Goodbye to Droop

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4

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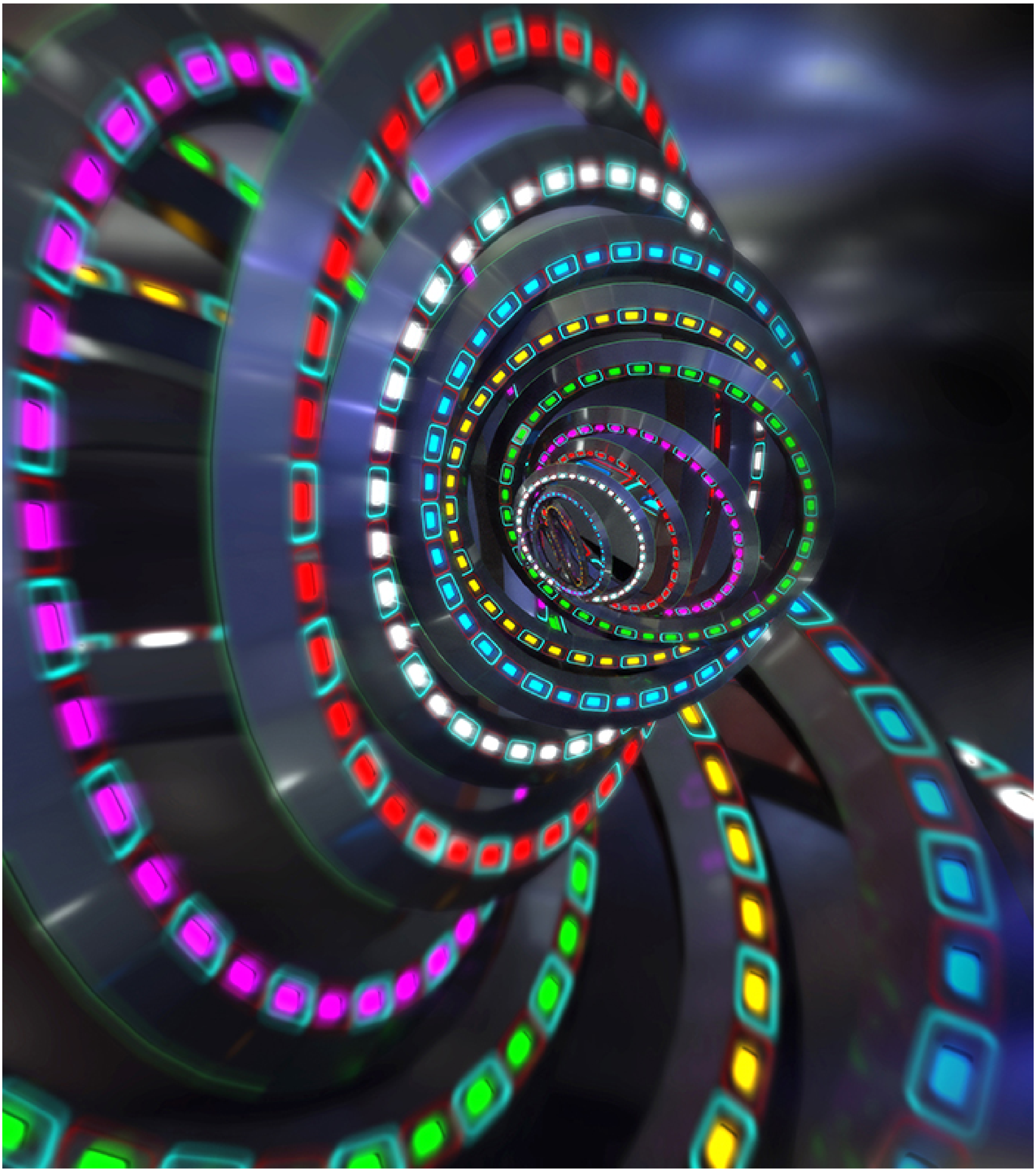
Case closed: researchers discover the science behind the mystery of efficiency droop

by K. M. Kelchner

 The ordinary light bulb is an innovation so extraordinary that a sudden brilliant idea is called ?a light bulb moment.?

Credit for inventing the first incandescent-style light bulb often goes to Thomas Edison, but even that wasn?t a light bulb moment. In fact, his patent for an improved electric light came after 75 years of hard work by several scientists and engineers, all scrambling to find the best way to run an electrical current through a filament and get it to glow.

Luminaires based on light-emitting diode (LED) technology already are 10 times more energy-efficient and last 20 times longer than old-fashioned Edison-style bulbs. Today, researchers in the Materials Department at UC Santa Barbara are working hard to get even more bang for the buck from these high-tech light sources.

A team led by professors James Speck and Claude Weisbuch from the Center for Energy Efficient

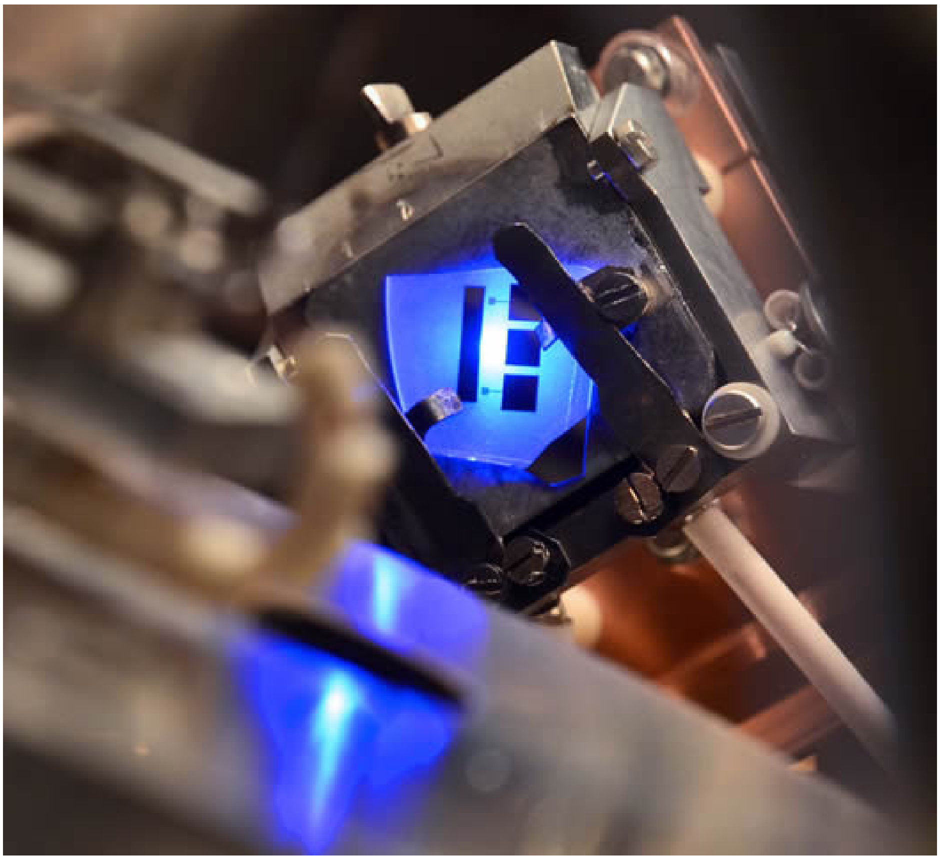
Materials (CEEM), along with collaborators at École Polytechnique in Paris, have developed a technique to tackle possibly the most difficult technological mystery of LED research: efficiency droop. Their recent discovery could have exciting implications in terms of how we understand and use this new way to make light.

Just like Edison?s tricky filament, though, the devil is in the details.

It is widely known that incandescent bulbs are terribly inefficient light sources; 90 percent of the electrical energy goes toward generating heat and only 10 percent goes to making light. An LED generates light a completely different way, by passing electric current through layers of semiconductor material called a diode. In a perfect LED, every electron passing through the diode would release its energy in the form of light. It would generate no heat at all.

In a real LED, however, not every electron does what it should. As you apply more and more current, the LED doesn?t emit a proportional, increasing amount of light. The LED actually becomes less efficient the harder you turn up the juice. The efficiency, for lack of a better word, droops.

The challenge of LED droop



LED emitting light under forward bias in an ultra high vacuum chamber allowing simultaneous electron emission energy.
Photo credit: École Polytechnique, Ph. Lavialle

LED droop is a challenge for LED bulb designers who want to squeeze the most light out of each chip, especially if they want to replace the incandescent light bulb, which despite being really inefficient happens to be really bright and really cheap.

?Efficiency droop has been the biggest problem for blue LEDs for a long time,? explained Shuji Nakamura, a professor of materials and co-director of the Solid State Lighting & Energy Center at

UCSB. While still a researcher in Japan in the late 1990s, Nakamura was the first to demonstrate a modern blue LED using an electrically injected diode made from a semiconductor called gallium nitride (GaN).

Since then, Nakamura has played an important role in seeing these tiny light emitters go mainstream for white lighting. According to Nakamura, solving the enduring efficiency droop problem could have a huge impact on reducing the cost of LED bulbs, which still sell for more than $10 a piece.

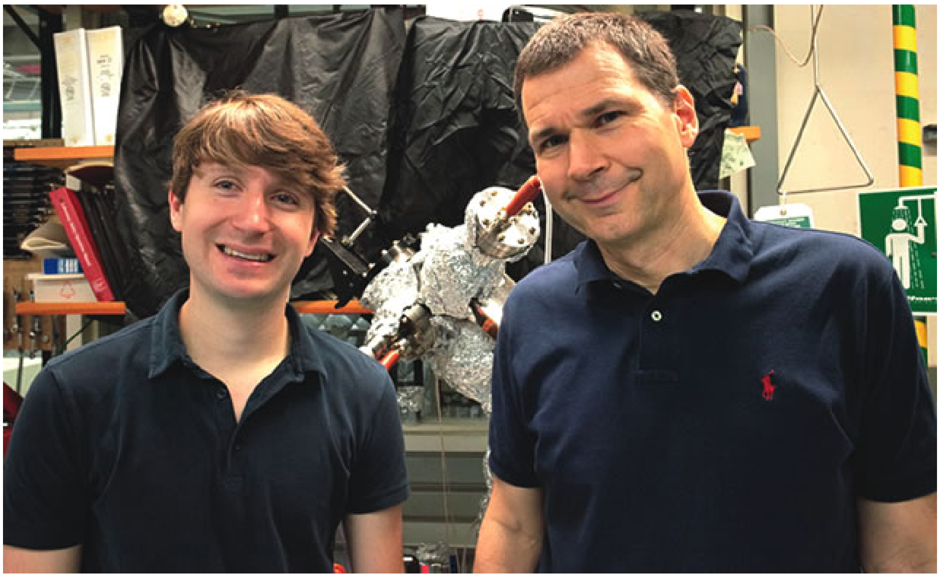
For years, the exact cause of efficiency droop has been hotly debated. LED manufacturers have engineered workarounds for the droop problem, but the answer to the mystery lies in fundamental science. How a single electron generates light at all involves some magic of quantum physics. Albert Einstein won the Nobel Prize in 1921 for explaining the so-called photoelectric effect.

The concept comes down to this: If you want to get as much light out of an LED as possible, you must account for all the electrons.

UCSB professor Chris Van de Walle and his research team theorized in 2011 that LED droop can be blamed on misbehaving electrons. Instead of releasing their energy as light as they should, some electrons traveling through the diode transfer all their energy to another electron. Think of billiard balls colliding in a game of pool. These pesky energetic electrons are called hot electrons or Auger electrons. The more Auger electrons you have, the less light you get. There have been several experiments trying to prove the existence of Auger electrons in LEDs, but measuring them directly has been nearly impossible.

Very recently, professors Speck and Weisbuch, along with their collaborators, have managed to directly measure Auger electrons for the first time.

The Paris connection



UCSB researchers Justin Iveland and Professor James Speck.

Justin Iveland, a materials graduate student who worked on this project for the past two years, joked that the most important piece of lab equipment was the trans-Atlantic airliner that let him travel to Paris to collaborate with researchers in the Laboratoire de Physique de la Matière Condensée at École Polytechnique.

?This kind of experiment takes experience,? said Weisbuch, distinguished professor of materials at UCSB and a faculty member at École Polytechnique.

Weisbuch enlisted his colleagues Lucio Martinelli and Jacques Peretti to help because, as he put it, they have more than 30 years of experience taking the kind of careful electrical measurements this experiment required.

Still, the experiment was quite complex. To start, the samples had to be carefully prepared and subjected to a very high vacuum. The equipment had to be aligned just so to detect Auger electrons, which have a unique high-energy signature. The hardest part of all, according to Weisbuch, was ?getting everything right.?

Not only was the measurement successful in detecting Auger electrons, but the more electrons pumped through the LED sample, the more Auger electrons they measured. The emergence of Auger electrons directly corresponded with the onset of LED efficiency droop. They call this kind of discovery unambiguous, which is perhaps a nicer way to say, ?We told you so.?

?Based on our data and analysis, it offers direct proof that Auger is the dominant mechanism for GaN-based LED droop,? explained Professor Speck, the Seoul Optodevice Chair in Solid State Lighting at UCSB. ?It?s the first direct measurement of Auger electrons in any semiconductor. The result provides a direct pathway to mitigate droop and the Auger process.?

Materials Professor Steven DenBaars, Mitsubishi Chemical Chair in Solid State Lighting and Displays and co-director of SSLEC, added: ?Professor Speck and Professor Weisbuch?s groundbreaking experimental verification solves one of the greatest mysteries of light-emitting diodes. Now that we understand the fundamental process, we can focus on ways to solve it through novel LED device structures and designs.?

The past 20 years have seen rapid developments in LED technology, but as Thomas Edison himself said, ?Genius is 1 percent inspiration, 99 percent perspiration.? This is a testament to the hard work that scientific discoveries and technological innovations often require.

In a few more years, the ordinary light bulb will be a thing of the past, and our options will be bigger, brighter and cheaper ? all thanks to contributions made in research labs around the world and right here at UCSB.

About the author:
K. M. Kelchner received her PhD from UCSB?s Electrical and Computer Engineering Department in 2012 and worked as a postdoctoral researcher in the UCSB Materials Department until 2013 investigating growth of nonpolar GaN-based materials. She currently lives in Portland, Oregon where she works in the semiconductor industry. Connect with her on Twitter at @KK_PhD [2].

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     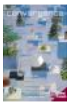

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