BY **MIKE WOOD**

How do Plasma lamps work?

I HAD SUCH A POSITIVE RESPONSE to my articles last year on how LEDs work that I thought I'd continue this as an occasional series and look at how light is produced in other sources. With the world's push towards energy efficiency we have seen significant R&D investment over the last few years in both the development of new light sources, and in improvements to existing ones. LEDs, of course, are the most prominent example, but there are other new sources such as OLEDs and plasma lamps as well as notable efficiency improvements to our old friends the incandescent and HID lamps.

". . . it's the oldest form of lighting in existence . . ."

For this article I'm going to look at the microwave energized high efficiency plasma lamps—sometimes called LEP or HEP. Now, you may recall that the name "plasma lamp" has been used at least a couple of times in the past. First, there were those large glass globes sold in novelty stores with ethereal multi-colored glowing filaments extending out from a small central sphere. Great for Halloween decoration and science fiction movies, but not much use as illumination. We aren't talking about those. Then there were the plasma lamps that appeared in the nineties that used microwave energy to excite sulfur and argon gas contained in slowly revolving 25 mm diameter quartz spheres. They were pushed hard for a few years and enjoyed some limited success in wide-area architectural lighting, but, unfortunately, were pretty much a commercial failure and all but disappeared by the end of the millennium. Even though they've made a little bit of a comeback in recent years in some areas, they aren't the lamps we are going to discuss here either. The high efficiency light emitting plasma lamps (LEP) used in some of today's entertainment lighting products have the name (and perhaps a trace of argon) in common with the older lamps of the same name, but that's where the similarities end. In fact, the current breed of LEP lamps arguably have more in common with the high intensity discharge lamps we use in follow spots and automated lights.

Note: I know of at least three current manufacturers of microwave energized high efficiency plasma lamps, Luxim, Tonanaga, and Ceravision. However, at the time of writing, it is Luxim who seem to have made the largest inroads into the entertainment lighting industry in this country so much of this article is based around their technology. The main concern of the article is with general principles of operation only and, as I understand it, the basic theory behind the lamps from all three manufacturers is very similar. They differ in the specific construction, operation and the secret sauces embodied by their distinct devices. There is no short name in common use for the technology at the moment so I'm using the initials LEP as a generic term referring to this particular technology and not to any particular manufacturer.

". . .what about any spare microwaves that leak out?"

So why are they called plasma lamps? It is perhaps a little bit of a strange name to choose. Although they undoubtedly produce a plasma, so do many other lamps, including HID, neon, fluorescent lamps, and even carbon arcs. Plasma is a generic term describing a fourth state of matter, along with solid, liquid and gas, and describes a high temperature, electrically conductive, ionized gas. The sun, stars, and lightning are all plasma sources so it's the oldest form of lighting in existence—familiar to man since the dawn of time. In all cases the extreme temperature and high energy of the plasma excites light output from fundamental particles.

Comparing HID and LEP lamps: both types use a quartz capsule, and both emit light from a plasma of superheated gases formed within the quartz envelope. The gases in both cases are a vaporized mix of various rare earths, metal halides, and other materials chosen for the mix of spectral lines and light output they produce when in the plasma state. What makes these lamps different is the way that plasma is produced. In HID lamps it's a high voltage electrical discharge between two electrodes enclosed within the lamp envelope, while in an LEP lamp there are no electrodes, and the plasma is formed by passing a high-intensity radio frequency or microwave field through the envelope. In both cases, the result is a large amount of energy in a small space coupled with strong electrical fields, which results in very high temperatures, vaporization of the chemicals, and the formation of a plasma. The absence of electrodes is cited as a big plus for the LEP lamp because electrodes, and the seals and pinches where they enter the quartz envelope, constitute a weak spot in normal HID lamps, and represent one of the primary sources of eventual failure if those seals break down. The need to keep the pinches cool and separated from the heat also means that the quartz envelope has to be relatively large. In the LEP lamp, however, there are no electrodes, so the envelope is continuous and unbroken without weak points. Accordingly, it can be a lot smaller and can run at higher pressures, which helps with broadening the spectral lines.

Figure 1 – LEP lamp module

Figure 1 shows a typical LEP lamp with a tiny central quartz capsule surrounded by the microwave resonator and a large heat sink. **Figure 3** shows in more detail what's going on inside. The quartz capsule illustrated in **Figure 2** contains a mixture of gases including argon, rare earths, and a small dash of mercury to help get things going. It's sealed at the bottom into a solid tail of quartz, which is used to help align the capsule in the resonator. There are no electrodes of any kind. The capsule is surrounded by a block or puck of alumina ceramic dielectric material, which, although opaque to visible light, is transparent to microwaves and forms a resonant cavity. Microwaves are fed in through a coaxial cable or waveguide from the RF driver and internal reflections within the puck both guide and magnify the microwaves so that they form a standing wave pattern. The cavity is shaped (and that shape is part of the secret sauce I'm sure) such that the maximum field strength is in the center, surrounding the quartz capsule, as represented in **Figure 4**.

Figure 2 – Quartz capsule

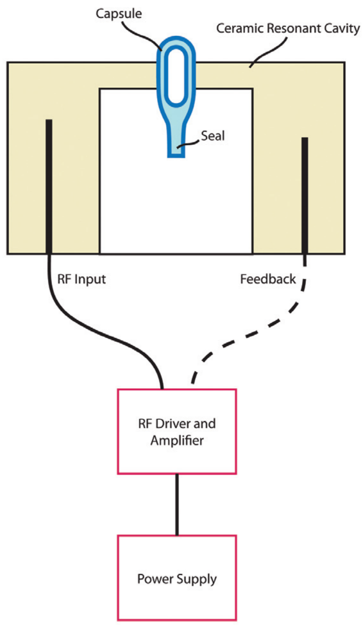

Figure 3 – System diagram

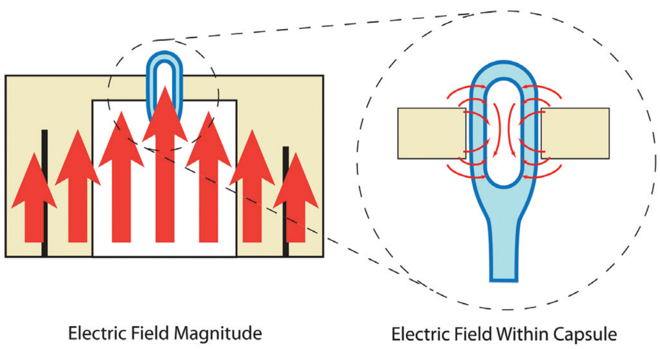

Figure 4 – Standing wave pattern

Note: The actual frequency used for the microwaves in an LEP lamp is not critical as plasma can be excited over a wide range. Current commercial LEP lamps tend to use the 450 MHz and 900 MHz bands to excite the plasma because those frequencies are well served by readily available amplifiers produced for use in the cell phone and communications industry. As the market grows and the LEP lamp manufacturers are able to produce their own dedicated amplifiers it is likely that the frequencies used will lower as RF amplifiers get more cost effective and efficient at lower frequencies.

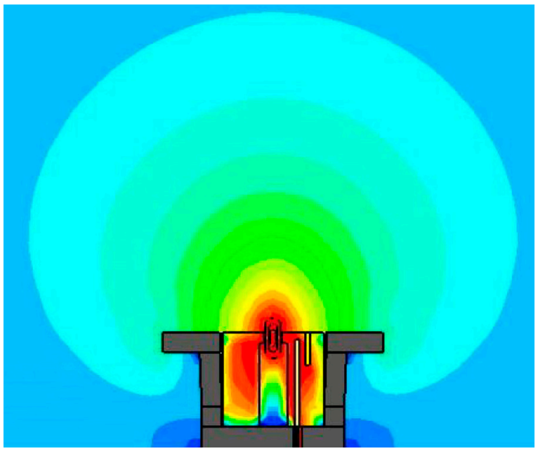

Figure 5 – Microwave field

A simulation of the RF energy circulation can be seen in **Figure 5**. The red areas show the maximum energy concentration within the ceramic resonator and through and around the lamp capsule. You can also see the diminishing emitted radiation indicated by the yellow, green, and blue areas. That high field strength induced within the lamp capsule injects large amounts of energy into the enclosed gas which heats up and ionizes very rapidly. This super heated ionized gas, or plasma, with a temperature of around 6000 K, circulates around the capsule driven by the induced electric field and evaporates the pool of metal halides at the bottom of the capsule. You now have a plasma cocktail, **Figure 6,** of ionized gas and metal halides, which emits light in the same manner as those in a regular HID lamp. Reflective powder is used behind the lamp capsule to direct light forwards and out of the lamp.

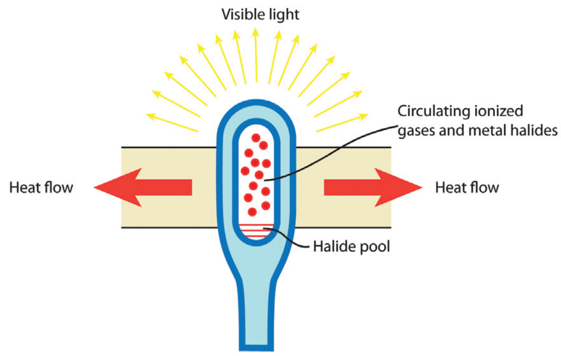

Figure 6 – Plasma formation

The axial electric field direction and shape tends to keep this plasma in a central column, away from the walls of the capsule, which helps in keeping the capsule cool. **Figure 6** also shows that the alumina ceramic dielectric performs another service, that of a heat sink to draw heat away from around the walls of the quartz capsule keeping them at around 1100 K or less.

The LEP manufacturers claim that this field shape, cool capsule walls, and the lack of electrodes and their associated, undeniably problematic, pinches offer significant advantages over conventional HID metal halide lamps. Certainly pinch failures where electrodes enter the quartz and devitrification (quartz crystals forming at high temperatures producing the familiar milky translucent spots on the envelope) are the most common failure modes for HID lamps.

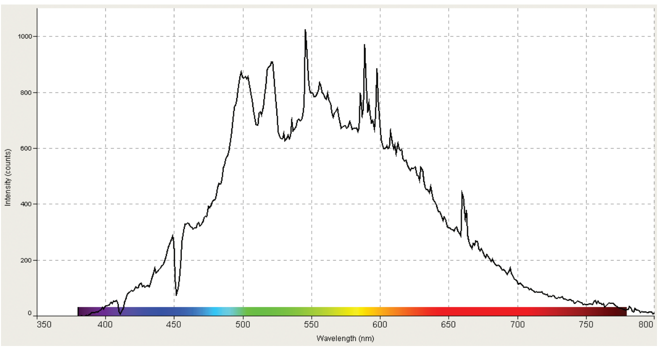

Figure 7 – Measured spectrum

Figure 7 shows the output spectrum that I measured from a luminaire fitted with an LEP lamp. This was measured at the output of the luminaire, after it has travelled through all the optics and lenses, so it will likely be slightly different than the raw lamp spectrum. Even though it's still fairly spiky, the spectrum is almost continuous, with just a couple of missing narrow frequency bands around 420 nm and 450 nm. This provides a published CRI of 94.

Okay, we now know where the microwaves go in and where the light comes out, but what about any spare microwaves that leak out? Are they dangerous? Although the bulk of the microwave energy is constrained within the lamp and the ceramic you can clearly see from **Figure 5** that there is some leakage from the front of the lamp that has to be taken care of in the luminaire design. Fortunately this high frequency emission is relatively easy to control, and luminaire manufacturers are dealing with it in different ways. However, the control and measurement of radiation leakage needs to become part of the expertise and design process for any manufacturer utilizing an LEP lamp. Most engineers have at least some familiarity with designing for EMC, and this is just an extension of that philosophy.

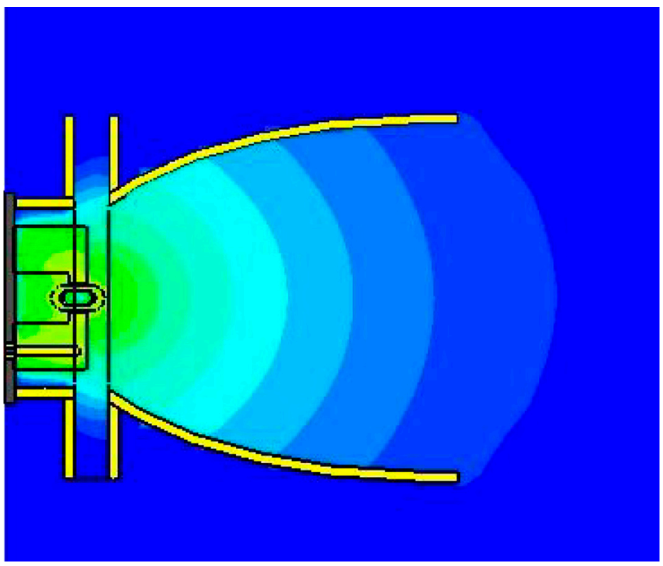

Figure 8 – RF Attenuation with metal reflector

One of the easiest ways to control RF leakage is to closely couple an electrically conductive metallic reflector to the lamp source, something you may want to do anyway for the optical system. If this reflector is sufficiently long and narrow, as shown in **Figure 8**, it will form an effective attenuator and drop the microwave leakage to acceptable levels. Another technique used by an entertainment lighting manufacturer is to use a TIR lens with an embedded wire mesh grid. At the wavelengths being used a simple 2mm mesh can provide as much as 50 dB of field reduction—take a look at the glass window in the microwave oven in your kitchen to see this technique in use.

Optically the lamp capsule provides both benefits and problems for the optical designer—the main benefit is that the source is very small which makes for efficient optics. On the problem side you can see that the designer has no access to, or control of, the reflector behind the lamp capsule and has to do all his work in front of the lamp. This isn't dissimilar to the problems presented by LED sources where, again, you can't get behind the light source and, indeed, some of the same solutions, such as TIR lenses, are being seen in both cases.

Will LEP lamps succeed in an increasingly competitive light source landscape? They are clearly efficient sources with some advantages, but it's their long life that could tip the scales. At the moment, it's still early to see if the claimed longevity is borne out in real entertainment luminaires with the rough treatment they receive, and if LEP lamps can carve a niche amongst the other light sources, both the novel and the old friends, vying for our fickle attention. Only time will tell. ■

Figures 1, 2, 5, and 8 courtesy of Luxim Corporation.

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