Summary

Spectroscopy on Metal-Halide Lamps under Varying Gravity Conditions

Worldwide, 20% of all electricity is used for lighting. For this reason, efficient lamps are economically and ecologically important.

High intensity discharge (HID) lamps are efficient lamps. The most common HID lamp these days is the metal-halide (MH) lamp. MH lamps have a good colour rendering index. They are high pressure lamps based on arc emission. These lamps are mainly used for applications where a high light output is desired; examples are shop lighting, street lighting, flood lighting of sport stadiums and city beautification. MH lamps have a high efficiency (up to 40%) and emit white light.

The MH lamp contains a buffer gas (usually mercury) and additives that act as the prime radiator in the visible. These additives increase the efficiency and the colour rendering. The additive is dosed as salt; in this thesis mainly dysprosium iodide (DyI_3) is used as additive.

The aim of this thesis is to characterize a well verifiable MH lamp and obtain a set of reliable measurement data. The experimentally obtained data is used to validate existing numerical models of the MH lamp, which gain a better understanding of the plasma properties and transport phenomena in the MH lamp.

When the lamp is burning vertically, segregation of the additives and colour separation occurs. The non-uniform light output has a bad influence on the efficiency and the colour rendering of the lamp. The distribution of the Dy atoms is determined by convection and diffusion in the lamp.

Convection is induced by gravity and therefore the lamp is measured under varying gravity conditions. Besides laboratory experiments the lamp is investigated during parabolic flights. Here the lamp is measured during periods of about 20 s of micro-gravity ($0g$) and hyper-gravity ($\sim 1.8g$). The lamp is also placed in in a centrifuge (1–$10g$). This centrifuge, with a diameter of about 3 m, is used as a tool to vary the (artificial) gravity and thus the amount of convection for a longer time than at the

parabolic flights to assure stable arc conditions.

To develop better lamps, the knowledge from the gravitational study can be applied to other parameters that influence the amount of convection. Examples in practice are changing the buffer gas pressure or the ratio between the length and radius of a lamp.

At $1g$ the radially and axially resolved density of ground state atomic Dy is measured by means of laser absorption spectroscopy. The radially resolved measurements show a hollow density profile with a maximum in the Dy density somewhere between the centre and the wall. In the outer region molecules dominate, while the centre is depleted due to ionization of Dy.

During the parabolic flights, line-of-sight density profiles of atomic ground state dysprosium were obtained at one axial position of the lamp by means of one-dimensional laser absorption spectroscopy. These profiles are a measure for the amount of axial segregation. The measured lamp voltage and integrated light output are in agreement with the results for the dysprosium density. Three processes with different time constants play a role when switching from hyper-gravity to micro-gravity. Axial diffusion is the slowest, and its time constant ($\sim$30 s) is proportional to the amount of mercury. As a result, at the end of the micro-gravity phase the lamp still is not in equilibrium.

The novel Imaging Laser Absorption Spectroscopy (ILAS) obtains the 2D ground state atomic dysprosium density distribution in the lamp. The measurements of the Dy density by ILAS clearly show that the setup and measurement technique are a useful tool to get more insight into the lamp.

The theory of E. Fischer gives the amount of axial segregation as a function of the amount of convection for an infinitely long lamp. This model is extended for our lamps, which are of finite length and have an axial temperature gradient. A change of temperature shifts the chemical equilibrium between salt molecules, atoms and ions. From this extended model the corrected Fischer parameter λ_c is introduced, which only has physical meaning when the temperature influence is not dominant. The axial inhomogeneity parameter α gives the non-uniformity in axial direction of any lamp property. We use it to describe the axial inhomogeneity in the additive density.

Various lamps with Hg and DyI_3 are measured by ILAS. The corrected segregation parameter λ_c presented in this thesis follows the predicted behaviour by Fischer better than the Fischer parameter λ, which does not take the temperature influence into account. The various lamps are on different positions on the Fischer curve. Furthermore, at $10g$, short lamps show the highest Dy density at the top of the lamp, caused by the dominant temperature effect.

The ILAS setup is accurate, but has been implemented for a particular geometry of the MH lamp and DyI_3 as salt filling, and can not be easily converted to other lamps. In addition, an easy and fast emission spectroscopy method is introduced, which derives axial intensity profiles for any wavelength of interest. From the line intensities the axial intensity inhomogeneity is deduced directly at different gravity conditions. The results obtained by using this technique are in agreement with the ILAS results for lamps with DyI_3, and next applied to the commercial Philips CosmoWhite lamp with a different salt mixture.

The ILAS measurements are compared with results obtained by numerical modelling with the TU/e plasma modelling platform PLASIMO and show good agreement. The competition between convection and diffusion is understood quantitatively.

In conclusion: the measurements on the MH lamps in this thesis are successful and are a set of reliable and consistent data. The results obtained by experiment and model are in agreement; the set of measurement data can be used for validation of future numerical models.