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Research Breakthrough for Fiber Optic Communications

Single-Crystal Semiconductor Lasers Grown in One Step Will Function as Low-Cost Transmitters

Santa Barbara, Calif.-- A University of California at Santa Barbara (UCSB) research group has successfully demonstrated operation of a high performance long-wavelength (1.55 µm) Vertical-Cavity Surface-Emitting L aser (VCSEL) grown as a single semiconductor crystal. Such a demonstration represents the crucial step towards providing low-cost transmitters for fiber optic communications.

A VCSEL (pronounced "vicsel") is an extremely small laser, about three microns long (i.e., approximately 1/10,000 inch), which consists of two mirrors sandwiching an active region. The mirrors reflect back and forth the light generated in the active region. The reflection back and forth results in "stimulated emission" providing emitted light at a single wavelength or color. Such "coherent" emission is the hallmark of lasing.

VCSELs are intended to function as components in systems such as data links, which transmit information in the form of light within optical fibers. For a system such as a data link to be cost-effective, its price cannot exceed, say, $100. So a single, if indispensable component?the VCSEL?can cost no more than about $10. The way to achieve that comparatively low cost is through mass production. So VCSEL research basically asks the question how can tens of thousands of little lasers be made inexpensively and reliably on a semiconductor wafer (with a two-inch diameter).

The UCSB research group headed by Larry Coldren, director of the Optoelectronics Technology Center and the Fred Kavli Professor in Optoelectronics & Sensors, has approached the problem by growing VCSELs on indium phosphide (InP) semiconductor wafers as single crystals via a technique called Molecular Beam Epitaxy (MBE) or just "epitaxy," for short. Think of this technique in terms of programming a machine to deposit layer by layer first a mirror then an active region then another mirror to form a complete VCSEL structure.

Coldren described the current results?presented to a gathering of more than 100 industry, academic and go vernment leaders at the end of July and scheduled for more general dissemination at the Sept. 25 Laser Conference in Monterey, Calif. -- "as the best obtained anywhere in the world by any technique."

Heretofore, the best results for long wavelength VCSELs had been achieved by another technique, "wafer fusion," mastered by Coldren's UCSB colleague John Bowers, professor of electrical and computer engineering. The wafer-fusion technique pieces together the mirrors and active region from layers grown on separate wafers.

What distinguishes Coldren's approach not only from Bowers' but all others is the single-step growth process of nearly defect-free, single-crystal material on indium phosphide. The single-step approach promises much greater reliability when the process is scaled up for mass production than do the multi-step competitors. Not only, says Coldren, is his group's approach to VCSEL-manufacturing intrinsically less expensive than other techniques, it is also inherently more reliable.

After the crystal is grown layer by layer on a two-inch indium phosphide semiconductor substrate, tens of thousands of individual lasers or VCSELs are isolated by etching down to the cavity where the active region exists. The result is a wafer dotted with perhaps 25,000 wells -- each of which is a miniscule laser.

The key to the single-step, single-crystal growth technique was the development of a viable process to grow high quality antimony-containing layers on indium phosphide.

In order to grow a perfect crystal by the epitaxy method, the lattice constants (i.e., the spacing between atoms) of the semiconductor substrate and the overlaid layers have to match.

Conventional VCSELs in production today are based on a substrate of gallium arsenide. These VCSELs operate at short wavelengths (around 0.85µm). One key problem that arises from using short wavelength V CSELs for transmitting light through a fiber optic cable is dispersion. In other words the information is blurred if it is transmitted at a high data rate and propagates a long distance.

VCSELs that emit at longer wavelengths reduce the blurring problem. But unless very exotic active regions are used, they require a different substrate wafer, indium phosphide instead of gallium arsenide.

The key research problem then is to find combinations of semiconducting elements (from Periodic Table groups III and V) with a lattice constant match to indium phosphide that also provide for a large range of refractive index values for good mirrors as well as high-quality active regions.

Two papers submitted this summer to professional journals by Coldren's research group report successful solutions to that problem.

"Selectively-Etched Undercut Apertures in AlAsSb-Based VCSELs" describes a single crystal 1.55µm-VCSEL i n which the mirrors are made of a combination of aluminum, arsenic, and antimony and the active region a combination of aluminum, indium, gallium, and arsenic.

The other paper, describing the more recent spectacular results, "1.55µm, Double-Intracavity Contacted, InP-L attice-Matched VCSELs," details experiments with the same materials grown in a more optimized structure.

The first author on the first paper is fifth-year graduate student Eric Hall. The first author on the second paper is third-year graduate student Shigeru Nakagawa. In addition to Hall, Nakagawa, and Coldren, authors on both papers include postdoc Guilhem Almuneau and fifth-year graduate student Jin K. Kim. Additional authors of the second paper are second-year graduate student David Buell and Professor Herbert Kroemer. All authors are affiliated with the UCSB departments of Electrical and Computer Engineering and of Materials.

Images

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http://www.engineering.ucsb.edu/~coe-web/Announce/coldren.html

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