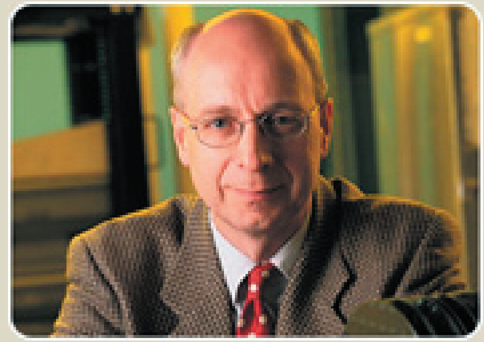
Smart Lighting

Rensselaer's Future Chips Constellation includes world-class photonics pioneers dedicated to advancing communications, lighting, sensing, and imaging.

By Sheila Nason

Candlelight flickering on a dinner table. Fluorescent lights emitting a bright glare over a factory floor. Colorful LEDs presenting an animated display on a baseball scoreboard. Since the first caveman learned to control fire, humans have shaped and used light in a constantly expanding array of technologies. Yet lighting – "smart lighting" – could do much more, according to E. Fred Schubert, Wellfleet Senior Distinguished Professor of the Future Chips Constellation at Rensselaer.



E. Fred Schubert, Wellfleet Senior Distinguished Professor of the Future Chips Constellation at Rensselaer. (Photo by Mark McCarty)

As one example, Schubert predicts that revolutionary lighting systems will provide an entirely new means of sensing and broadcasting information. By blinking far too rapidly for any human to notice, the light will pick up data from sensors and carry it from room to room, reporting such information as the location of every person within a high-security building.

New photonic crystal light emitters will be 10 to 30 times more efficient than light bulbs, says Shawn-Yu Lin, Future Chips Constellation Professor and professor of physics. They will have a huge impact on worldwide energy consumption and the environment. It will be possible to change their color and their intensity independently, so that a homeowner can easily adjust both to match the time of day, the current use of the area, or the mood of the occupants.

Shawn-Yu Lin, Future Chips Constellation Professor and Rensselaer professor of physics. (Photo by Randy Montoya)

Christian Wetzel, the Wellfleet Career Development Constellation Professor, Future Chips, and associate professor of physics, envisions an inexpensive spectroscopy lab the size of a laptop computer – or even a ballpoint pen. A person with a serious allergy to shell food or peanuts could carry the device and test food for herself to be sure of its safety. "The computers exist. The limiting factor is the light source, and we're the ones working on that," he says. "The computers are already very smart. They are waiting on us to provide the data."

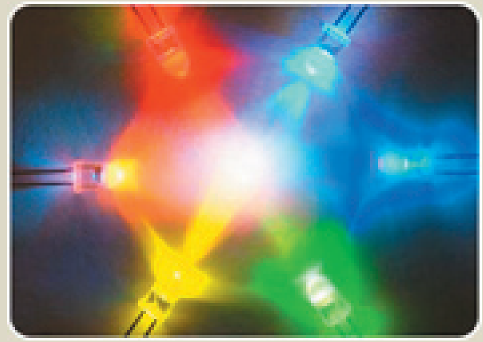
Schubert, Lin, and Wetzel – all recognized photonics pioneers – have come together at Rensselaer to form the nucleus of the Future Chips Constellation, a multidisciplinary group that is conducting leading-edge research in compound semiconductor materials and devices with the goal of enabling significant advances in communications, lighting, sensing, and imaging.

Christian Wetzel, the Wellfleet Career Development Constellation Professor, Future Chips, and Rensselaer associate professor of physics. (Photo by Mark McCarty)

At Rensselaer, a constellation is a multidisciplinary team of senior faculty, junior faculty, and graduate students led by outstanding stars in a strategic research field. The Future Chips Constellation, which is expected to grow, also includes Thomas Gessmann, a research assistant professor; James Bur, a senior research scientist; Jong Kyu Kim and Ibrahim Yilmaz, two postdoctoral researchers; a number of doctoral students, and three undergraduate students.

In addition, such major Rensselaer research centers as the Center for Advanced Interconnect Systems Technologies, the Interconnect Focus Center-New York, the Rensselaer/IBM Center for Broadband Data Transfer Science and Technology, the NSF Nanotechnology Science and Engineering Research Center, and the Lighting Research Center provide a broad range of expertise, potential collaborations, and facilities.

A major focus of the Future Chips Constellation is smart lighting, a revolutionary new field in photonics based on efficient light sources that are fully tunable in terms of such factors as spectral content, emission pattern, polarization, color temperature, and intensity.



This image illustrates color mixing and the creation of white light using several LEDs. A specific spectrum can be attained by a suitable intensity ratio of LEDs.

Schubert, who leads the group, says smart lighting will not only offer better, more efficient illumination; it will provide "totally new functionalities." He offers additional examples:

Studies have shown that spectral (color) variations in light have profound effects on the human circadian and visual systems (See related article from Rensselaer's Lighting Research Center). Controlling the amount of red, yellow, and blue in white light has implications for sleep in Alzheimer's patients, growth of premature infants, seasonal depression, jet lag, and the well being of nightshift workers. Some researchers have suggested that inappropriate lighting can upset the body chemistry and even lead to certain types of cancer.

At Rensselaer, Wetzel is tackling the challenges of making green LEDs even brighter and to vary their color into the yellow part of the visible spectrum.

In live-cell biological imaging, smart lighting could make it possible to coordinate intensity, wavelength, and polarization with image scanning to reveal a new wealth of features. Using this revolutionary cellular microscopy technique, for example, researchers could observe and analyze multiple single cells in real time as they react to a drug or infectious agent.

Studies show that central and peripheral vision react to different color spectrums. Automobile headlamps with dispersive characteristics perfectly adapted to human vision characteristics could provide enhanced visibility and safety for nighttime driving.

Smart lighting could address the world's pressing need for increased food production because light plays a pivotal role in plant growth and photosynthesis. Adjustable smart light sources predominately made up of blue, red, and infrared wavelengths, the portions of the spectrum best absorbed by plants, could provide a low-cost, energy-efficient way to grow crops off-season.

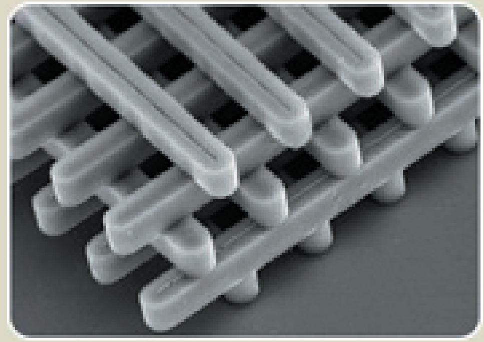
The "Century of the Photon"

Such technologies are possible, Schubert says, because of advances in photonics that are transforming society just as electronics revolutionized the world in recent decades. In fact, some have called this the "century of the photon." North America's optoelectronics market grew to more than $20 billion in 2003. The LED (light-emitting diode) market is expected to reach $5 billion in 2007, and the solid-state lighting market is predicted to be $50 billion in 15-20 years, Schubert says.

LEDs are specialized semiconductor devices that can potentially convert electricity to light, without the wasteful creation of heat. The color emitted is controlled in large part by the energy gap of the semiconductor and, in advanced structures, by the "photonic band gap" of the material, a term that describes a range of wavelengths that cannot travel through that particular substance. By suppressing certain wavelengths and enhancing others, the band gap determines the color.

LEDs are most familiar in such roles as indicator lights, displays on consumer electronics, exit signs, traffic signals, and roadwork signs. The first LEDs, which were made of GaAsP (gallium arsenide phosphide), emitted red light. New materials and technologies made amber, green, and blue LEDs possible. Now that several types of white LEDs have become available, manufacturers have begun to look beyond the specialized display market to the use of LEDs for general illumination, television monitors, and large-area displays.

Researchers are now exploring new organic materials (polymers) for the fabrication of organic light-emitting diodes (OLEDs). The goal is to use these light-emitting polymers to create thin, flexible sheets of light. Light-emitting wallpaper or even clothing would be possible.



Photonic lattice (side view).

A World-Class Team

Rensselaer's goal of smart lighting will require revolutionary advances in fields such as materials science, device design, physics, and nanotechnology. To meet this interdisciplinary challenge, Rensselaer has invested heavily in attracting a world-class research team and providing state-of-the-art laboratories.

Rensselaer recruited Schubert in late 2002 to head the new Future Chips Constellation. Internationally known for his work on semiconductor doping and light-emitting diodes, Schubert holds 28 patents. He invented the resonant cavity LED that helped transform traffic signals and airport runway lighting, as well as the photon-recycling semiconductor LED, a promising new approach to the challenge of white LEDs.

Wetzel joined the team in March 2004. He is known for his work in materials physics and the chemistry of light emission. Since 1993, he has explored the use of gallium nitride compounds for LEDs, first in Berkeley and next in Japan in the lab of Isamu Akasaki, where gallium nitride materials were used to pioneer the fabrication of blue LEDs. With Uniroyal Optoelectronics in Tampa, Fla., Wetzel developed successful MOCVD (metal organic chemistry vapor deposition) techniques to produce very intense green LEDs.

At Rensselaer, Wetzel is tackling the challenges of making green LEDs even brighter and to vary their color into the yellow. He says the large band-gap energy in our LEDs, gives them the ability to emit short-wavelength colors such as purple, blue and green. Since it is easier to lower the band-gap energy than to raise it, it should be possible to adjust the design to create the whole range of colors, he says.

Rensselaer recruited Lin from Sandia National Laboratory, with the help of a $750,000 NYSTAR (New York State Office of Science, Technology and Academic Research) grant to support his research. Lin, who joined the Rensselaer faculty in July 2004, is known for his pioneering work in photonic crystals and optical waveguide devices, which are needed for optical signal routing. The waveguide built by Lin's team from a photonic crystal was listed by Science Magazine as one of the 10 most important breakthroughs of 1999.

Photonic crystals, which are critical to Schubert's vision of a tunable light source, were strongly advanced by Lin, who holds two patents on them. He was the first to demonstrate fabrication and testing of a 3-D photonic crystal at optical wavelengths. He demonstrated the use of photonic crystals of tungsten instead of the conventional dielectric materials, and he has already used VLSI (very large-scale integration) techniques to build a photonic crystal with enhanced emissions at a 1.5 micrometer wavelength. At Rensselaer, he plans to move on to a crystal with emissions in a visible wavelength. Reaching his goal of the emission of photons in a narrow wavelength of visible light with no radiation at other wavelengths would revolutionize lighting, making huge energy savings possible.

Making Smart Lighting Possible

For some smart lighting applications, "design tunability" (fabrication of LEDs that have the desired color, polarization, etc.) will be adequate, Schubert says. Structural control can be provided by the use of photonic crystals, reflectors, and cavities (resonator structures with deliberate defects that control photons).

Real-time tunability will be required, however, for such applications as lighting, imaging, and communications. Schubert plans to achieve real-time tunability by designing devices that include multi-channel electrical and optical controls. Because such factors as temperature and voltage can affect the properties of the light emitted, it is possible to tune the light by controlling these factors. The controls could also be used to activate various portions of a photonic crystal.

With incandescent lights independent tunability of color and intensity is not possible, Lin says, because increasing intensity raises the heat and shifts the color spectrum. With LEDs, the color is largely determined by the material, which is deposited in layers. Color shifts must be obtained by using several different colors of LEDs in an array. Photonic crystals, however, are created by lithography, the technology used to fabricate computer chips. One chip could be designed to carry several colors or intensities, making very precise tunability possible.

Much basic science and computer modeling is still needed, however, to understand what light characteristics are best for specific applications and how to design tunable LED arrays and photonic crystals which produce the desired light. A number of research projects are under way to develop the needed technology, particularly work in materials, photonic crystals, and improvements to LED devices. See: http://www.rpi.edu/futurechips/

One problem, for example, is that current systems do not extract all of the light from an LED, both because of poor reflectivity and because polymers used to encapsulate the working structure lose transparency in reaction to the light, particularly in short-wavelength and high-power emitters.

Schubert is developing an omni-directional reflector that makes it possible to extract more than 99 percent of the light from both inorganic and organic LEDs. This reflector consists of a semiconductor layer, a dielectric (insulating) layer perforated by an array of micro-contacts, and a metal layer.

In the meantime, Rensselaer chemists and chemical engineers have synthesized new siloxane resins with superior qualities for LED encapsulation and low-refractive-index materials with unprecedented properties. The materials display excellent transparency and long-term stability. Further research is needed to improve mechanical and thermal properties.

Turning the Dream Into Reality

The photonics revolution now under way already has provided tremendous benefits in energy savings, improved lighting, versatile new display technologies, and optical communications. Yet, the science and technology are still not available for the full control of many basic characteristics of light. As technical problems are overcome and new photonic products reach the marketplace, smart lighting will revolutionize such fields as illumination, imaging, display, and communications. Improved LEDs and new photonic crystal light emitters, moreover, are expected to greatly reduce the world's consumption of energy and diminish harmful environmental impacts.

Formidable technical roadblocks remain, but the researchers in Rensselaer's Future Chips Constellation are optimistic. They have come together at Rensselaer because they believe that working together in a multidisciplinary constellation focused on a common goal offers them the best opportunity to move the concept of smart lighting from dream to reality.