Annual Report 2008-09

ECE@UNM

Centennial Year: 2009-10

1909 - Then and Now - 2009

- 1909: UNM's Electrical Engineering program takes on departmental status, offers a four-year degree in EE (first EE courses were offered in 1904)
- 1909: UNM tuition is free for New Mexico residents, $10/semester for nonresidents
- 1910: EE confers its first undergraduate degree
- 1917: EE curriculum includes water power engineering, DC and AC machinery, electrical measurements & meters, and electrical applications
- 1929: Francis Denton becomes the first department head
- 1937: EE gains two-year accreditation from the Engineering Council
- 1956: EE enrollment exceeds that of any other UNM department; D.Sci. is offered

- 2009: Both the Computer Engineering and Electrical Engineering graduate programs are ranked among America's Best Graduate Schools by *U.S. News*
- Both undergrad programs—Computer and Electrical Engineering—continue to be accredited by ABET
- The N.M. lottery scholarship provides free undergraduate tuition for state residents
- Graduate degrees offered in 14 areas
- Sixteen research concentrations in Computer Engineering, Electrical Engineering, and Optical Science & Engineering

Tenured, tenure-track faculty	32
Degrees awarded 2008-09	105
Enrollment (grad + undergrad)	412
New research contracts	$18,088,470

THE UNIVERSITY *of* NEW MEXICO
Electrical & Computer Engineering Department

LASER TRAILBLAZER: Dr. Lester's ideas set records with quantum-dot lasers

A pioneer in quantum-dot laser development, ECE Professor Luke Lester continues to push past limits in technology.

Lester fabricated the world's fastest transistor in 1988, a record that stood for more than a decade and was not lost on the Guinness Book of World Records. His device is found today in many cell phone receivers. In 1990 he made a quantum well (QW) laser diode with an operation speed greater than any previous semiconductor laser, and today's industry standard is based on his design. He created the world's fastest long-wavelength photodetector in 1993, with a 1.3 picosecond response time that has yet to be beat. And in 2000, Lester and his colleagues at UNM's Center for High Technology Materials (CHTM) produced the first quantum dot (QD) laser whose properties surpassed those of QW devices.

"Luke is an extremely respected member of the optoelectronics community," said the University of Michigan's Pallab Bhattacharya. "Luke is considered one of the pioneers in the development of QD lasers. In fact, he is credited with demonstrating the lowest threshold current—16 A/cm^2, nearly zero—in a QD laser. Later he went on to demonstrate extremely low chirp and linewidth enhancement factor in these lasers. Luke has been a true pioneer."

Lester's research focuses on lasers with qualities useful to telecommunications—for instance, brightness that can be modulated to transmit data across fiber-optic networks, or a "tunable" laser that offers a range of wavelengths. A tunable laser would enable simultaneous transmission of many data streams in the same optical fiber.

Solutions up for grabs

Lester is pursuing a number of research topics. One is a QD passively mode-locked laser called a QD photonic integrated circuit. The device consists of up to 30 linked, independently controlled optical waveguide sections made of gallium arsenide (GaAs) embedded with indium arsenide (InAs) QDs. Depending on how a segment is biased or injected with current, it can be made into an absorber, a saturable absorber, a passive wave guide, an active laser medium, or a spontaneous LED emitter.

Lester's group has demonstrated optimization of an 11-segment device by measuring the output of different configurations of absorber, gain and passive sections (see Figure 2). The group reports a record peak power of 224 mW for QD mode-locked lasers operating over 40 GHz. They have also explored how moving the absorber section produces harmonics. For instance, when the sixth section is the absorber and the rest is gain, the frequency between pulses changes from 7.2 GHz to 14.4 GHz, the second harmonic.

Lester, who plays the cello, says this is analogous to harmonic generation on a stringed instrument. He is developing a paper for SPIE studying high laser harmonics in more depth and comparing them to the work of Jean-Louis Duport, a cellist who wrote a treatise on very high "false harmonics" in the early 19th Century.

The ability to produce different frequencies and switch between them -- in effect, creating an arbitrary waveform -- can be applied to military laser sensing and ranging where high resolution is needed to identify often obscured targets. Pulsed lasers are also useful as diagnostic tools for characterizing high-speed optical devices and for "optical time division multiplexing" that could enable communication at speeds up to 100 gigabits per second. For all applications, QD lasers promise more compact designs than existing technologies.

Another possible application of a QD photonic integrated circuit (QDPIC) is optical coherence tomography (OCT), which images tissues in medicine and paintings in art conservation. OCT is a noninvasive technique that penetrates 2-3 millimeters and produces images interferometrically. With the introduction of wide-bandwidth light sources emitting wavelengths over a 100 nm range, researchers have achieved micro meter resolution, better than ultrasound or magnetic resonance imaging.

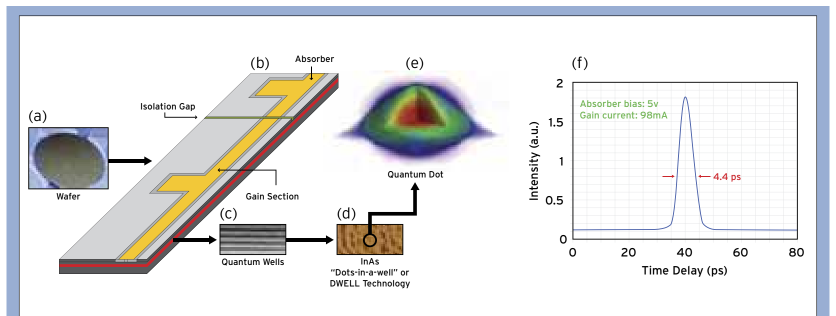

Figure 1: Grown on wafer (a), this mode-locked laser (b) has an 8 millimeter active gain length and contains four layers of indium arsenide dots-in-a-well (c). The dots, which self-assemble during molecular beam epitaxy growth,are about 15 nanometers wide and 7 nanometers tall (d). Depending on how a section is biased, it can act as either an absorber or emitter. The calculated quantum mechanical wavefunction for an electron inside a quantum dot is shown in (e). The time domain is seen in (f). This mode-locked laser has a 5 Ghz repetition rate.

However, the original sources lack power. QDs are a good candidate to broaden the bandwidth because of their range of sizes, and to boost power. With its QDPIC, Lester's group is the first to simultaneously achieve a bandwidth greater than 150 nm at a power greater than one milliwatt. Their design can be adjusted to independently change power and bandwidth and, unlike other methods, does not require a complex growth regime. One gain section is biased to saturate the low energy states in favor of high energy emission, while the other segment encourages low energy emission. By adjusting the length of each section, the researchers can saturate the lower energies sooner and use proportionately more dots to generate higher energy emission, producing more power than other technologies.

It turns out that this interplay between the filling of lower energy transitions and higher ones is also important to the linewidth enhancement factor, or chirp parameter (α). For ultrashort laser pulses, chirp means the pulses spread out due to the dispersion of the material through which they propagate, with some wavelengths moving faster than others. This is a problem for telecommunications. Lester and colleagues have a theory to explain this. As the injection current increases, α balloons from 4 to 60 as the lower energy states of the QDs are saturated. Frederic Grillot of the National Institute of Applied Sciences in Rennes, France, who is currently a visiting research professor with CHTM, saw Lester's paper and extended it, showing that after ballooning, the factor plummets to negative 30. The researchers think this happens when higher excited energy states begin "stealing" electrons and holes from the filled lower states. In a paper accepted by the Journal of Quantum Electronics, they hold out the prospect of chirpless optical transmission over much greater distances. A laser with a negative value could counteract the positive chirp of optical fibers, allowing signals to travel much farther without degrading.

The path to innovation

Bulk semiconductor lasers in the 1960s and '70s suffered from optical noise, had inconsistent wavelengths (linewidth enhancement factor), and required a lot of current (and heat) to work. Calculations in the 1980s indicated that thinning the active layer until the electrons and holes were confined to two dimensions and became trapped in energy-potential wells would improve the device. Quantum wells (QW) concentrate more electrons in energy states that contribute to laser action, making them more efficient and faster than bulk devices.

Lester, while a graduate student at Cornell, was the first person to demonstrate the predicted increase in speed of a high-frequency QW laser diode. Then, in 1998, he was handed a new GaAs wafer on which a layer containing millions of nanometer-sized dots of InAs had been grown. With the spectrum it produced, it was what he'd been searching for. It could operate at room temperature and had a low-threshold current density of 26 A/cm^2, 10 times lower than most QWs. The current record, still held by CHTM, is 10 A/cm^2. Its spread of distinct wavelengths spanned 190 nm, twice as broad as QW lasers. The CHTM team ultimately upped the span to 201 nm. Testing also showed that the device had the lowest linewidth enhancement factor measured to date.

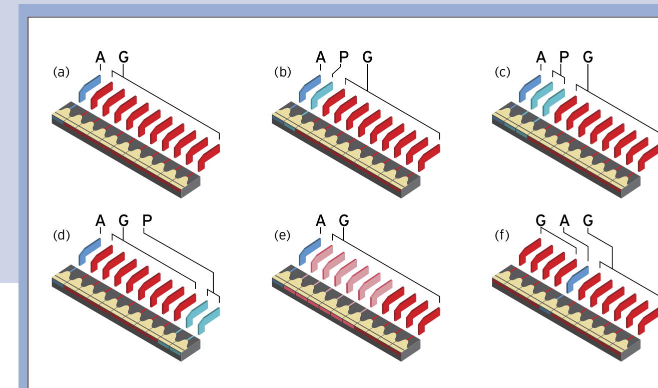

Figure 2: This quantum dot photonic integrated circuit consists of eleven 0.5 millimeter (mm) sections, each of which can be made into an Absorber (blue), Gain region (red), or Passive waveguide (cyan), depending on how that section is biased. With this flexibility, many kinds of devices can be configured. For example, laser (a) has a 0.5 mm absorber and a 5 mm gain region. With an absorber in the 5th section and a 2 mm and a 3 mm gain region on either side, the device (f) produces higher order harmonics.

The laser wafer was designed and grown at CHTM by Lester's colleagues, ECE Professor Kevin Malloy and Research Assistant Professor Andreas Stinz. Lester coined the now trademarked term DWELL (dots-in-a-well) to describe the structure. The group's first three papers announcing the DWELL laser and a later paper explaining the physics have been cited more than 520 times, and their work resulted in five patents (four U.S. and one Japanese), which are the only patents issued to date for this laser technology. Other groups subsequently demonstrated that DWELLs afford high-speed, high efficiency, and temperature-insensitive operation.

Almost everyone in the laser community now makes QD devices this way.

In 2004, Lester was named associate director of CHTM, and in 2009 he was appointed to the UNM Microelectronics Chair Professorship, which will further support his research. ◆

Excerpted from a story by Stefi Weisburd in the fall 2008 issue of "Innovative Research," a publication of the UNM School of Engineering.