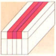
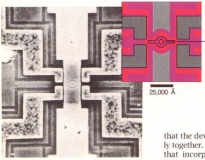
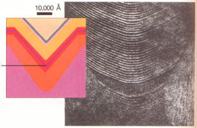
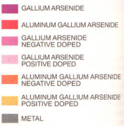


ONE DIMENSION: QUANTUM WIRE

A transparent layer of metal covers the quantum wire loop built at IBM, which is used to make electrical measurements in a magnetic field (*left*). Quantum wires fabricated at Bellcore are formed in the crescent at the bottom of the V groove in a compound semiconductor (*right*).







ever, growing the layers is straightforward. To make use of the quantum wells, researchers try to carve or pattern devices—such as lasers—from the stacked layers. (Semiconductors that emit light when energized with light or electricity can be used as lasers.)

For this purpose, Bellcore researcher Edward M. Clausen, Jr., has customized a chemically assisted ion-beam etching machine. Using a lithographic process, Clausen prints a pattern on the wafer. Then he places it in the etcher filled with chlorine gas to speed etching and bombards the wafer with ions, or charged atoms. In theory, the ions blast through any unmasked material, leaving the protected area intact. In practice, the ions can also irrevocably damage the wafer.

Clausen and his colleagues have spent countless hours trying to carve microscopic lasers from multiple quantum wells. Still, the efforts are paying off. Earlier this year a joint Bellcore and AT&T team captured newspaper headlines after etching almost two million lasers in an area slightly smaller than a square centimeter. Unlike conventional semiconductor lasers that emit light from an edge, these lasers shine from either the top or bottom surface.

Incorporating a quantum well into a laser brings one major advantage: such a device can put out light very efficiently, powered by much less current than conventional lasers require. As a result, quantum lasers radiate far less excess heat. This feature, combined with the small physical size of the lasers, means that the devices can be packaged tightly together. In this way, surface emitters that incorporate quantum wells may become the building blocks of optoelectronics devices, amalgamations of lasers and transistors working together on the same chip or circuit board.

Connie Chang-Hasnain, a Bellcore researcher, is exploring other ways to exploit such lasers in communications. On a small video monitor above her laboratory table is an unwavering picture of columns of tiny quantum well lasers. Each is surrounded by a metallic contact pad. Spindly metal probes, like overgrown mosquitoes, rest on three of the lasers' contact pads. Chang-Hasnain cautiously pumps a few milliamps of current into the probes. "It's easy to blow them out," she explains. The result shows up on another computer screen: three distinct peaks of light.

Chang-Hasnain's data indicate that each of the lasers is emitting a different frequency of light. By controlling carefully the rotation of the semiconductor substrate during MBE growth, she and her colleagues have grown a microscopic forest of lasers. Because each device has layers of slightly different thicknesses, the lasers are unique. The best result so far, Chang-Hasnain believes, is an array of 77 lasers—each capable of transmitting data on its own frequency. Tying such a bevy of lasers to a fiber-optic line "would be like adding thousands more channels to your cable television," she says.

Still, the marriage of optical and electronic components will be far from trouble free, cautions Paul L. Gourley, an investigator at Sandia National Laboratories in Albuquerque. Gourley, who is also building arrays of surface-emitting lasers, agrees the devices show the potential for high efficiencies. But coupling tiny lasers to optical fibers requires enormous precision, he points out. In addition, because light waves remain in phase—or have a longer coherence length—than do waves of electrons, building integrated optoelectronics components may prove extremely challenging, he says.

Practical Dimensions

Others continue to worry about the grittier problems of making the lasers. "Until a year ago it was so damn hard to make them," says Ann C. Von Lehmen, another member of the Bellcore team. Turning these laboratory prototypes into dependable, mass-produced devices will demand painstaking work.

Case in point: after more than 15 years of research, few quantum well lasers have reached the marketplace. One is a single quantum well, edge-emitting laser built by Spectra Diode Laboratories in San Jose, Calif. The 100-milliwatt device can convert as much as 60 percent of the electricity fed into it to light—twice as much as comparable semiconductor lasers. (Arrays of such lasers emit more light but have lower overall efficiencies.) Nevertheless, such lasers have to be built one at a time.

Like Clausen at Bellcore, John N. Ran-