Laser Focus World

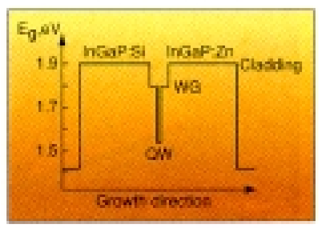
WORLD NEWS

SEMICONDUCTOR LASERS

Aluminum-free high-power diodes have long lifetimes

Scientists at Northwestern University (Evanston, IL) have fabricated high-power laser diodes based on indium gallium arsenide phosphide (InGaAsP) lattice-matched to gallium arsenide (GaAs) substrates. These devices have operated with significantly improved reliability in the same wavelength range as commercially available aluminum gallium arsenide (AlGaAs) laser diodes. They reported that structure design is the key factor in fabricating this type of laser diode. With an emission wavelength of 808 nm, the devices have power outputs of 3 W in the pulse mode, 750 mW in quasi-continuous mode, and 650 mW in continuous mode (per uncoated facet).

Because the active areas of commercially important Nd:YAG lasers are insulating, such solid-state lasers must be pumped optically, usually at 808 nm. Semiconductor laser diodes such as aluminum gallium arsenide (AlGaAs) are useful pumping sources because they are efficient and can be tailored to emit at a wavelength that matches the absorption properties of the active media. While AlGaAs technology is mature and relatively easy to manufacture, devices that use aluminum compounds suffer optical degradation rates that are at least an order of magnitude greater than aluminum-free compound semiconductors, according to developer Manijeh Razeghi.



Undoped quantum-well (QW) active region ($In_{0.13}Ga_{0.87}As_{0.74}P_{0.26}$) and waveguide (WG) ($In_{0.35}Ga_{0.65}As_{0.27}P_{0.73}$) are sandwiched between silicon- and zinc-doped InGaP cladding layers in the separate confinement heterostructure.

Degradation is attributed to the enhancement of oxidation on the mirror facet caused by the presence of aluminum. As a consequence, the lifetime of the device is decreased due to nonradiative recombination and overheating. The research team avoided the problem by designing Al-free devices based on 808-nm InGaAsP materials. In addition, dislocations that thread their way through the layers are pinned by the oversized indium atom. This effect minimizes the occurrence of dark-line defects, a lifetime limiting factor. Razeghi said that these devices have suffered no observable degradation after more than 3000 hours of operation in the quasi-continuous regime.

Separate confinement heterostructures were grown on silicon-doped GaAs substrates by low-pressure metal-organic chemical vapor deposition techniques (see figure). The device could be tailored to emit at wavelengths from 0.7 to 1 μm by changing the composition and thickness of the quantum wells. Stripe widths were 100 μm, and cavity lengths varied from 100 to 4300 μm.

The series resistance in 1-mm-long diodes was 0.04 Ω—three times less than similar AlGaAs structures. Besides improved reliability, these laser diodes offer impressive advantages in performance compared to AlGaAs-based laser diodes. In the quaternary structures, typical threshold current densities (J_{th}) were 220 A/cm^2 with a differential efficiency as high as 1.1 W/A—the corresponding values in the AlGaAs structure are 300–400 A/cm^2 and 0.5–0.8 W/A, respectively. The optical beam divergence—an important criterion for optical pumping applications—is only 26°, significantly less than the typical 32°–48° for AlGaAs laser diodes.

The aluminum-free laser diodes should have excellent electrical, optical, and structural characteristics over the whole compositional range from 0.77 to 1 μm. Razeghi said that an investigation of J_{th} and differential efficiency as a function of cavity length revealed several peculiarities that point to structure design as a key element to making high-power 0.8-μm laser diodes. For example, very rapid increases in J_{th} occurred at minimum cavity lengths (0.5 mm and 1 mm for 30-nm- and 150-nm-thick quantum wells, respectively), and for cavity lengths of 1.5-2 mm the J_{th} values are the same for both diode types. Internal quantum efficiencies approached 100%.

The team has also had success in fabricating 0.98-μm single-quantum-well laser diodes using the same techniques. This wavelength is important in pumping schemes used in fiberoptic-amplifier and laser technology.

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