X-ray Absorption Imaging for Analysis of Gas Discharges in Energy-Efficient Lighting

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Over the last 10 years, we have examined the capabilities and pitfalls of x-ray absorption imaging and x-ray induced fluorescence as research and development tools for the lighting industry. Our efforts have focused on applications to high-intensity discharge (HID) lamps, a technology that is widely used for general purpose lighting because such lamps are capable of excellent color-rendering at high luminous efficacy. Major and minor lighting companies have substantial research efforts aimed at further improving HID lamp technology including advances in luminous efficacy, lifetime, and lamp-to-lamp uniformity. We have collaborated with several of these companies, seeking to use x-ray techniques to better understand the physics and performance of HID lamps. Here, we will discuss our work with x-ray absorption imaging.

We have found x-ray absorption to be primarily useful for measuring the distribution of the hot vapor in operating lamps. (2 pictures – cartoon and photo) The vapor distribution subsequently enables the determination of the discharge temperature distribution. As high-intensity discharges are, to varying degrees, in thermal equilibrium, the temperature is a fundamental parameter from which many other important quantities may be, partially or wholly, derived. These include spatially-resolved conductivity, chemical equilibrium, and spectral radiance.

Figure 1. A high-intensity discharge lamp with a ceramic arc tube.

HID lamps consist of a sealed fused silica or ceramic arc tube that contains a high-pressure, high-temperature discharge. Although the lamp is usually dosed with variety of metal additives for improving color and other properties, the vapor in the operating lamp consists primarily of mercury. Typical operating characteristics include mercury vapor pressures of 1 to many atmospheres and temperatures ranging from 1000 K to 7000 K. The additives make up less than 1 % of the vapor phase. A significant challenge is to quantitatively determine mercury mass densities that are more than 1000 times smaller than the mass density of the arc tube containing the mercury.

I will discuss why we prefer to use a tube source instead of synchrotron radiation, how we deal with the broadband spectrum of a tube source, the impact of scattering, different detection schemes, data analysis, and practical limitations on sensitivity, spatial resolution, and time resolution.