# LET THERE BE LIGHT: A BRIGHTER FUTURE FOR OLEDS

*Surface plasmon modeling and nanostructured electrode design show promise for increased light output and efficiency in organic LED (OLED) systems.*

By **LEXI CARVER**

**ALTHOUGH IT'S BEEN NEARLY** a century and a half since Thomas Edison flipped a switch to turn on the world's first practical light bulb, the search for better light sources continues unabated. Many other lighting technologies have been developed since that day in 1879, bringing features such as brightness, color quality, dimming capability, and low life-cycle costs.

Organic LEDs, or OLEDs, are attracting strong interest because they can be used in lightweight, paper-thin, light-emitting panels in a variety of shapes and sizes. They can be used to create flexible or bendable lighting devices applied to a flat or curved surface area to build parts such as car tail lights and even "lighting flowers" (see Figure 1).

But OLEDs aren't nearly as bright or as energy-efficient as their inorganic cousins, LEDs, and so researchers at Konica Minolta, Inc. are racing to develop designs to meet growing demand. The company is a world leader in OLEDs that supports the development of cutting-edge devices for imaging and optics, often working in partnership with Japan's leading universities.

Leiming Wang is a senior researcher at the Konica Minolta Laboratory USA in San Mateo, CA, working with a team that uses numerical simulation to analyze light-loss mechanisms in OLEDs to virtually test ways to improve designs. "Despite all their advantages, OLEDs suffer from a number of limitations we are working to minimize," he said. "Most impactful is a complex plasmon coupling phenomenon accounting for 40% of the light lost through interactions within the device."

## » HOW OLEDS WORK

**OLEDS ARE COMPOSED** of organic semiconductors sandwiched between positive (anode) and negative (cathode) electrodes. Figure 2 shows the layout of an OLED device, with an anode made of transparent indium tin oxide (ITO), three organic layers — a hole transport layer (HTL), emitting layer (EML), and electron transport layer (ETL) — and a silver cathode. These are all fabricated on a glass substrate, which light passes through when the device is turned on.

When current is applied, electrons are injected at the cathode and holes at the anode. Electrons and holes travel toward each other through the layers, combining in the emissive layer to release energy in the form of photons. This happens quickly while current is flowing, causing a stream of continuous light.

*We could understand the breakdown of loss mechanisms, easily test the influence of different design constraints, and adjust our OLEDs accordingly. COMSOL has shown us how to cut these plasmon losses in half.*

— **LEIMING WANG, SENIOR RESEARCHER, KONICA MINOLTA**

Figure 1. Huis Ten Bosch is a theme park in Sasebo, Nagasaki Prefecture, Japan, designed to look like the Netherlands. Konica Minolta developed "OLED tulips" in collaboration with the park for use in its tulip festival.

## » CATCHING THE PHOTON THIEVES

**BUT SOME PHOTONS NEVER** make it to the outside world. Light losses in an OLED can occur through several mechanisms, such as differences in the refractive indices of each layer that can cause light to reflect within the layers rather than traveling outward, as Figure 2 depicts.

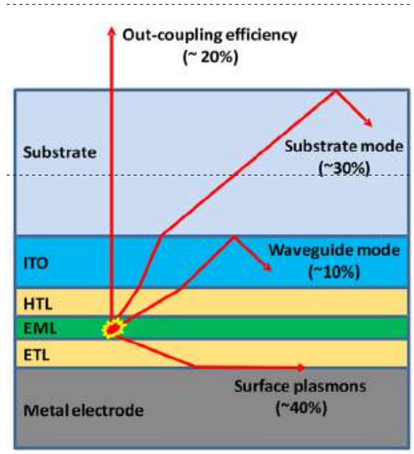


Figure 2. Schematic of a multilayer OLED structure showing various types of light losses.

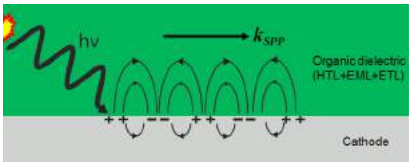


Figure 3. Schematic showing surface plasmons coupling with dipole radiation in the OLED, catching the photons in the SPP wave rather than allowing them to be emitted through the OLED glass substrate.

Wang's team primarily explored another mode of loss, the coupling of dipole emission with surface plasmons at the interface between the cathode and the organic material. Surface plasmons are waves of oscillating electrons on the surface of a conductor. In OLEDs, light emitted from radiating dipoles (molecular excitons) in the emissive layer can couple to the electron oscillations in the cathode, resulting in the presence of waves called surface plasmon polaritons (SPPs). These travel along the cathode surface as they decay, carrying away the emitted photons rather than permitting them to radiate through the glass (see Figure 3).

In other words, due to the presence of the metal cathode in the close vicinity of the organic emitters, some light is absorbed by the electrons in the cathode, causing the electrons to oscillate and form SPPs. These are eventually dissipated as heat, leading to significant energy loss.

Using numerical simulation in COMSOL Multiphysics® software Wang modeled light emission from the EML and the SPPs present in the system to analyze ways to prevent light loss. One promising concept included a nanograting cathode structure

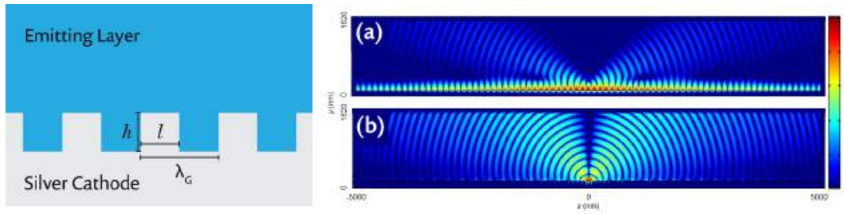


Figure 4. Left, Nanograting surface for the cathode. Wang's simulation team tested the effects of different pitch heights and widths to determine the optimal arrangement. Right, simulated 2D field distribution of dipole emission with (a) flat and (b) nanograting cathode surfaces. For the flat surface most of the emission is coupled to the SPP wave, with only a small portion radiated as free light. The coupling is greatly suppressed by the nanograting structure in (b).

(see Figure 4, left) that disrupts the formation of the SPP mode, reducing the energy coupling between the dipole emission and the plasmons.

Wang's simulation revealed the electromagnetic field distribution and the portion of light that escaped from the OLED for different cathode shapes (see Figure 4, right). From the results, his team was able to confirm that this phenomenon accounts for significant amounts of light lost.

COMSOL® software is an important tool at Konica Minolta Laboratory because it's not only powerful but versatile and user-friendly. Lab personnel use the software for a variety of topics under study there. "For this OLED project we were able to do everything in COMSOL, including postprocessing the data. We also imported wavelength-dependent optical properties from our own files and incorporated them into the simulation," Wang said.

His team modeled the OLED with flat and nanograting cathodes, changing geometric parameters to determine the optimal configuration (see Figure 5). They also performed a simulation to study the influence of different dipole orientations, studying the effect of the dipole position and wavelength on the level of light loss due to SPPs. They used a power flow analysis to calculate the portion of light emitted from the EML that actually escaped the glass.

Through their simulations, Wang's team determined that they could reduce the plasmon losses by 50% using the optimized nanostructure surface for the cathode.

## » VERSATILE MODELING BRINGS BRIGHTER LIGHTING

**THROUGH HIS SIMULATION WORK,** Wang was able to offer a promising new OLED design with significantly increased efficiency. "We were able to model the OLED system and determine the optimal configuration of the cathode nanograting structure," he concluded. "We could understand the breakdown of loss mechanisms, easily test the influence of different design constraints, and adjust our OLEDs accordingly. COMSOL has shown us how to cut these plasmon losses in half." ◎

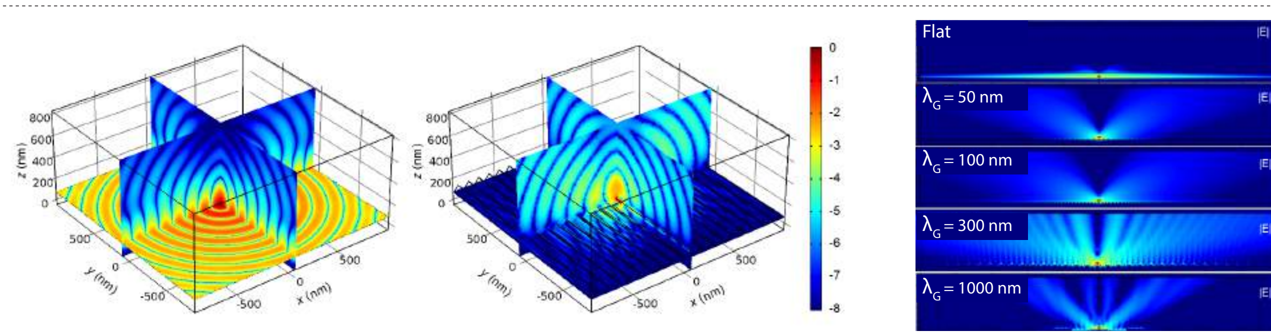


Figure 5. COMSOL® software results showing the distribution of emission when a flat structure is used (left) and a nanograting (center). The intensity is normalized and plotted on a log scale. At right are shown emission patterns for several nanograting cathode designs.

# SURFACE PLASMON POLARITONS EXPLAINED

By **ANDREW STRIKWERDA**

**SURFACE PLASMON POLARITONS**, or SPPs as they are often known, are an integral and exciting element of plasmonics and nanophotonics research. As the name suggests, SPPs are electromagnetic waves in the infrared or visible region of the spectrum propagating along surfaces, and much of the recent interest into SPPs is due to their excellent confinement of electromagnetic energy beyond the diffraction limit. As a result, they are well represented in numerous areas of near-field optics, biosensing, and metamaterials. Unfortunately, the presence of SPPs is not always desirable! In the previous article on optimization of a multilayer organic light-emitting diode (OLED), SPPs are a dominate loss factor. If the loss via SPPs can be reduced, the out-coupling efficiency of the OLED can be increased, which means better, more efficient devices for you and me. Here we will briefly discuss what an SPP is, when they may occur, and why they will automatically be accounted for in your COMSOL® software simulation.

As mentioned earlier, SPPs propagate along surfaces. But not any surface. SPPs can only propagate along an interface between two materials that have a different sign in their permittivity. Many common materials, such as air, water, plastic, and paper have a positive permittivity. Metals like gold, silver, and aluminum have a negative permittivity, and so SPPs can exist at the interface between gold and air, for example.

Just because an SPP can exist at that interface, however, does not mean that it is trivial to generate and control them. Generating an SPP with a traditional light source such as a laser is slightly more complicated, as is the inverse process – converting a SPP to visible light as in an OLED.

To couple freely propagating light and SPPs, their dispersion curves need to intersect, which is analogous to matching the energy and moment of the two. If we look at the figure shown here, the diagonal black line is the dispersion curve for light propagating freely in air, while the blue line is the dispersion curve for an SPP at an air/metal interface. The two lines approach each other asymptotically, but they do not intersect. There are several techniques to make these two curves meet, such as using a prism in either a Kretschmann or Otto configuration, but today we will focus on the use of a grating.

A grating has a regularly repeated pattern, like a sine wave or sawtooth pattern. This periodicity has its own wavevector, which can be added (or subtracted) to the wavevector of the SPP to allow dispersion curve matching. This is represented by the red arrow in the figure.

So how do we do implement this coupling in the software? It's quite straightforward, actually. Simply create the geometry of interest, and then assign the material properties and boundary conditions as in any other high-frequency electromagnetics simulation. That's it! This is because COMSOL Multiphysics® is solving Maxwell's Equations, which means that the coupling between free space light and SPP is inherently accounted for without any additional modifications. ◎

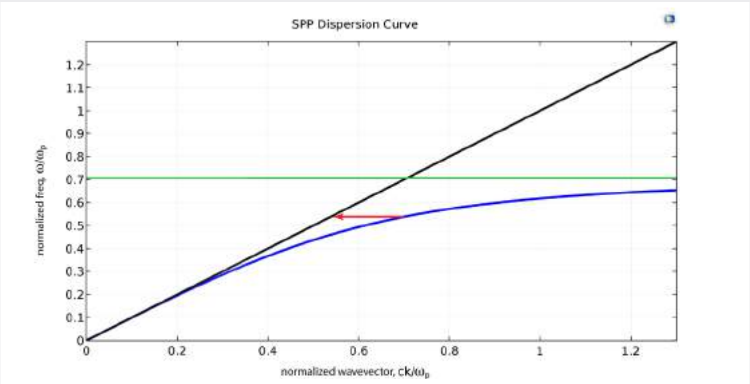


**FIGURE 1:** Plot in COMSOL® software showing the SPP dispersion curve. The black diagonal line represents the light line while the green horizontal line represents the surface plasmon frequency. The blue SPP dispersion curve approaches these asymptotically in the low- and high-frequency limit, respectively. The red arrow represents the grating wavevector that allows a surface plasmon to couple to a freely propagating light wave.