input electrical power density. I compare the strengths and drawbacks of different applied voltage excitation waveforms within the context of relevant practical aspects involved in the course of the research and development of a fluorescent DBD light source.

Presented research results show significant improvements in DBD performances. Based on these foundations the realization of efficient compact fluorescent light source founded on the DBD technology seems reasonable and feasible

The results are summarized in 3 main findings.

## Main findings:

1. – A computer simulation of a Xe dielectric barrier discharge fluorescent light source was developed. The simulation is based on a detailed one-dimensional fluid dynamical model of the discharge plasma. A comprehensive reaction-kinetic analysis of the plasma processes (~ 100 chemical reactions) and a luminous efficacy calculation associated with the phosphor light-conversion process are integrated into the model. The simulation is capable for investigating the principal processes inside the plasma, and also makes the optimization and further development of a fluorescent light source possible.

The model allows detailed examination of the transfer of input electrical power into radiated emission and losses and hereby the calculation of partial discharge efficiencies on specific wavelengths can be performed.

Detailed comparison of the calculated and measured emission, electrical and spectral properties of a fluorescent Xe dielectric barrier discharge light source was performed. Precise verification of the calculated discharge efficiency and luminous efficacy represents a novelty compared to previous evaluations of DBD light sources and models presented in the literature.

Using the proposed light source and fast rise-time short (~ 600 ns) unipolar square pulses of the driving voltage, an intrinsic discharge efficiency around 56% was predicted by the simulation. Overall discharge efficiency of 50 %, which corresponds to more than 60 lmW<sup>-1</sup> luminous efficacy (for radiation converted into visible green light by phosphor coating) was demonstrated experimentally.

Corresponding publications: [1], [6], [7]

2. – The performance of the light source presented in main finding 1 was improved by shortening the unipolar voltage pulses ( $\sim 200$  ns) at different gas pressures ranging from 100 mbar up to 300 mbar. In this case according to the calculations most of the power deposited into the plasma efficiently produces  $\text{Xe}_2^*$  excimers, while other energy dissipation processes (ion heating, e-Xe elastic collision) are kept at a low rate.

The overall VUV radiation efficiencies monotonically increase with pressures and with shortened pulse-widths. Highest published intrinsic discharge efficiency theoretically ( $\sim 67\%$ ) and experimentally ( $\sim 62\%$ ) was demonstrated. Highest extrinsic luminous efficacy ( $\sim 80 \text{ lmW}^{-1}$ ) presented in the literature up to date was achieved at  $890 \text{ mW/cm}^3$  input electrical power density.

Corresponding publications: [2], [5]

3. – In order to simultaneously achieve high efficiency and high input power I have proposed a novel amplitude modulated sinusoidal excitation waveform (burst wave) for driving Xe dielectric barrier discharges. I found that the burst excitation method provides an enhanced light source performance compared to the pulsed wave. A nearly two-fold increase in input electrical power densities and VUV luminous flux was demonstrated while maintaining high discharge efficiencies.

The overall VUV radiation efficiencies monotonically increase with pressures, reaching 61.4 % calculated discharge efficiency at 250 mbar gas pressure. The experimentally measured overall discharge efficiency was around 58 % which corresponds to  $\sim 74 \text{ lmW}^{-1}$  luminous efficacy at  $1520 \text{ mW/cm}^3$  input electrical power density.

Corresponding publications: [3], [4]

# List of Publications

- [1] Sz Beleznai, G Mihajlik, A Agod, I Maros, R Juhasz, Zs Nemeth, L Jakab, P Richter: High-efficiency dielectric barrier Xe discharge lamp: theoretical and experimental investigations, *J. Phys. D: Appl. Phys.* **39** (2006) 3777–3787
- [2] Sz Beleznai, G Mihajlik, I Maros, L Balázs, P Richter: Short-pulse excited fluorescent Xe dielectric barrier light source, *J. Phys. D: Appl. Phys.* **41** (2008) 115202 (6pp)
- [3] Sz Beleznai, G Mihajlik, I Maros, L Balázs, P Richter: High frequency excitation waveform for efficient operation of a xenon excimer dielectric barrier discharge lamp, *J. Phys. D: Appl. Phys.* **43** (2010) 015203 (9pp)
- [4] Sz. Beleznai, L. Balázs, P. Richter: New Modulated Driving Signal for Efficient Excitation of DBD Discharges, *HAKONE XI International Symposium on High Pressure Low Temperature Plasma Chemistry, Oleron Isl. France Sep 7-12 2008*, Article 5-4
- [5] Sz Beleznai, P Richter, L Balázs, Higanymentes fényforrások fejlesztése, *Kvantumelektronika 2008, 6th National Symposium on Quantum Electronics, 17. October 2008, Budapest, Hungary; Eds: Péter Á, Kiss T, Varró S, 2008*, P-01
- [6] L Bánkuti, L Reich, Sz Beleznai: *Dielectric barrier discharge lamp*, CN1744275(A), 2006
- [7] L Reich, Sz Beleznai, A Agod, L Jakab, P Richter: *Dielectric Barrier Discharge Lamp with Electrodes in Hexagonal Arrangement*, European Patent EP1615258, 2009