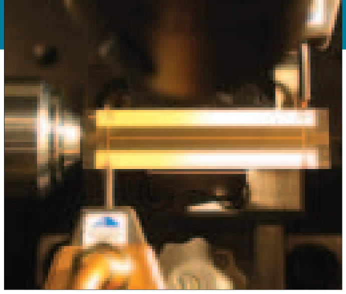
COVER STORY



Photonics Powerhouse

UW center moves information and computing technologies into the ultra-fast lane

From the Internet to telephones and television, we have an appetite for information. Like fast food, we want it now and we want it super-sized. As these demands for bandwidth continue to grow, so do new research efforts to support our need for speed.

Driving in the express lanes of this information highway is Larry Dalton, professor of chemistry at the University of Washington (UW). Dalton studies photonics—the science of generating and manipulating photons, the energy packets that form light.

Photonics research at the UW has sparked enormous interest and support. In August of 2002, the National Science Foundation (NSF) chose the University of Washington as one of six prestigious Science and Technology Centers in the country. The UW's Center on Materials and Devices for Information Technology Research received a five-year award of $18.35 million, and additional millions will funnel through the Center in the next ten years.

Dalton has become a Pied Piper for the Center, bringing in a dream team of professors and students and creating collaborations with companies like IBM, Boeing, Intel, and Agilent. Now, the UW is recognized as a leader in photonics research and continues to strengthen its position.

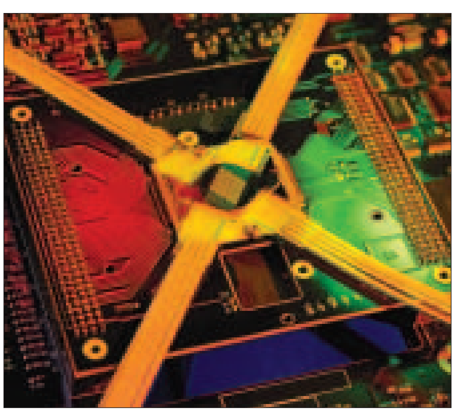
The initial excitement hit the headlines a few years ago, when Dalton developed a new material for "electro-optic" modulators, which transform electrical signals into optical signals and back again as they enter and leave the ends of a fiber optic cable. This material transforms signals ten times faster than other materials, thus increasing the bandwidth—the amount of information that a device can carry. For consumers, this could mean ultra-wide bandwidth for ultra-fast Internet connections.

by Marita Graube

In a dust free environment, materials like chromophores are integrated into wafer chips. Photo: Agilent Technologies

The technology also will affect a much broader range of applications—everything from new generations of sensor technologies to improved navigational systems and even advanced radar in airplanes.

"The vision is to make the UW a powerhouse in photonic materials and devices," says Alvin Kwiram, executive director of the Center. Formerly, Kwiram was UW Vice Provost for Research after serving for many years as chair of the chemistry department.



One of the collaborating companies with the UW Center is Agilent Technologies, which created the first all-optical switch. Although not in current production, the switch reroutes an optical stream from one path to another. Photo: Agilent Technologies

Kwiram and Dalton first met at Harvard, where Dalton earned a doctorate working with Kwiram. At the time, Dalton studied solid state magnetic resonance, a method that can determine the structure of materials. More recently, Dalton moved into optics research. "I felt that the optics work he was doing was extremely important," says Kwiram. "It was not yet widely recognized, but had enormous potential."

Kwiram capitalized on that potential by encouraging Dalton to come to the UW to join other collaborators such as chemistry professors Bruce Robinson and J. Michael Schurr. His efforts, together with those of the current chemistry chair Paul Hopkins and David Hodge, dean of the UW College of Arts and Sciences, eventually paid off. Dalton has since become an invaluable asset to the UW, attracting numerous grants, scholars, and most recently, the NSF Science & Technology Center.

Having an NSF Center at the UW means different things for different groups. For students, it means cutting-edge research in the broad field of photonics. At the UW, the technology can translate into license agreements, royalties, and an influx of talented students and professors. Within industry, the Center plays an important role in commercializing new technology.

Lumera Corporation of Bothell, Wash., is one example of local research affecting the local economy. Born three years ago as a result of UW's photonics research, Lumera acquired the rights to commercialize some of the intellectual property in the area of electro-optic materials. As a subsidiary of Microvision Inc., the company was initially funded by private investments and $24 million from the telecom giant Cisco Systems. Through a sponsored research agreement, Lumera will provide about $10 million to the UW over four years to support research.

Due to the recent upset of the telecommunications market, Lumera's primary focus has shifted from telecommunications to defense applications. With support from a large grant with the government's National Reconnaissance Office, electro-optic devices could expand current capabilities for radar and navigational technology.

With photonics technology, airplanes could be equipped with advanced radar systems. Photo: Agilent Technologies

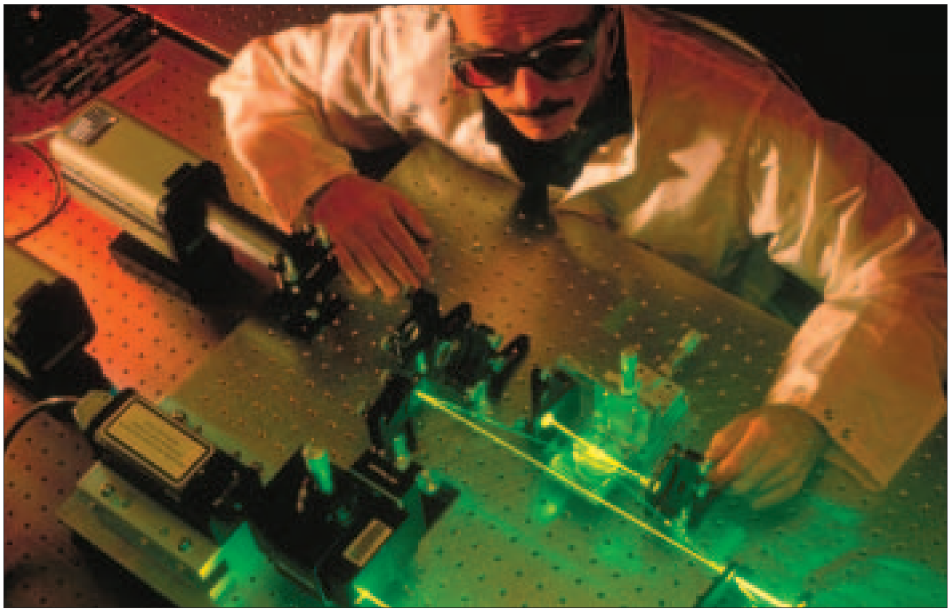


Photo: Agilent Technologies

"We're pushing the electro-optic index of the material along with the UW," says Thomas Mino, CEO of Lumera. "We are hoping to win several larger contracts from the government." He adds that Lumera may partner with commercial companies in both the device and processing areas of electro-optics.

Mino joined Lumera in September of 2001 and helped the company grow from 25 to 35 employees.

Recently, Lumera released prototype electro-optic devices, which demonstrated bandwidth capable of 200 gigahertz (GHz). In addition, the electro-optic devices have a low operating voltage of about three volts, with the capability to go below one volt. Low voltage is key for keeping the destructive heat at a minimum. These results go well beyond the capabilities of today's common materials used for electronic modulation, like lithium niobate, which has a maximum bandwidth around 40 GHz and requires a hefty five to six volts to operate.

Optical technologies also benefit from a process called multiplexing. A multiplexer allows more information to be carried over a fiber. By color-coding the information on individual colors of light, a multiplexer encodes information on individual wavelengths with a resolution around one-hundredth of a nanometer. This process called "wavelength division multiplexing," promises enormous data-handling capabilities.

In the next year, Lumera plans to release engineering samples that meet the specifications for a commercial device. "I think the interesting thing about this technology and material is that it's a platform for a lot of different applications," says Mino. Those possible applications, he says, range from stress analysis tools in airplanes to flat panel displays in entertainment systems.

Lumera values its close relationship with the UW, drawing on the knowledge of researchers like Dalton and other Center members like chemistry professors Robinson and Alex Jen. "There's a real connection between the people here and the people at the university," says Mino. Typically, the leaders between the two groups meet once a month for a formal review while the researchers speak on a weekly basis.

"Larry is the kind of person that drives the leading edge. He's probably our strongest marketing tool and his depth of knowledge in this area is probably unchallenged internationally," says Mino.

Robinson agrees: "His real genius is to see it from one end to another. His connection with device companies is extremely important because he's worked with engineers for fifteen years, trying to deliver materials to them and understanding their needs."

Dalton notes that three new start-up companies have formed this past year based on intellectual property generated by Center

Partners in Research

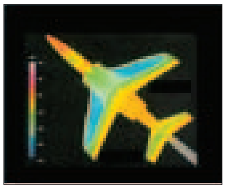
Many corporations, federal agencies, private companies, and federal laboratories have connections to the research at the UW Center on Materials and Devices for Information Technology Research. These include:

Areas of Interest	Organization
Computing	Agilent
	Cray Inc.
	Dow Corning
	IBM
	Intel
	Motorola
	Sun Microsystems
Defense	Air Force Research Lab
	Boeing
	DARPA
	General Electric
	Hughes/Raytheon
	KVH Industries Inc.
	Lockheed Martin
	National Reconnaissance Office
Telecommunications	Akzo Nobel
	Battelle Corporation
	Ciba Chemicals
	Cisco Systems Inc.
	Corning
	DuPont
	Honeywell
	IPITEK
	JDS-Uniphase
	Lucent
	Lumera
	Marconi
	Pacific Northwest National Laboratory
	Pacific Wave
Entertainment & Commercial Displays	3M
	Brewer Science
	Durel Corporation
	Philips
	Pioneer Japan

researchers. "It's always been natural for me to interact between industry and academia," says Dalton. "I've always enjoyed seeing research connected to real world applications."

The interactions do more than just create new products or generate royalties. As the research has gained recognition, the UW chemistry department has attracted students who want to take part in the photonics research. In addition, the Center dedicates a portion of its resources to outreach programs, targeting students from grade school through college. "The fantasy," says Dalton, "would be to develop a situation where we could all benefit from the Center." Early outreach to the students could help prepare the future photonics workforce for the information technology age.

The UW also plans to hire six new professors: two in chemistry, two in electrical engineering, and two in material science engineering. In the future, the computer science department may also get involved with an aspect of the research. "We want to encourage key departments to have an active program in electro-optics," says Kwiram.



Using the technology of organic light emitting displays, pressure sensitive paint can simultaneously detect pressure and temperature. This is one of the four areas of photonics research in the Center.

With a fully functioning Center and local company connections, both loaded with grants and a trained workforce, when will we see commercialized technology?

In some areas, like computing, the technology already exists. Although expensive, Agilent makes optical connections to hook up individual computers.

Some researchers speculate that within the next ten to fifteen years, the optical connections will soon affect all elements of a computer, down to the communication within a chip. By eliminating the use of lethargic copper wire to carry signals, the flow of information will take flight. "The fact that copper wire is still used to transport internet signals the last distance to the home typically limits Internet bandwidths to a few gigahertz and, in some cases, to hundreds of megahertz," says Dalton.

Often, researchers will compare the photonics research with "Moore's Law," the 1965 prediction that computer processing power would double every two years. "Many of the fundamental technologies, which have enabled high performance computing to keep pace with and exceed Moore's law, result from breakthrough academic research organizations like the UW Center of Materials and Devices for Information Technology Research," says James Rottsolk, president and CEO of Cray Inc., of Seattle, Wash. "The coupling of photonics with semiconductor technology promises material and device technology to continue this trend."

The first major application for Dalton's electro-optic materials will likely be for military purposes. Then the technology could flood areas like computing and telecommunications. It's likely that transportation will also benefit.

"Even though one of the early applications is for electro-optic modulators, the goals of the Center are much broader," says Kwiram. For example, Boeing and Lockheed Martin are already testing the technology for advanced airplane communications and sensors. Even today, photonics are being incorporated into the F-18 Hornet, the aircraft that is flown, for example, by the Blue Angels Squadron. Says Dalton, "Incorporation into other aircraft should follow shortly."

In the long term, Dalton envisions that every car would contain electro-optic sensor equipment, alerting drivers of possible collisions. Even buildings could have high speed detectors to monitor earthquakes, while emergency personnel could download the location and medical information of an ill patient. A network sensing system could

Beyond Bandwidth

The research at the Center on Materials and Devices for Information Technology Research includes scientists from the University of Washington, University of Arizona, University of California at Berkeley, California Institute of Technology, University of Southern California, the Georgia Institute of Technology, and the University of California at Santa Barbara. The Center covers a broad range of photonics research, divided into four main areas.

ELECTRO-OPTIC & ALL-OPTICAL-SWITCHING MATERIALS & DEVICES

Integrating electro-optic and optical materials into devices that have a combination of desired properties: low voltage, high speed, and low signal loss.

Team Leader: Alex Jen, University of Washington

LIGHT SOURCES AND ORGANIC ELECTRONICS

Developing new light sources for telecommunications, organic light-emitting displays, and stable organic materials to incorporate into electronic devices.

Team Leader: Bernard Kippelen, University of Arizona

MICROFABRICATION AND NANOENGINEERED MATERIALS

Incorporating and assembling electro-optic polymers and organic materials into devices, working at the nanoscale (1 billionth of a meter) to produce inexpensive systems.

Team Leader: Joseph Perry, University of Arizona

THEORY

Understanding the general structure and properties of the chromophore molecules; creating large arrays of these chromophores and determining the best geometric arrangement that can self-organize and efficiently transfer electric charge.

Team Leader: Bruce Robinson, University of Washington

From Molecules to Devices

Compare the Materials

Material	Bandwidth	Voltage (V)	Insertion loss	Used in:
Organic chromophores	up to 200 GHz	0.8V	5-6 dB	mostly prototypes
Lithium niobate	up to 40 GHz	5- 6 V	5-6 dB	commercial semi-conductors
Gallium arsenide	up to 35 GHz	1-2 V	10-20 dB	mostly prototypes

Although the photonics researchers may think of big ideas for the future of electro-optic devices, they had to start by thinking small. Creating a material for electro-optic devices is an involved process that starts at the molecular level.

Organic molecules called chromophores are the key energy transfer molecules that modulate (add information to) a laser beam, generating the optical signals that flow through a fiber optic cable.

One of the researchers at the University of Washington's Center on Materials and Devices for Information Technology Research working to design the perfect chromophore for electro-optic devices is Bruce Robinson, UW professor of chemistry.

Bruce Robinson, professor of chemistry at the UW, creates new structures for chromophores.

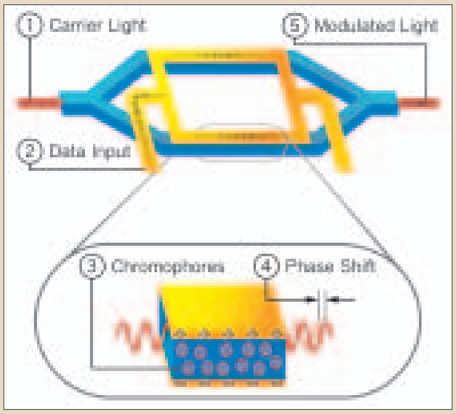
Scientists use a variety of measurements to determine how well materials can modulate electrical and optical signals. The ideal combination includes: high bandwidth—the capability of the material to carry massive amounts of information; low voltage—less voltage means less power and less heat generated in the material; and low insertion loss—the amount of signal in decibels (dB) lost as the signal passes through a device.

Organic chromophores have many of the desired characteristics, but they can be temperamental. Like a teacher trying to get hyperactive kindergartners to take their seats after recess, scientists struggle with placing chromophores in an organized structure. The chromophores prefer to align themselves in a structure that reduces their efficiency. To counteract this natural alignment and thereby maximize the electro-optic activity, scientists use electric fields to align the molecules. They have also reshaped molecules containing the chromophores. What were once more like ellipses became more spherical. The researchers are also trying to make the chromophores transfer electrons from the "donor" to the "acceptor" more efficiently.

The quest to find the perfect chromophore alignment isn't over. Robinson and his team use modeling techniques to explore new ways to order the chromophores. Using computer modeling and statistics, Robinson's team analyzes thousands of arrangements. "We basically roll the dice," says Robinson, "and try everything to see what works best."

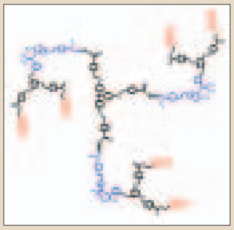
"Bruce is working at the leading edge of simulation of the molecular structure and properties," says Thomas Mino, CEO of Lumera Corporation, Bothell, Wash. "His work is probably two years ahead of where Lumera is going to be. It will be essential in the future to shorten the research and development time for new molecules."

UW professor Alex Jen also studies chromophores, but his work has more of a present-day connection with the Lumera's commercialization efforts. However, Mino points out that whereas UW researchers like Jen make efficient chromo- phores in gram-sized quantity, Lumera must reproduce the results in large batches.



Mach-Zender interferometry provides one means of applying chromophores to data transmission over optical fibers.

1. Unmodulated light enters the waveguide.
2. Data enters the system as electrical signals on broadband electrodes.
3. Electrical signal shifts the charges in the chromophores, changing the index of refraction.
4. Changing the index of refraction shifts the phase of light.
5. Light recombines and leaves the system with data encoded.



Chromophore structure.

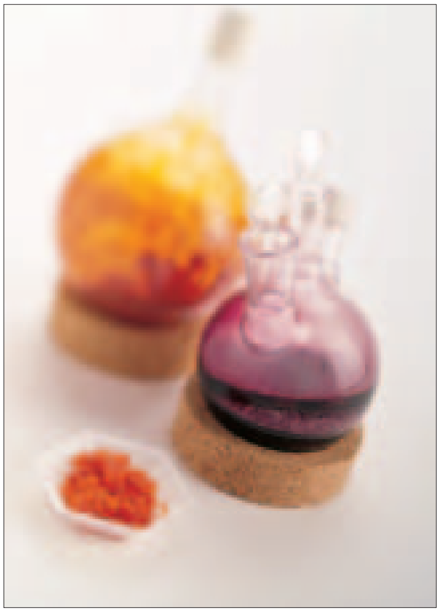
"Our job is to take that molecular formula and scale it up to 50, 100, or 1,000 grams," says Mino. Therefore, the Lumera researchers must consider how to handle the complex molecules in large quantities, while controlling the desired molecular properties.

When the scientists single out a decent chromophore arrangement, they put it to the test as part of the electro-optic modulator. First, the chromophores are created and dissolved into a warm liquid solution. The gooey mixture, says Robinson, is like honey.

The mixture is spread out thinly onto a piece of glass—the conducting surface. Before the "honey" dries, the sample is placed in a strong electric field. Then, as the plastic solution cools and hardens around them, the chromophores are frozen into partial alignment. Chemical cross-linking then stabilizes the structure even further.

In Lumera's electro-optic devices, the cured chromophore sample is only 3 microns thick, a tiny fraction of the diameter of a human hair. Five separate layers of this material form a sandwich called the "waveguide," that guides the signals. A thin layer of gold, like the bread portion of the sandwich, lies on top of the waveguide. The gold is used as the electrode that applies the electronic signal to the electro-optic material. As a whole, the device looks like a mini stick of gum with brilliant metallic stripes.

While the UW may make one or two of these devices at a time, Lumera is working on a much larger scale. Says Mino, "When we get into production, we'll have a system where we can do thousands of devices a day."



assist energy providers in preventing blackouts and finding energy inefficiencies.

While these high-speed sensing technologies seem beneficial, one of the overall considerations is cost. Some skeptics wonder if greater bandwidth will be of commercial interest. Dalton admits there are skeptics, especially with current market conditions, but says, "It comes down to the consumer like you and me. If you'd have asked me in the 1970s if personal computers would ever be of interest, I'd have said 'no.' And I actually worked with IBM on the PC." Dalton believes there will ultimately be a tremendous drive in the consumer market as electro-optics become the next generation of technology.

If the technology hits mainstream, high volume manufacturing becomes essential. Therefore, the Center is exploring manufacturing options through Paul Burrows, scientist at Pacific Northwest National Laboratory in Richland, Wash. Burrows studies thin film devices for flat panel displays, a technology that is already manufactured overseas. While flat panel displays are a separate technology from electro-optic devices, both make use of similar chromophores, the key molecules in electro-optic devices.

"The chromophores are related cousins," says Burrows. "Understanding in one field can cross over into the other." Burrows and Dalton hope to design a way to create "roll-to-roll" manufacturing, where miles of chromophores could be created in one continuous process, similar to a four-color printing press that churns out material on one paper roll.

Burrows explains that current semi-conductor technology is created in a time-consuming "batch-by-batch" process. "That's like building an auto by having one guy install all the parts." Roll-to-roll manufactur-

ing for chromophores would be the equivalent to the success of Ford's automobile assembly line.

Beyond manufacturing, the PNNL and UW researchers continue to investigate the basic science of the chromophores, to better understand their mechanical properties and electrical transport abilities.

"It takes a sustained investment in basic research," says Burrows. "Larry deserves kudos. Ten years ago everyone pretty much gave up on organic electro-optic materials, but the Dalton group kept at it. The hard work is paying off and now everyone is jumping into the field."

Although the researchers know that more hard work lies ahead, they can also pause and reflect on the past success. Says Kwiram, "What has been accomplished in the last three years is quite extraordinary." ■

Marita Graube recently received a bachelor of science in technical communication at the University of Washington.

About Science & Technology Centers

The University of Washington faced tough competition in the quest to win a Science & Technology Center award from the National Science Foundation. Surpassing more than 200 initial applicants and several dozen finalists, the University of Washington became one of six institutions to receive a Center in August 2002. Ten additional NSF Centers exist throughout the nation, each exploring a specific area of science and technology.

"A Science & Technology Center is focused on the issue of supporting innovation, research, and education," says Nathaniel Pitts, Director of the Office of Integrative Activities at the National Science Foundation.

Investment in a Center also yields a great return. "At the end of the NSF's ten year support and grants of about $40 million, a Center will have yielded a large impact that is national in scope." That national impact, says Pitts, includes building a foundation for basic research, transferring the technology and research products into industry and the public sector, and educating students. "The most valuable products coming out of Centers are the students," says Pitts.