Gap Closure in a Cold Metal Halide Lamp

Brian Lay, Shahid Rauf, and Mark J. Kushner

***Abstract*—The breakdown of a cold metal halide lamp has been investigated using a two-dimensional, plasma transport model. Images are presented of the electron density during the trigger and sustain voltage pulses. Charging of the sidewalls of the lamp are found to be important during gap closure.**

***Index Terms*—Arc discharges, avalanche breakdown, glow discharge devices, lighting, plasma applications.**

METAL halide high-intensity-discharge (HID) lamps operate as high-pressure thermal arcs [1]. The cold fills of HID lamps are typically 50–100 torr of a rare gas, usually argon, and a dose of the metal or metal-halide salt. The vaporized metal (-halide) produces the multiatmosphere plasma which is the source of quasi-continuum radiation. Although the steady state voltage of the thermal arc is only tens of volts, many kilovolts are required to breakdown the cold lamp [2]. As excessively high breakdown voltages increase electrode sputtering, thereby reducing lifetimes, there is motivation for developing strategies for lamp starting which minimize the duration of large applied voltages. One method to reduce sputtering is to employ an auxiliary trigger electrode to preionize the gap.

To investigate startup strategies, a two-dimensional plasma transport model, based on that described in [3], has been developed. The improved model uses an unstructured mesh, gridded using Skymesh2 [4], discretized using finite volume algorithms. The transport equations for electrons, ions, and neutrals are separately implicitly solved simultaneously with Poisson's equation. Secondary electron emission by ion and excited state impact is included, as is thermionically enhanced electric field emission. Radiation transport is also included as a source of ionization. The species in the model are Ar, Ar(4s), Ar^+, Ar_2^*, Ar_2^+, Hg, Hg(6p) and Hg^+.

The cylindrical model geometry, shown in Fig. 1, is for a quartz discharge tube 2 cm in diameter with an interelectrode gap of 3.7 cm. The rod electrodes, 1 mm in diameter, have wire windings near their tips. A trigger electrode is a few millimeters from the lower electrode. The gas fill is 75 torr Ar and 0.08 torr Hg, corresponding to about 40 C lamp temperature. At 20 ns, a 70-ns wide -600 V pulse is applied to the trigger electrode while the powered (lower) and grounded (upper) electrodes are held at ground. At 115 ns, a 285-ns-wide -3500 V pulse is applied to the lower and trigger electrodes. Seed electrons are provided by electric field emission from the tip of the trigger electrode. The images were prepared using Tecplot v8 [5] and combined using Photoshop v5 [6].

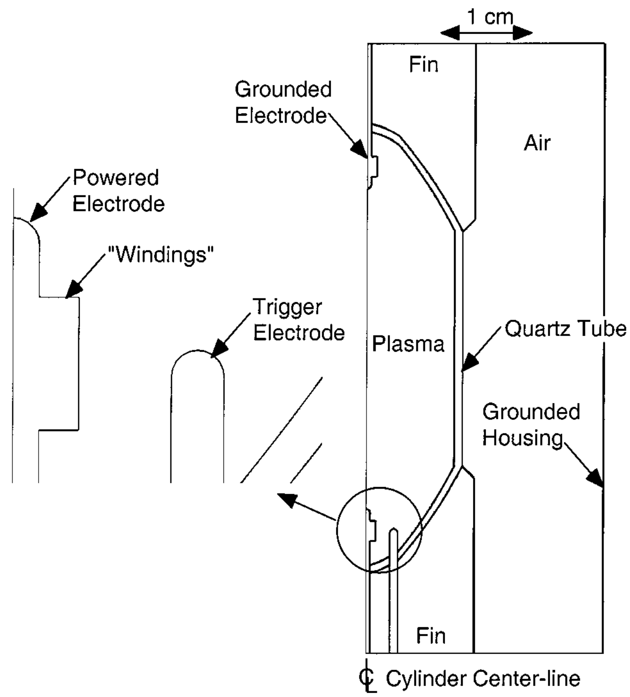

Fig. 1. Schematic of the cylindrical model lamp geometry.

Images of the electron density during gap closure are in Fig. 2. As the voltage ramps up on the trigger electrode, field emission from the trigger electrode tip produces seed electrons which drift toward the lower electrode (30 ns). By 60 ns, the electron density is rapidly increasing in the high electric field near the windings. During the interpulse period (105 ns), the electrons diffuse between the lower and upper electrodes. Upon application of voltage between the lower and upper electrodes (130 ns) an avalanche begins from the high electric field regions at the tips of the trigger and lower electrodes. At 180 ns, the avalanche front is first directed toward the upper electrode and radially outward (along electric field lines) toward the lamp wall. Charging of the lamp walls and reduction of the local electric field due to the increasing plasma conductivity redirects the avalanche toward the upper electrode (230 ns). By 280 ns, photoionization initiates an avalanche in the high field region between the plasma and the tip of the upper. Upon gap closure, a cathode (lower electrode) directed secondary avalanche occurs (345 ns).

Manuscript received June 28, 2001; revised November 2, 2001. This work was supported in part by the General Electric R&D Center and in part by the National Science Foundation under Grant CTS99-74962.

B. Lay was with the Department of Electrical and Computer Engineering, University of Illinois, Urbana, IL 61801 USA. He is now with Sun Microsystems, Chelmsford, MA 01824 USA (e-mail: Brian.Lay@sun.com).

S. Rauf was with the Department of Electrical and Computer Engineering, University of Illinois, Urbana, IL 61801 USA. He is now with Motorola Inc., Austin, TX 78721 USA (e-mail: Shahid.Rauf@motorola.com).

M. J. Kushner is with the Department of Electrical and Computer Engineering, University of Illinois, Urbana, IL 61801 USA (e-mail: mjk@uiuc.edu).

Publisher Item Identifier S 0093-3813(02)03070-9.

REFERENCES

[1] J. Waymouth, *Electric Discharge Lamps*. Cambridge, MA: MIT Press, 1971.

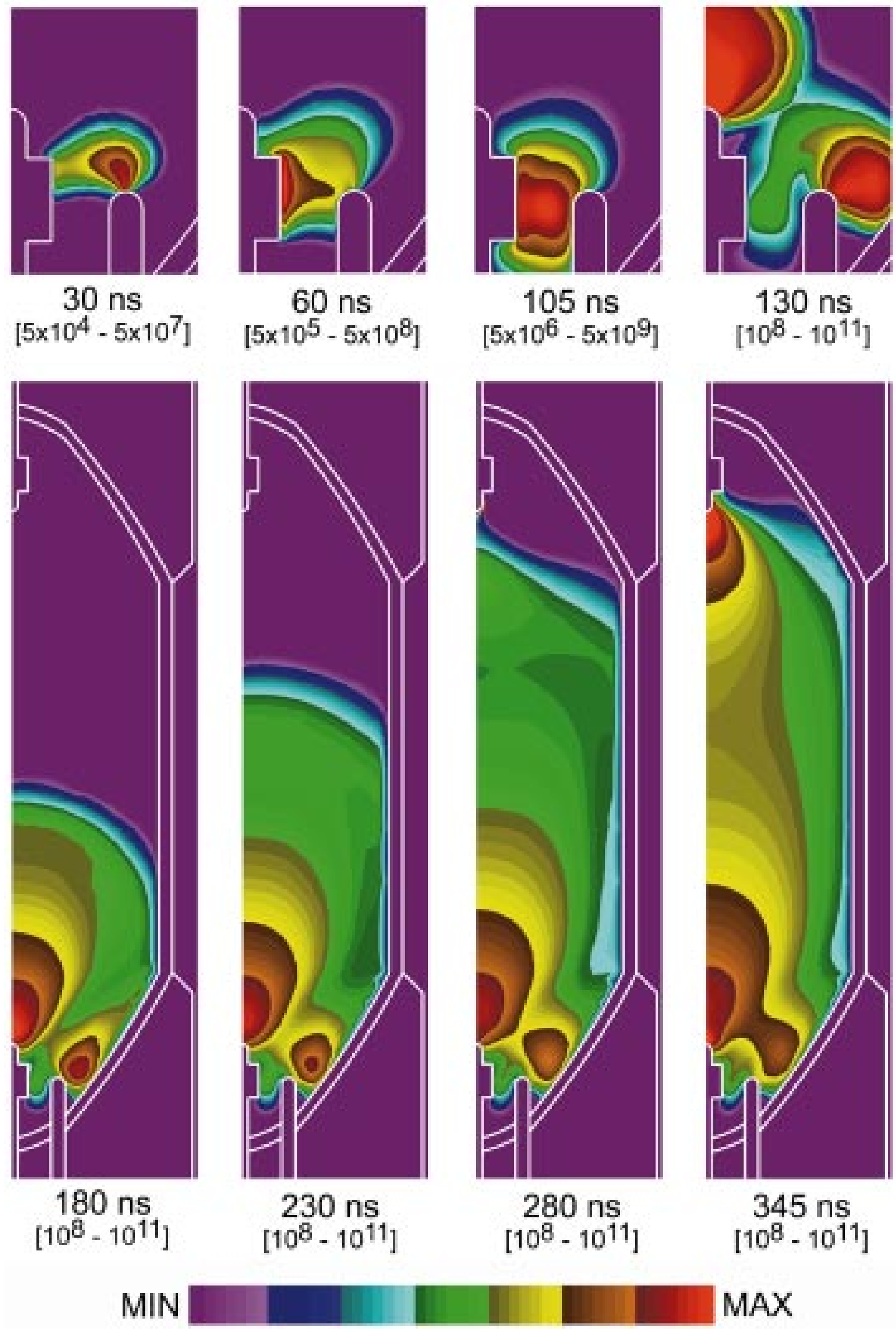

Fig. 2. Electron density at different times during gap closure as noted below each figure. The range (cm^{-3}) of the electron density in the figure is noted in the brackets. The trigger pulse ends at 90 ns. The sustain pulse begins at 115 ns and ends at 400 ns.

[2] S. Cohen, G. Zaslavsky, and J. N. Lester, "Pulse starting the 100-W metal halide lamp," *J. Illumin. Eng. Soc.*, vol. 18, pp. 3–9, 1989.

[3] S. Rauf and M. J. Kushner, "Dynamics of a coplanar-electrode plasma display panel cell. I. Basic operation," *J. Appl. Phys.*, vol. 85, pp. 3460–3469, 1999.

[4] Skyblue Systems., Delmar, NY. [Online]. Available: http://www.skybluesystems.com.

[5] Amtec Engineering., Bellevue, WA. [Online]. Available: http://www.amtec.com.

[6] Adobe Corp., San Jose, CA. [Online]. Available: http://www.adobe.com.