CST APPLICATION ARTICLE

# A MULTIPHYSICS APPROACH TO PLASMA LIGHTING SYSTEM DESIGN

*The plasma lighting system operates on radio frequency, which is in the ISM band, 2.45 GHz. This paper presents microwave simulation of a cavity and feeding system using CST® STUDIO SUITE®, with the goals of testing the electrical, magnetic, thermal and mechanical characteristics of the system design.*

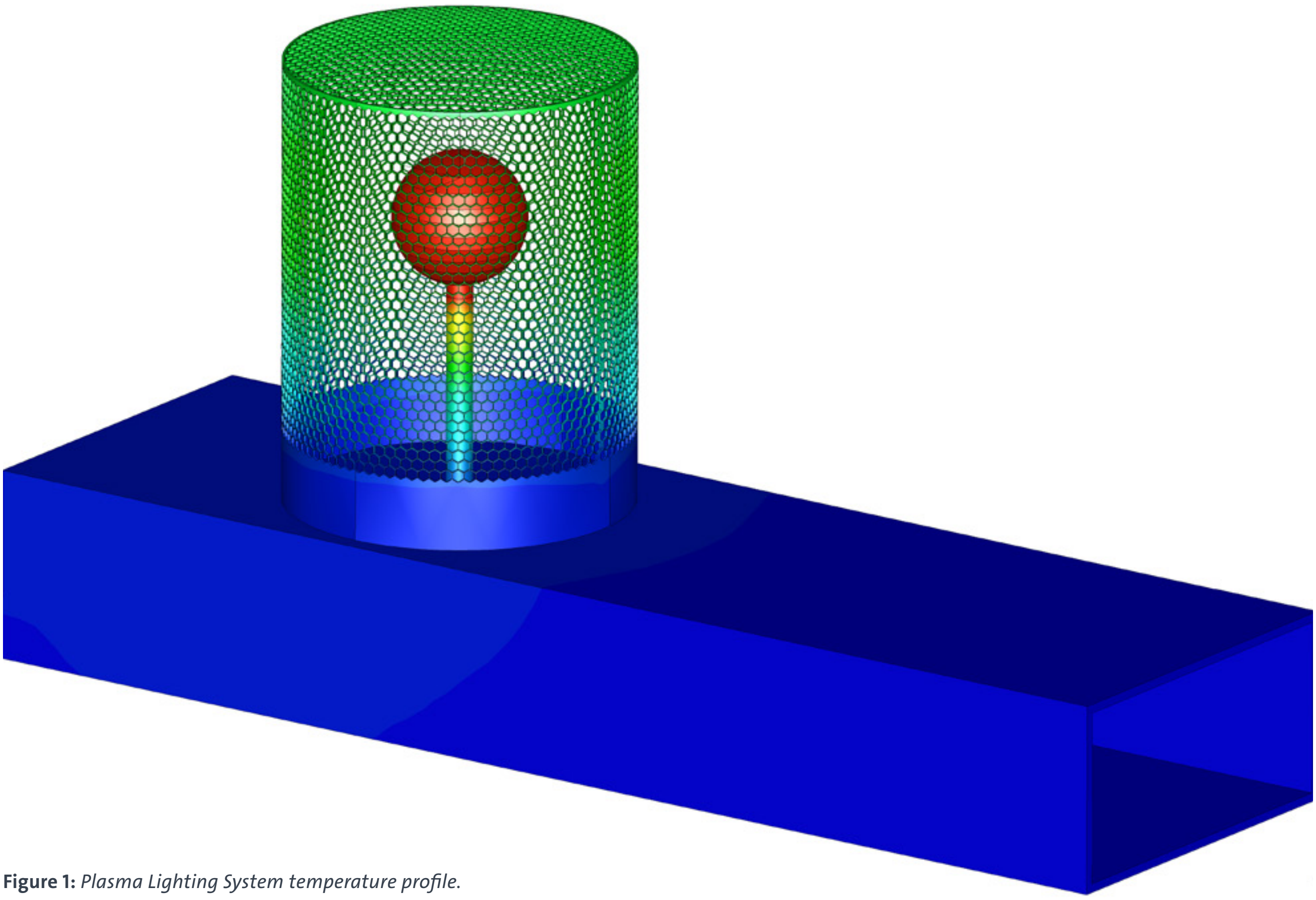

**Figure 1:** *Plasma Lighting System temperature profile.*

Plasma lighting systems (PLS) are increasingly widely used in daily life especially for outdoor systems. Plasma lighting offers a lot of benefits over traditional sources such as light emitting diode (LED) and traditional high intensity discharge (HID) light sources. Plasma lighting provides higher lumen density and offers a bright, high-quality sun-like spectrum which is pleasing to the eye and beneficial to photosynthesis in plants. Compared to metal halide and sodium sources, PLS lighting uses less energy and has lower costs. In addition, plasma lighting systems have a much longer lifespan, almost 20 times higher than traditional incandescent sources.

The challenges of the plasma system design are that resonant frequency changes after loading different dielectric material components to support the plasma light inside. The ones used in plasma lighting is radio wave generated by magnetrons at 2.45 GHz, which is also happen to be the same range as some short-range wireless communication system such as Wi-Fi and Bluetooth. Because of the high energies achieved, a well-shielded cavity is required to prevent leakage of RF fields causing injuries to operators or interference to other systems.

A mesh sheet can be placed right outside the cavity to shield the RF fields. However, this mesh also needs to have a good transmission so that the visible light can escape. There is therefore a trade-off between shielding and visibility, and mesh design is restricted by these concerns and other manufacturing constraints.

Another point that needs to be taken into account for safe operation is thermal and mechanical effects. The plasma releases a large amount of heat (Figures 1 and 2) and the thermal effect needs to be considered for all the materials of the different components. The temperature change will in turn cause mechanical changes. Thermal expansion can deform the device and reduce its efficiency or damage components, especially if parts are misaligned.

The properties of the material can be affected by temperature changes, such as thermoelectricity, strain, stress and displacement. For these reasons, the mesh needs to be made of a material with high melting point and good mechanical properties to resist to heat. In this article, thermal deformation and bending will be considered.

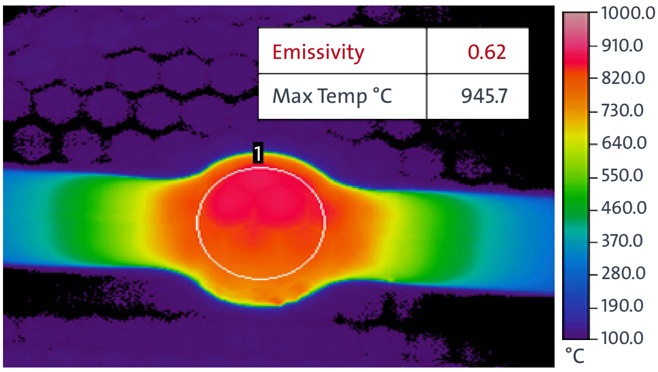


**Figure 2:** *Temperature measurement profile.*

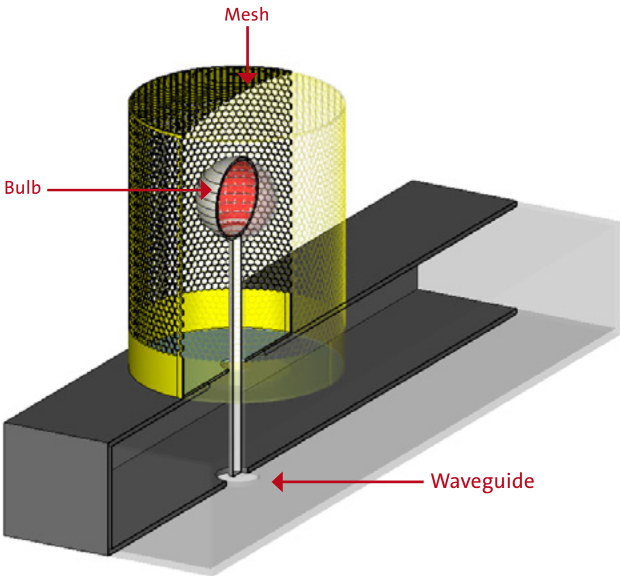


**Figure 3:** *Cavity design.*

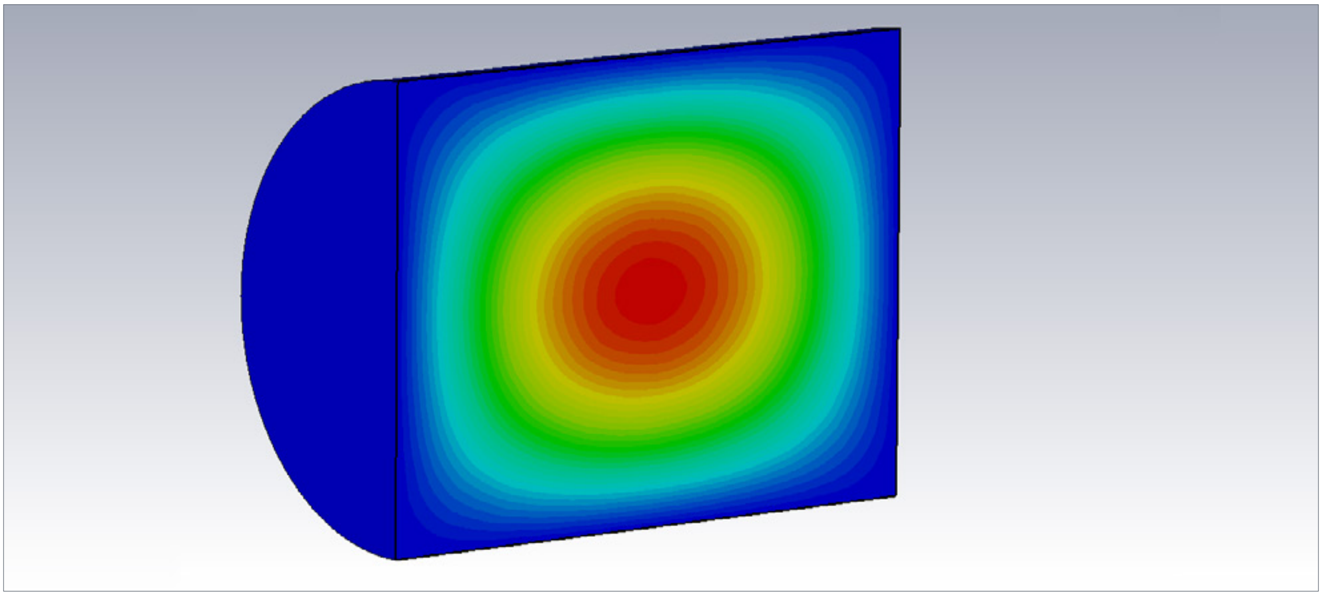

**Figure 4:** *TE111 mode with Eigenmode solver.*

## CAVITY DESIGN AND SIMULATION

The first step of the process is to design a cavity and waveguide connected by a slot. There are several ways of coupling to a cavity at microwave frequencies. In this article, a circular cavity resonator aperture coupled to a rectangular waveguide (Figure 3).

The cold resonant frequency can be found using the Eigenmode solver.

By changing the size of the cavity, the dominant resonant frequency can be adjusted to the desired value which is around 2.45 GHz as shown in Figure 4.

## PLASMA SIMULATION

The properties of plasma are different to those of unionized air, as shown in Figure 5 and Table 1. CST STUDIO SUITE includes ionizable material models which are critical for simulating plasma. A Drude material is used to model the plasma inside the device, as shown in Figure 6, and the system was simulated with the time domain solver. After adding the bulb, mirror and plasma, the resonant frequency shifted again, and this shift depends on the material inside the bulb. A higher dielectric constant results in a lower resonant frequency. Adjusting the slot size again and even the size of the cavity – for example, with a parameter sweep – can be used to get the resonant frequency to desired value. The output signal and excitation signal at resonant frequency can be found using a Fourier Transform from post processing template which can be easily applied with a CST STUDIO SUITE post-processing template.

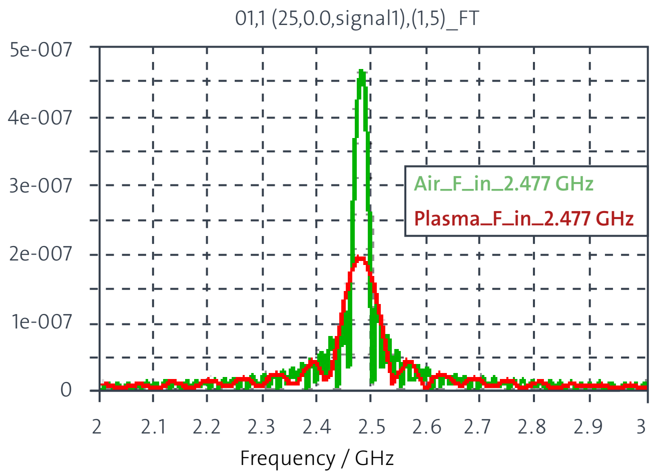


**Figure 5:** *Output signal from Fourier Transform, showing the effect of ionization on the resonance.*

| Bulb | Air | Plasma | Delta Freq. | |
|---|---|---|---|---|
| Frequency | 2,479 | 2,473 | 0.006 | Simulation |
| (GHz) | 2,464 | 2,456 | 0.008 | Measurement |

**Table 1:** *A comparison between a simulation and a measurement.*

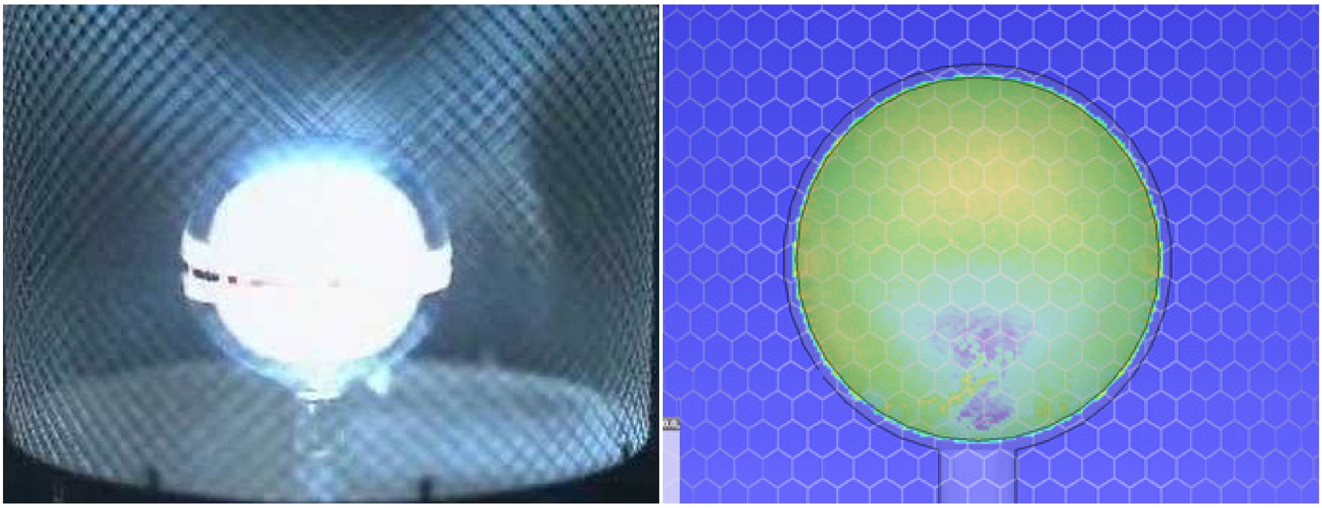

**Figure 6:** *Plasma photo and plasma monitor plot.*

## MESH DESIGN

The mesh will cover the whole area of the plasma light, so it is very important that the mesh can shield the RF field to prevent injury and interference. This mesh should work both for stopping microwave radiation and allowing visible light to get through. Mesh design is restricted by shielding effect, visibility and manufacturing constraints. The most popular mesh designs are circular, rectangular and hexagonal mesh (Figure 7). In this case, a hexagonal "honeycomb" mesh was used as it offers the best thermal properties and is robust against mechanical deformation. Depending the shape and thickness of the mesh, shielding effectiveness varies. The mesh thickness needs to be thicker than the skin depth in order to shield the RF wave effectively. Also, the diameter of the holes should be much smaller than the wavelength.

In order to increase the shielding effect, the line width needs to increase and hole size needs to decrease (Figures 8 and 9). However, this will decrease its transparency. A good mesh is one with both good visibility and shielding effectiveness.

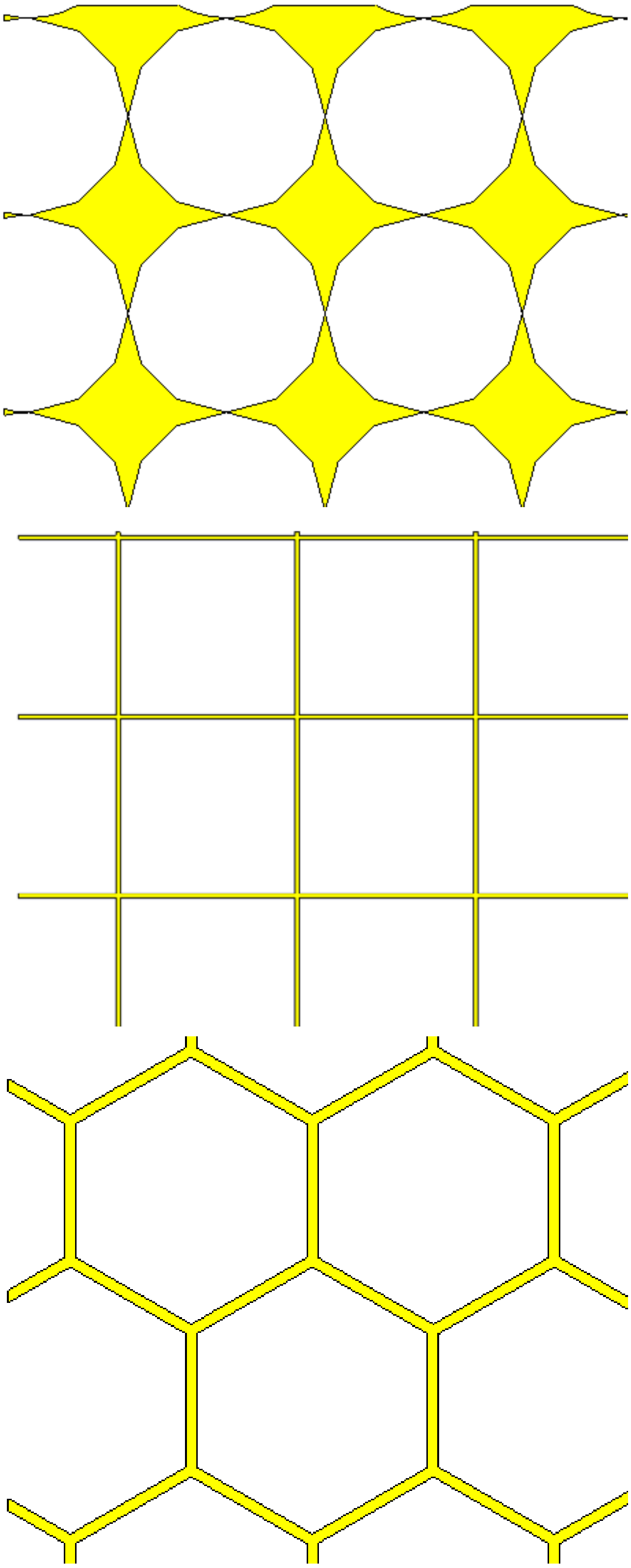

**Figure 7:** *Top: Circular. Middle: Rectangular. Bottom: Hexagonal.*

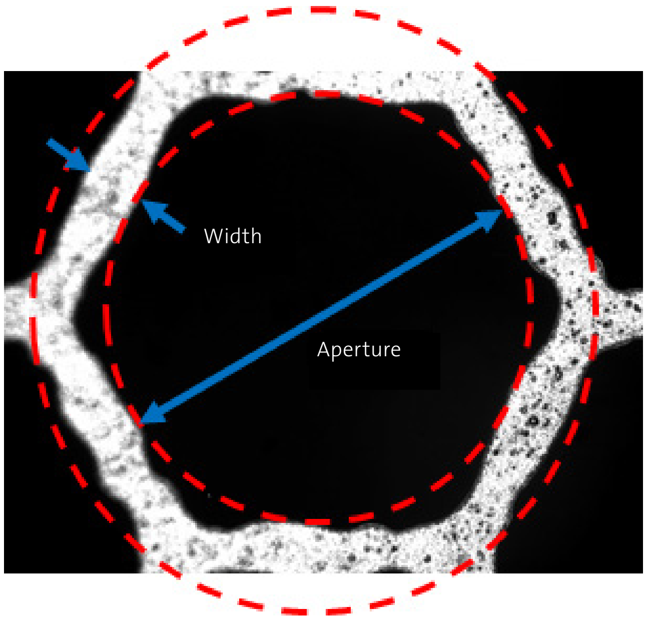


**Figure 8:** *Real mesh photo with two parameters.*

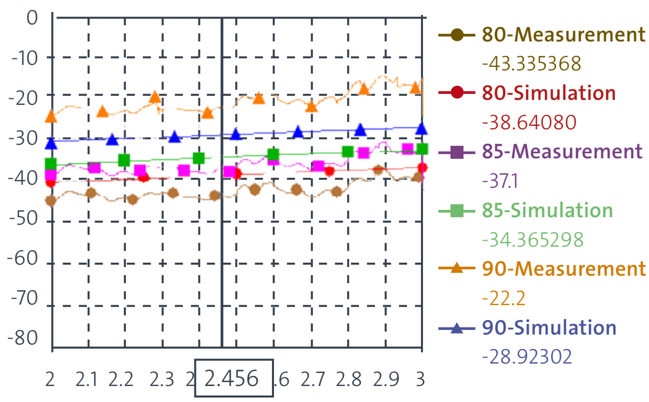


**Figure 9:** *Comparison of different mesh sizes.*

## THERMAL AND MECHANICAL ANALYSIS

The bulb transfers the generated heat of plasma from the RF field inside the cavity and toward the ambient environment. Temperature distributions and heat flows can be efficiently simulated using CST MPHYSICS® STUDIO. The stationary thermal solver calculates the steady-state temperature distribution when the device is in use (Figure 10).

In reality, not all the components are necessarily aligned perfectly (Figure 11). Studies of misalignment can be performed to see the thermal effect in different situation. Higher temperature may cause the mesh to be deformed or damaged especially when the mesh is misaligned (Figure 14).

The change in temperature can cause a corresponding change in the shape of the components, as they expand under heating. The mechanical solver in CST MPHYSICS STUDIO can be used to simulate the thermal expansion, using the temperature distribution calculated in the previous simulation (Figures 12 and 13).

A 3D model of the deformed mesh can be used to analyze that if the model is stable or safe to operate in such temperature profile.

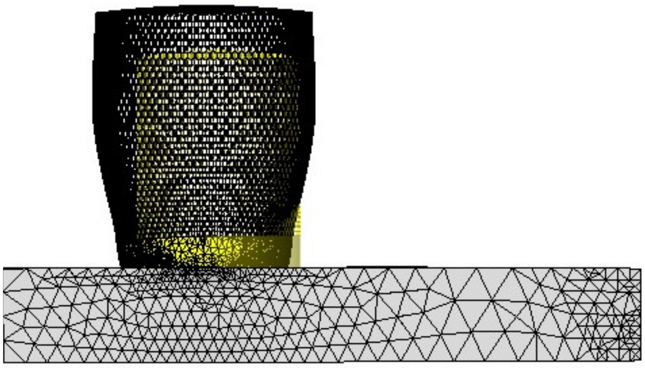

**Figure 12:** *Exaggerated deformation from mechanical simulation.*

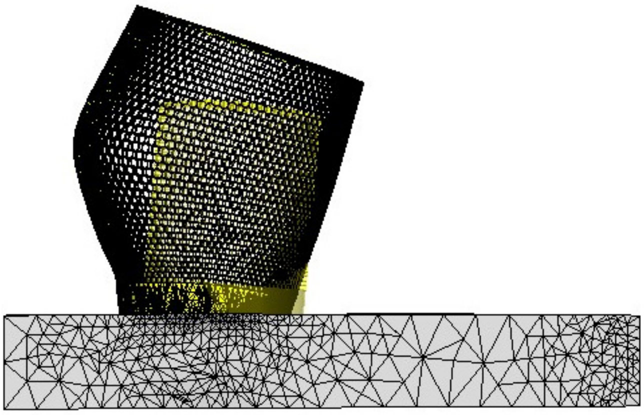

**Figure 13:** *Exaggerated deformation of misaligned structure.*

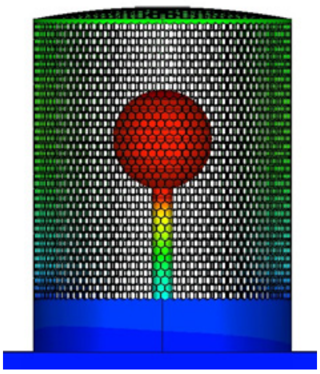

**Figure 10:** *Temperature profile of PLS.*

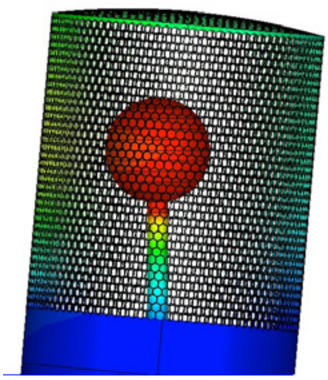

**Figure 11:** *Temperature profile of misaligned mesh (5° rotation respect to horizontal axis).*

**Figure 14:** *Hole on a mesh caused by misalignment.*

## CONCLUSION

The process of designing and testing plasma lighting systems is complicated. Electromagnetic simulation can be used to calculate and optimize the resonance frequency and develop shielding mechanisms. Different designs can be compared using parameter sweeps and optimization, helping the engineer to select the best dimensions for the design to fit in the situation. Thermal and mechanical simulations can check the heat flow and temperature profile to help identify possible mechanical causes of failure.

CST STUDIO SUITE provides a range of solvers in an integrated interface which can be linked together into a smooth workflow.

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## ABOUT CST