Are Laser Manufacturers Blue with Envy?

Charles T. Whipple

Blue (or purple) diode lasers should hit the market this year and change all the rules in consumer electronics, data storage, printing and displays

Lyricists have been infatuated with blue for centuries. Songs speak of blue eyes, blue velvet, blue angels and singing the blues. Scientists' and engineers' love affair with blue light, however, hearkens back only a few decades, to the 1960s and the invention of semiconductor lasers.

They thought they'd found the key in 1969 when RCA Laboratories in Princeton, in the US, developed crystalline thin films of gallium nitride. But the next step was 22 years in coming.

Thin-film semiconductors must be grown on a substrate, and the substrate's lattice – the spacing between its atoms – must be an almost perfect match for the semiconductor's lattice. Gallium nitride grows at temperatures near 1000 °C, a factor that further limits possible substrates. In fact, only two materials match both lattice and temperature requirements: silicon carbide and sapphire. The former is prohibitively expensive, and the latter's lattice doesn't match ideally. Early on, sapphire substrates caused so many defects in the gallium nitride semiconductor layer that devices wouldn't lase.

Then, in 1986, Isamu Akasaki and his Nagoya University research group laid down a sacrificial layer of aluminum nitride on the sapphire, and topped it with a smooth layer of gallium nitride. The team also discovered how to make p-doped gallium nitride by adding *continued over page*

Laser Sources

Günter Huber, Hamburg University
Jean-Pierre Huignard, Thomson CSF, France

Compact and efficient diode pumped solid-state laser sources in the near infrared and visible spectral region are required for many applications such as measurement techniques, communications, and surgery. Besides Nd^{3+}, various efficient diode-pumped near infrared rare earth lasers have been operated with Er^{3+}, Tm^{3+}, Ho^{3+} and Yb^{3}. Compact solid-state lasers in the visible spectral region are of potential interest, especially for display, medical, and high-density optical data storage applications. Recently, optical efficiencies of more than 20 per cent with respect to the pump power were obtained in $Nd:Y_3Al_5O_{12}$, $Nd:YVO_4$, and $Nd:LaSc_3(BO_3)_4$ lasers by internal frequency doubling with a potassium titanyl phosphate (KTP) crystal. An alternative approach for the realization of visible laser sources is up-conversion pumping by energy transfer processes of two adjacent excited ions or two step pump processes as ground state plus excited state absorption.

Up-conversion Lasers

Lasers which emit at higher frequencies than the pump light usually are called up-conversion lasers. In these lasers the active ion is excited by internal up-conversion of near infrared or red light via multistep photon excitation or cooperative energy transfer and emits anti-Stokes visible light. The advent and rapid improvement of high power laser diodes in the red and near infrared spectral ranges have caused new interest in the development of up-conversion lasers. The output wavelength of laser diodes can be tuned to match the absorption lines of the active laser ion, resulting in a substantial fraction of ions excited into higher energy levels, thus enhancing the up-conversion process.

Visible up-conversion lasing at room temperature has already been demonstrated in Tm-doped crystals and in various rare earth doped fluorozirconate fibres. Er^{3+} is a very interesting ion for continuous wave (cw) up-conversion to the green spectral region.

Recently, research teams at Hamburg and Hannover demonstrated a cw Pr,Yb-fibre up-conversion laser with 1.1 W output power at 635 nm (*see photo*). This device was pumped with 5.5 W Ti-sapphire radiation near 850 nm. The pump mechanism in the ZBLAN-fibre is mainly due to avalanche up-conversion. High power diode pumping of this system seems also feasible.

The ions Tm^{3+}, Er^{3+}, Pr^{3+} provide up-conversion schemes which lead to visible cw laser operation with near infrared pumping. The simple scheme of up-conversion lasers make them attractive candidates for further research.

The beam quality of laser sources can be improved by efficient phase conjugate laser architectures based on 4 wave-mixing interactions using two different nonlinear mechanisms: the gain gratings in saturable amplifiers, and the photorefractive gratings in doped $BaTiO_3$ crystals. Both mechanisms have shown excellent capabilities for the correction of severe spatial aberrations. A nearly diffraction limited beam was obtained even when the average power and the repetition rate of the source was varied. Both configurations are attractive for compact and efficient diode pumped solid-state lasers with a diffraction limited beam quality.

Photograph of the 1.1 Watt continuous wave up-conversion fibre laser showing the pump input coupling optics, the fibre, and the red output (dark grey fibre tip, top left of picture)