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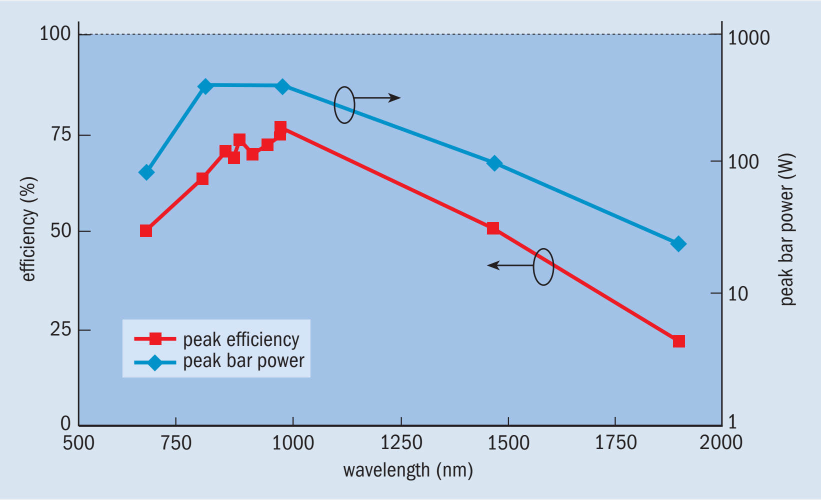
nLight expands wavelength range in order to attack new markets

nLight is aggressively targeting medical applications, displays, eye-safe communication and atmospheric sensing by extending the wavelength range of its high-power diode bars. **Richard Stevenson** reports on 660 nm and 1.9 μm emitters that feature record output powers.



nLight's diodes that span the wavelength range from 660 nm to 1.9 μm can address a range of applications as diverse as photodynamic therapy, illumination, gas sensing and eye-safe sensing.

> "It's harder [to use aluminum to build diode lasers], but if the technology is up to it, it's not a fundamental barrier."
>
> **Paul Crump**
> nLight

Manufacturers of infrared laser-diode bars are continually increasing their emitters' efficiency, with progress spurred on by the US Department of Defense's (DoD's) three-year super-high-efficiency diode-sources program. This initiative, which runs until September, has already seen companies such as nLight, Alfalight and JDSU all approach the 80% efficiency target. The improvements will aid the country's battlefield laser weapons, because increased efficiency cuts heat generation and allows refrigeration units to be smaller and easier to maneuver.

The processes that are used to fabricate these efficient infrared emitters are also applicable to the production of efficient lasers operating at other wavelengths. This has not escaped nLight, which has been developing laser diodes at both longer and shorter wavelengths than the DoD's focus on 880–980 nm. The US-based company is now offering cooled 12 W diode-bar packages at 665, 680 and 690 nm, and has just started development of 1900 nm lasers.

nLight's director of device technology, Paul Crump, says that the increased wavelength range is opening up its addressable markets. According to Crump, the market for medical applications of diode lasers was worth more than $100 million in 2005 and is growing at a frenetic pace. Applications enabled by new wavelengths include fast-growing sectors such as photodynamic therapy, where a laser activates drugs within the body. Red lasers are also in great demand for illumination and display applications, says Crump, and nLight is shipping volume products in all of these fields. Meanwhile, bars operating at around 1900 nm can be used to pump holmium-doped crystal lasers, for eye-safe communication and for atmospheric sensing.

Two factors restrict the peak power output of red-emitting lasers – thermal rollover and facet failure due to catastrophic optical mirror damage (COMD).

Thermal rollover occurs when the device temperature rises and causes the carriers to jump straight out of the quantum wells and into the contacts. This can be addressed by cryogenic cooling, says Crump, but it also increases system complexity and cost.

An alternative approach to combating the effects of thermal rollover involves designing a laser with a deeper quantum well, which improves carrier confinement. However, these red-emitting lasers have to be built on GaAs substrates and employ the AlInGaP material system that has a relatively small bandgap range. Crump explains that the greatest degree of confinement could be produced with an AlP cladding region, which has a 2.45 eV bandgap at room temperature. However, this layer is extremely strained when grown on a GaAs substrate, which limits its thickness. As a result, alloys with even smaller bandgaps are often used to form the cladding region. So in practice the maximum possible confinement voltage is only 0.5 eV, and for many commercial devices it is just 0.25 eV. This is much less than the 0.6 eV confinement energy for 980 nm commercial diodes.

Cooling without cryogenics

Although nLight avoids cryogenics, it does employ water cooling to limit thermal rollover effects and improve diode-bar output power. This may not suit applications demanding high portability, but is fine for car production plants and doctor's surgeries. The firm is also improving the bar's output power by balancing the trade-off between the number of emitters and the thermal performance, because having more emitters increases device output and operating temperature.

The second factor that restricts reliable high-power diode emission is COMD – a failure mechanism initiated by photoabsorption at the laser's facets that produces a rapid rise in local temperature. Absorption occurs because the free bonds that are formed during the cleaving process to define the laser's cavity oxidize to form mid-bandgap traps. Many diode manufacturers, including nLight, have developed various passivation techniques to reduce COMD by coating the facets with a wider bandgap material that does not absorb the laser's light.

COMD is particularly important for 660 nm lasers because the photon's energy is relatively high and the diode needs to incorporate aluminum-containing materials that are very reactive. However, Crump points out that highly reliable telecom lasers have been built with aluminum-based compounds, adding, "It's harder [using aluminum], but if the technology is up to it, it's not a fundamental barrier." The problems can also be partially avoided by using an InGaP quantum well, as aluminum then only features in the barrier layers that are subjected to a much lower optical-power density.

By addressing the problems associated with thermal rollover and COMD, nLight's engineers have fabricated 660 nm laser bars that deliver a peak optical output power of 90 W. "I don't believe anyone else has published results anywhere near us in terms of power," claimed Crump.

The emitters, which were grown on 3 inch GaAs substrates by low-pressure MOCVD and are based on the AlInGaAsP material system, have a width of 1 cm and a 1.5 mm cavity length, and feature standard dielectric high- and low-reflection coatings on the rear and front facets. The bars have 30% fill factor, defined as the ratio of the individual emitter widths to the spacings between the emitters, and were cooled by a copper microchannel heat sink that is fed with 0.5 l of water per minute at a temperature of 10 °C.

The approach indicates that output powers in excess of 200 W are possible with higher fill factors, with device degradation due to COMD limited by nLight's passivation technique. Crump reckons that it will be possible to produce commercially reliable 30 W diode bars.

Beyond telecom wavelengths

nLight has also been developing 1.9 µm diode lasers that are an extension of the company's 1 cm-wide 1.5 µm diode bars that produce more than 100 W. These InP-based sources contain InGaAs quantum wells and InGaAsP barriers and are less affected by COMD because the photon's energy is only one-third of that of a red-emitting laser.

However, they do have strain-related issues that result from the additional indium content needed to reach the longer wavelengths. Although low levels of crystal strain can benefit laser performance, higher levels lead to material deformation and a higher defect density, or phase-segregation of the alloys into regions of differing composition. Both effects reduce device performance, but can be avoided by careful control of the growth conditions, says Crump. According to him, various well-established methods are available, including optimization of the ratio of group III to group V gases, the growth rate and temperature, and by balancing the compressively strained wells with opposing tensile-strained barriers.

Integration, integration, integration

nLight, which is based in Vancouver, WA, and was founded in 2000, now employs more than 100 staff. The company has its own manufacturing facility that allows all manufacturing processes to be carried out in-house. The 56,000 ft^2 fab features a 23,000 ft^2 Class-1000 cleanroom equipped for high-volume epitaxial growth, facet coating and passivation, packaging and final device testing.

NLIGHT

NLIGHT

nLight targets many markets with a range of laser-diode products, including single-emitter packages, conduction-cooled and actively cooled diode bars, and vertically and horizontally stacked arrays.

The other issue restricting the output power of long-wavelength laser performance is carrier loss due to Auger recombination. This effect – which reduces threshold current and temperature performance, and is 10 times stronger at 2 than at 1.5 µm – is caused when the electron-hole pair transfers its energy to a third carrier instead of combining to emit light. Auger recombination is very temperature-sensitive and limits the maximum output power in these devices. Because this loss mechanism is a three-carrier process, its rate is proportional to the cube of the carrier density, so reducing the threshold current improves laser performance. A lower threshold means fewer carriers and less Auger recombination, improving high-temperature performance and increasing output power.

By using the low-threshold-current designs to minimize Auger recombination and heat sinks to control the device's temperature, nLight's engineers extracted 23.5 W at 1916 nm, from 1 cm-wide diode bars featuring a 1 mm cavity length and a 20% fill factor. Crump believes that nLight has again produced the most powerful bars ever at this wavelength, giving the company a head start at both ends of its range. This puts nLight in a strong position to capture the emerging markets for these wavelengths and drive up manufacturing volumes of its wide range of laser diodes. ●