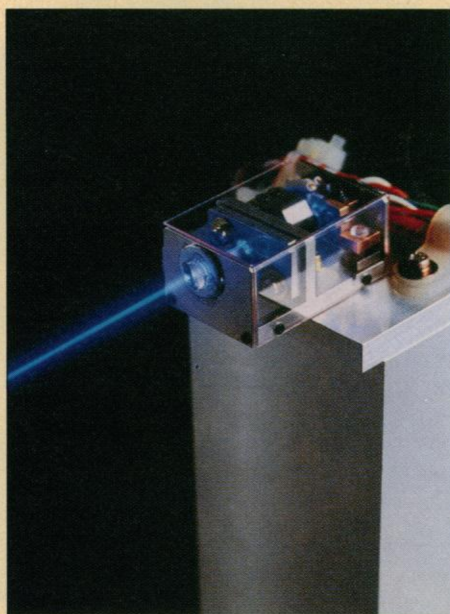
Blue-Light Special

Laser manufacturers have long wanted to sing the blues—and with nonlinear optics they may soon get their wish. A blue-light semiconductor laser—a device much like the cheap, compact infrared lasers found in CD players but with shorter wavelengths—has topped their wish list. Short wavelengths mean information could be more tightly packed on optical disks, increasing their storage capacity. "The demand for blue lasers is here now. There are huge potential markets for this," says Derek Nam, an electrical engineer at SDL Inc., a laser diode manufacturer in San Jose, California.

But demand is far ahead of supply. Laser makers have had real trouble getting blue light from semiconductors. Materials that emit blue light when they're jolted with electricity, such as zinc selenide, are not very durable, and the emitted light is often too dim (*Science*, 24 February, p. 1093). So researchers are trying to enter the blue-light marketplace via a back door known as nonlinear "frequency doubling."


DUPONT

Mo' better blues. Firing an infrared semiconductor laser through a nonlinear crystal produces a blue light beam.

Specific frequencies of light entering a nonlinear material set in motion a complex interaction among electrons that affects the frequency of the light leaving the substance, doubling it and cutting its wavelength in half (see main text). That means light from a conventional, durable infrared semiconductor laser with a wavelength of 860 nanometers can be shot through a nonlinear crystal and generate light at 430 nanometers—comfortably in the blue part of the spectrum.

But in nonlinear optics, things are rarely comfortable or straightforward, particularly solutions. "The problem," says Nam, "is power." Stamp-size semiconductor lasers don't generate a beam with much power, and at low intensities only a fraction of the beam actually converts into blue light. But over the last few years advances in the power of small lasers combined with efficiency-boosting nonlinear techniques have made the blue picture brighter.

The laser group at Coherent Inc. in Santa Clara, California, for example, has used a technique codeveloped with the IBM Almaden Research Center known as "resonant doubling." Laser light is shot through a nonlinear crystal called potassium niobate, and any light not converted to blue is captured by a mirrored "resonant chamber" and sent through again. "It allows you to build up power at a particular frequency," explains John Trail, an optical engineer heading the project. With efficiency rates of 30% even a small, 100-milliwatt infrared laser can generate nearly 30 milliwatts of blue light—plenty of illumination for reading and writing optical disks. Coherent's blue laser will be on the market this spring, but at $25,000 it's destined for high-end computer systems with massive storage needs. Despite the cost it is something of a landmark: the first solid-state blue laser on the market. "People have wanted to do this for a long while," says Trail.

At DuPont, physicist John Bierlein has taken a different route. Instead of recycling the unconverted light, his group confines the original infrared beam in a "wave guide," a thin channel of nonlinear material that doubles the frequency of the infrared photons and keeps the laser beam tightly focused, maintaining its intensity. The device is still only about 10% efficient, but starting with a typical infrared laser the final output is well over 2 milliwatts—still the minimum needed to read an optical disk. Japan's Pioneer Electronic Corp. has licensed the technology from DuPont and built a prototype system which packs an entire movie's worth of high-quality video on a laser disk the size of today's audio CDs.

Promising as these developments now seem, some blue-laser specialists see frequency-doubling devices as little more than stopgaps. "It's an engineering package very much for 1995," says Brown University's Arto Nurmikko, "but no one can argue that real blue lasers won't replace them." Such devices, he argues, will ultimately be more efficient, smaller, and cheaper than the nonlinear variety. But Nurmikko admits that "ultimately" is probably 5 to 10 years down the line. And that "is a fairly big window of opportunity [for] a temporary solution," Trail says.

–Antonio Regalado

and returning eventually to the point where they were split, where they reunite. The channels of the splitter are designed so that if the pulses are in phase at this point, they are sent off in one direction; if they're out of phase, they are routed down a different fiber.

In order to change the phase of one of the signal pulses coursing through the fiber loop, a control pulse of light is injected at the beginning of the loop so that it travels alongside one signal pulse. As it travels the loop, it "deforms electron clouds" in the glass, says Islam, causing a slight polarization of the glass molecules and increasing the material's refractive index, slowing the progress of the signal photon. But this reduction is so slight that the two pulses must travel together for several kilometers before the signal pulse is fully out of phase with its counterpart traveling in the opposite direction.

The advantage of such fiber-optic–based systems, says Islam, is that they can change the index of refraction extremely quickly, because the electron manipulation is so fast. That, Ippen adds, enables them to "switch very short pulses in very rapid succession." Last year, for example, Masatoshi Saruwatari and his colleagues at NTT showed that they could get such devices to switch light pulses at a speed of 100 gigabits per second.

But the size of the devices—the kilometers of coiled fiber pack into a container the size of a shoe box—remains a real obstacle. The transistors that form present-day switches, in contrast, can be packed by the millions onto a microchip. In an effort to shrink the optical devices, researchers around the world have been working to replace the long fiber component of the NOLMs with a tiny chip-based device made of semiconductor.

Switching phases, switching materials

Last year, the first true semiconductor analog to the NOLM, the terahertz optical asymmetric demultiplexer (TOAD), was built by Paul Prucnal and his colleagues at Princeton University. The device retains the