Long-Life True-Color Projection Displays Using LIFI™ Light Sources

A new light source developed for projection displays utilizing radio-frequency (rf) electrode-less plasma technology makes possible low-étendue light sources utilizing metal halides without the adverse chemistry associated with refractory metal electrodes. The results are projection-display applications that have long stable lifetimes (without re-lamping) plus wide color gamuts and fast start times. This article outlines the basic high-intensity-discharge (HID) physics and chemistry that enable high-brightness wall-stabilized plasma sources with excellent color rendition in fused-silica envelopes.

by Richard P. Gilliard, Abdeslam Hafidi, and Apurba Pradhan

THE NEED for a practical high-brightness white-light source in projection-display applications has previously required a trade-off between shorter lamp life and limitations in spectral output. As a result, conventional light sources to date have had limitations in spectral output (low in red) as well as the need for the replacement of the light source within the lifetime of the projector or television.

The recently introduced LIFI™ technology has opened the door to structurally reliable plasma light sources without the degradation mechanisms related to conventional lamp electrodes. It has also enabled a much-improved light-source chromaticity not limited to the high-pressure mercury or high-pressure xenon spectrum. This new light-source technology enables the use of high-efficacy metal halides in high-brightness electrode-less lamps in compact arc applications. The result is a lamp operating at 170 W

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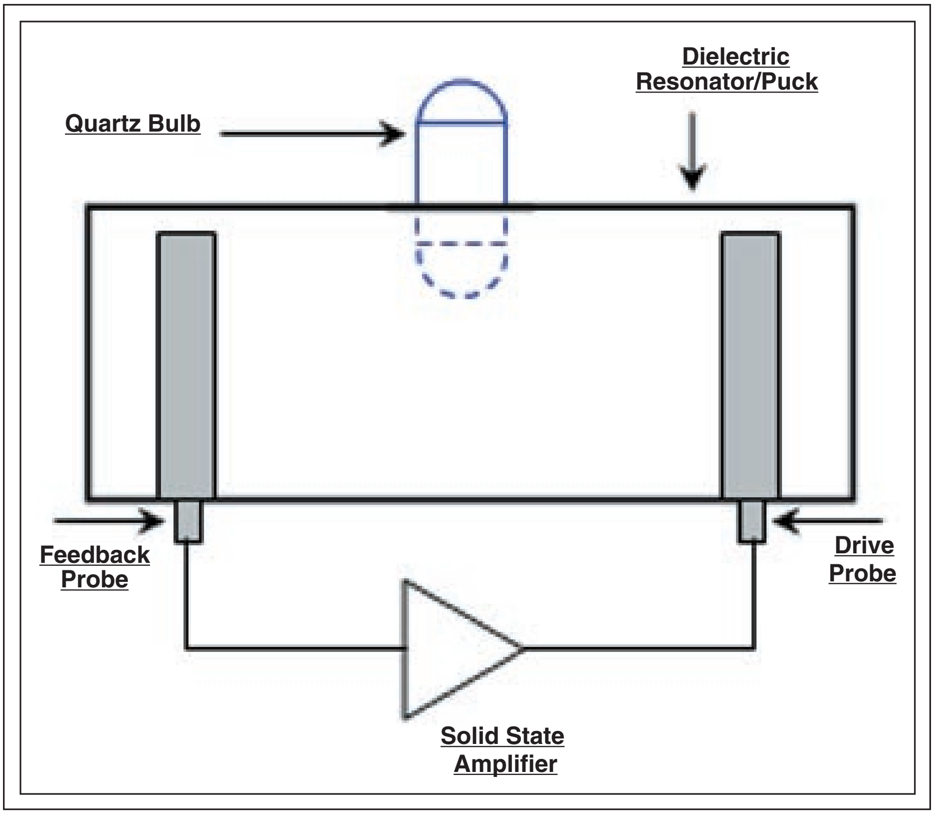

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***Fig. 1:** Schematic of the electrode-less lamp.*

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Fig. 2: *LIFI™ bulb and puck.*

that delivers 5500 lm into an étendue of 27 mm^2-sr.

Due to the continuous spectrum of metal halides, these electrode-less lamps offer a saturated color gamut and significant advantages when color balancing at the cinematic white points compared to the relatively incomplete spectrum of the high-pressure mercury lamps. The flexibilities offered by this lighting mechanism to bulb pressure and fill allow rapid start times, typically less than 10 sec – conventional projection-display light sources often require more than 60 sec to warm-up. These improvements in the performance and lifetime greatly improve the viewing experience of projection high-definition television (HDTV).

Products using the design described below are the first successful applications of electrode-less lamp technology to display applications with lumen maintenance of greater than 80% at 25,000 hours. In the application, this level of lamp performance produces more than 400 lm from a typical microdisplay projection engine, satisfying the brightness needs of HDTV sets up to 71 in. on the diagonal. In January, Panasonic introduced two lines of microdisplay projection TVs – the LCZ and LCX 50-, 56-, and 61-in. models – utilizing the LIFI™ lamp technology.

Lamp Configuration

The electrode-less lamp[1] consists of a quartz bulb configured in a high-dielectric constant cavity coated with a conductive material, operating as a surface-wave sustained rf discharge. The device is driven by an rf circuit. A schematic of the lamp is shown in Fig. 1.

A photograph of the bulb and puck (dielectric resonator) is shown in Fig. 2. Figure 3 shows the actual bulb (capsule).

Using Radiative Materials

The choice of radiative materials for use in a compact electrode-less light source involves a number of considerations. First, the materials must be compatible both chemically and physically with a very compact vessel. Specifically, a compact source must produce an arc size on the order of 1 × 3 mm or less. Without the use of electrode tips to define the geometrical extent of the plasma, the electrode-less lamp must rely on the walls of the arc vessel and the electric-field configuration to define the geometrical dimensions of the arc. This may necessitate extremely high pressures and wall temperatures on the arc vessel. Clearly, radiative materials that can efficiently convert electrical power to visible radiation without extremes of pressure and wall temperature are preferable.

In accordance with the basic principles outlined in Ref. 2, metal-halide additives were chosen that have the following characteristics: high vapor pressures at typical wall temperatures (1000 K and above); low vapor pressures at room temperature; low chemical reactivity with wall material (in this case fused silica) at operating wall temperature; chemical stability at wall temperatures, but fully dissociated at core temperatures (~6000 K) so as to emit the characteristic atomic spectra of the metals; and emission of high-intensity visible atomic and in some cases molecular spectra at typical core temperatures and vapor pressures.

The list includes many additives such as iodides and bromides of sodium, indium, thallium, scandium, and lithium, as well as halogens of various rare-earth metals such as thulium and dysprosium. The reaction of rare-earth halides (specifically iodides) with fused silica has been investigated by van Erk and Rietveld.[3] Their conclusions when iodine is the halogen include the following:

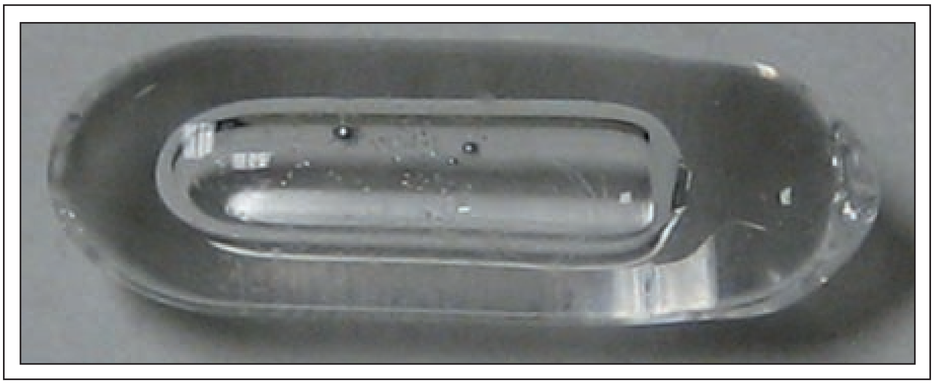

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Fig. 3: *The electrode-less bulb.*

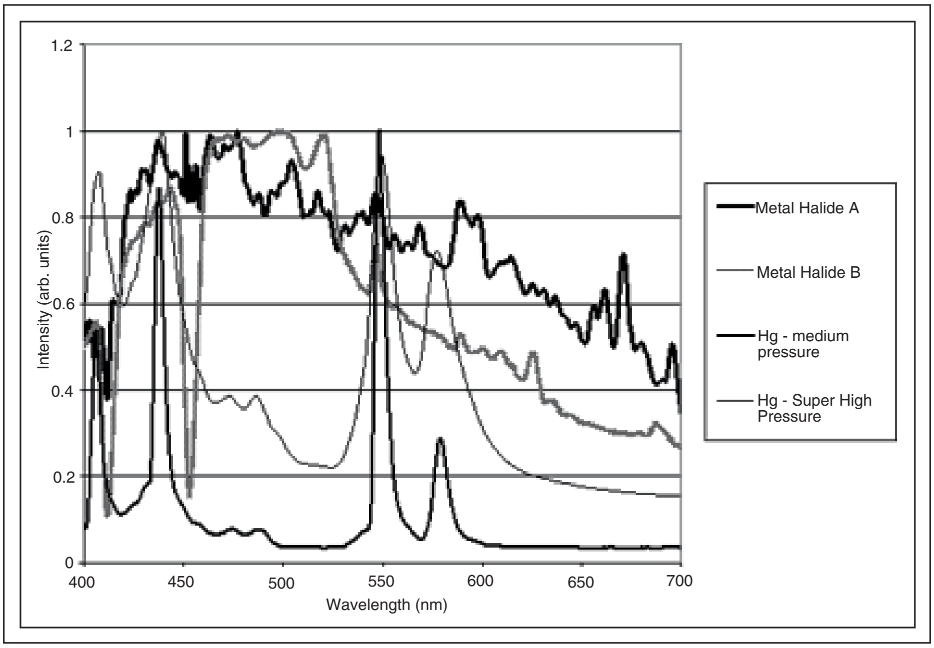

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***Fig. 4:** Collected spectral output in 27 mm^2-sr for halides of various metal combinations for the electrode-less lamp.*

- The relative rankings of four commonly used metal halides (mostly rare-earth) in terms of the aggressiveness of their reactions with fused silica are scandium (most aggressive), thulium, and dysprosium (least aggressive).
- The effect of creating molten salt mixtures of more-reactive metal halides with halides of other metals such sodium or thallium can be the formation of stable complexes in the gas phase which, in the case of $NaScI_4$, results in greater stability and less reaction with the silica wall.
- Thermodynamic considerations dictate the need for an optimal balance between high vapor pressures of dosed materials and lower wall temperatures to slow adverse reaction rates.

Experimental Results

An important feature of the LIFI™ lamp is the high rate of heat conduction from the arc vessel enabled by the close proximity of the dielectric resonator to the fused silica bulb. This results in significantly lower wall temperatures at higher wall loadings than conventional high-intensity discharge (HID) lamps. [The presence of refractory metal electrodes in a conventional HID vessel results in a multitude of problems, including wall darkening caused by evaporation of tungsten and transport to the discharge envelope wall because of operating temperatures that are generally greater than 2000°C; serious electrode deformation due to the transport of silicon from the interior wall to the electrode tips causing an increase in arc length, arc displacement, and flicker; and the need to use glass-to-metal seals (*e.g.,* molybdenum foils), which become potential failure points in the discharge vessel, particularly at very high operating pressures.]

In the electrode-less lamp, hot-spot outer-wall temperatures in the 800–900°C range were achieved with some external air flow despite inner wall loadings of greater than 250 W/cm^2. The use of compact arc vessels, an innovative means of embedding the bulb in the resonator, and an efficient optical design in turn enable high-brightness wall-stabilized arcs confined to a small volume for low-étendue applications.

We constructed experimental lamps using many individual metal halides with and without mercury as well as their combinations to include iodides and bromides of indium, thallium, aluminum, and a variety of rare-earth elements such as cerium, gadolinium, dysprosium, holmium, and thulium. We generally do not use alkali metals because of their propensity for being removed from the halide pool over time. Typical spectra from lamps made using various metal halides collected in an étendue of 27 mm^2-sr are shown in Fig. 4.

The absence of electrodes in the lamp enables greater flexibility in the use of more-reactive doses without wall darkening, flicker, and a change in arc-size. As a result, in many cases there are essentially no degradation mechanisms for the arc vessel itself. Figure 5

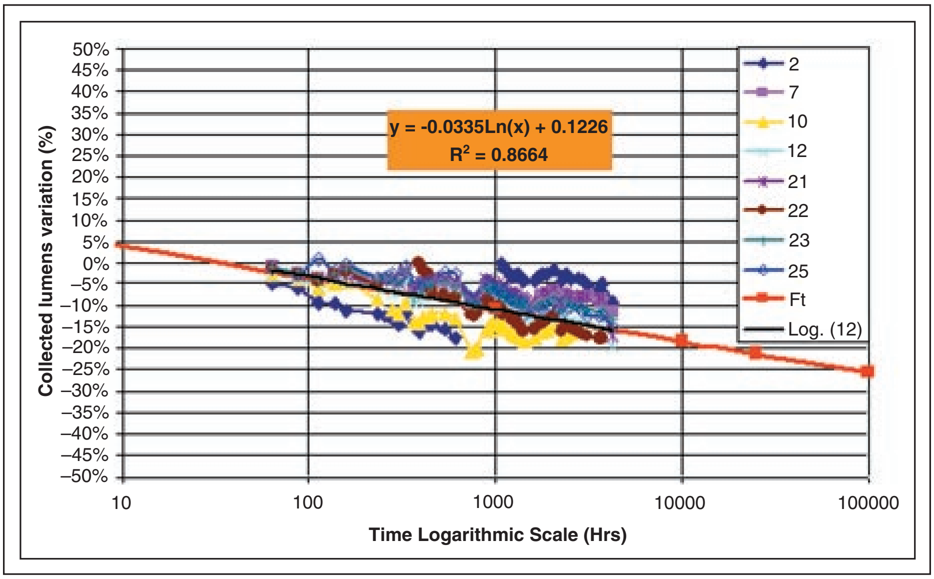

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***Fig. 5:** Lumen maintenance curves for the electrode-less lamps*

shows typical lumen-maintenance curves for lamps as they age.

Conclusion

Emerging projection-display applications that utilize this new light source that lasts for years have a wide color range and fast start times. In order to enable this performance, the LIFI™ lamp technology effectively uses metal halides in high-brightness compact arc applications through highly loaded wall-stabilized electrode-less discharges. The result has been long-life lamps. The absence of electrodes and glass-to-metal seals eliminates the primary failure and degradation mechanisms of standard HID lamps. Embedding the quartz bulb into a dielectric waveguide not only provides an efficient means of power delivery, but also results in a favorable heat sinking of the quartz body which in turn makes possible higher wall loadings (and more compact wall stabilized arcs) than is the case for lamps operating in air or in sealed jackets.

Acknowledgments

The authors acknowledge the helpful inputs of many that include J. Waymouth, R. Shaffner, C. Joshi, T. McGettigan, M. DeVincentes, G. Hollingsworth, M. Duelli, P. Sagala, T. O'Halloran, and P. Lamond, through the course of development of the arc vessel and dose.

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