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Multiline DPSS Lasers — a True Ar-Ion Alternative

by Dr. Jenni Nordborg and Dr. Håkan Karlsson, Cobolt AB, Stockholm

A diode-pumped solid-state laser, in which a periodically poled KTP crystal acts as wavelength generator, produces blue and green output simultaneously.

Mehrlinien-DPSS-Laser — eine wahre Argon-Ionen-Alternative
Ein diodengepumpter Festkörperlaser, in dem ein periodisch gepolter KTP-Kristall als Wellenlängengenerator fungiert, erzeugt gleichzeitig blaue und grüne Strahlung.

Les lasers à raies multiples DPSS — une véritable alternative Argon-Ion
Un laser solide pompé par diode dans lequel un cristal KTP agit périodiquement comme un générateur de longueur d'onde, produit une sortie simultanée en bleu et vert.

Laser pompati a diodo a linea multipla: una vera alternativa al laser ad argon
Un laser allo stato solido pompato da diodi in cui un cristallo di KTP a polarizzazione ferroelettrica periodica funziona come generatore di lunghezze d'onda, producendo nello stesso tempo il blu ed il verde.

During the past year, solid-state lasers finally started to take over a significant portion of the argon-ion gas laser market. They are finding applications ranging from flow cytometry systems, DNA sequencers, microarray scanners and confocal laser-scanning microscopy to semiconductor inspection and printing equipment.

Several technologies producing wavelengths near the 488-nm Ar-ion laser line have appeared on the market: diode-pumped solid-state lasers and optically or electrically pumped semiconductor lasers combined with frequency conversion elements or with up-conversion fibre lasers. All produce laser light with similar optical specifications, but because they have the advantages of much smaller size, lower power consumption and longer lifetime, they are rapidly taking over a substantial portion of the market. Ar-ion 514- and 488-nm wavelengths frequently can be replaced by solid-state lasers operating at 532 and 473 to 491 nm, respectively, and the latter have proved to work well in targeted applications.

Still, because manufacturers — e.g., of confocal microscopes — have long experience with and established data on Ar-ion lasers, they continue to design them into their systems. Perhaps the foremost reason that designers stay with the gas lasers is their ability to emit multiple wavelengths in the blue and green — 458, 476, 488 and 514 nm — propagating in the same beam. An important drawback of solid-state lasers has been that they emit only one wavelength. For applications that require simultaneous multiple wavelengths, one has had to combine laser units and couple the beams via complicated schemes of mirrors or into an optical fibre.

Developers at laser and crystal manufacturer Cobolt AB have created a diode-pumped solid-state laser that can generate multiple wavelengths in the visible, propagating in a single beam. The company's visible lasers are based on frequency conversion of the radiation from gain materials made of rare-earth-doped crystals, with diode lasers used as the pump source. The gain

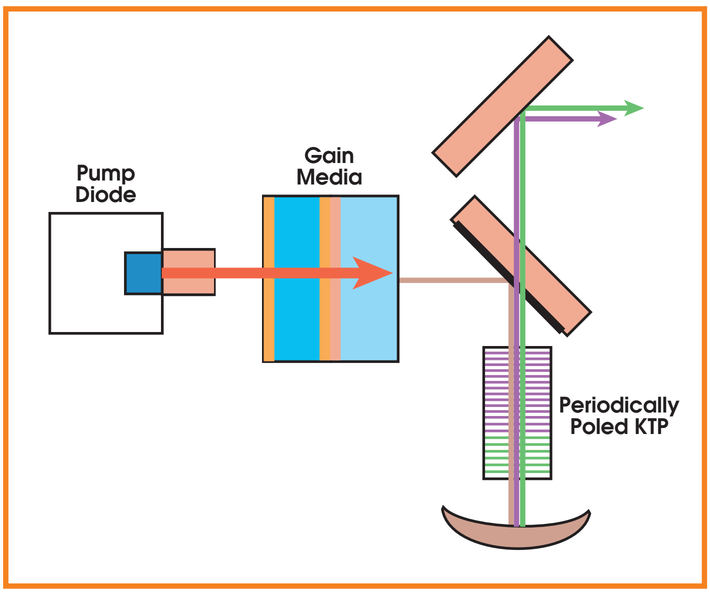

Figure 1. A schematic drawing of the dual Calypso laser shows how the two gain materials are pumped with one laser diode. Emission is sum-frequency generated using a specially designed periodically poled crystal that has two consecutive gratings along the direction of propagation to produce two wavelengths — 491 and 532 nm — shown here in blue and green stripes.

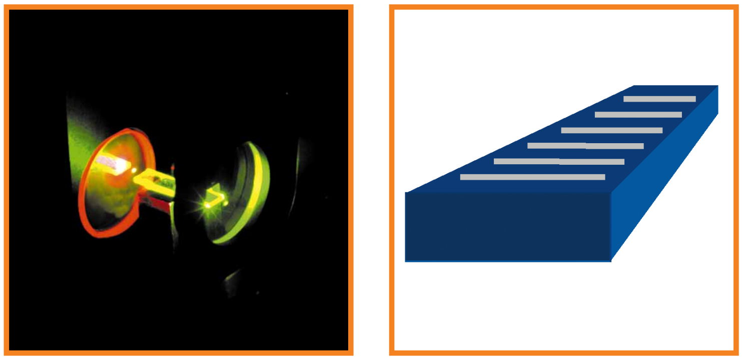

Figure 2. Periodically poled KTP crystal (left) can generate arbitrary wavelengths with a transparency spectrum of 0.35 to 4.5 µm. It has a high nonlinearity d_{eff}>7 pm/V, a high damage threshold in the visible and high mechanical and thermal stability. It maintains a single polarization for all interacting waves. The crystal can be structured with multiple quasi-phase-matching gratings (right), each with a different grating period, to achieve multiple frequency conversion.

materials are widely available, of very high quality and characterized by high efficiency and high optical power density damage thresholds, and they enable output power scaling while maintaining good beam properties. However, the emission wavelengths from lasers built on this technology are determined by a limited number of possible transitions between distinct energy levels.

By not only frequency doubling these lasers to reach the visible spectrum, but also frequency mixing several emission lines, the developers have dramatically increased the number of available wavelengths in the visible. The multiline Calypso laser exploits this technology and uses periodically poled KTP crystals for nonlinear optical frequency conversion. Periodically poled KTP is a tailored nonlinear optical material that enables quasi-phase-matching of the interacting waves, allowing the generation of arbitrary wavelengths within the transparency range of the material. Furthermore, because the crystals have a high damage threshold in the visible and a high degree of mechanical and thermal stability, they are suitable for use in the construction of high-power CW blue and green solid-state lasers. The company manufactures the crystals in-house using a patented electric field poling process.

The IR radiation from multiple gain materials is combined in the KTP crystal, which is partly inside the laser resonators to take advantage of the high intensity of the intracavity circulating field and thereby to increase the efficiency of the mixing process. In the laser's configuration, the two gain materials are pumped with the same diode laser to reduce the volume of the laser and the cost of manufacturing (Figure 1). A 491-nm beam stems from sum-frequency mixing the 914-nm emission from an $Nd:YVO_4$ laser with the 1064-nm from an Nd:YAG laser. Simultaneously, the 532 nm is generated by frequency doubling the remaining 1064-nm emission. Spatial overlap and codirectional propagation of the visible beams are ensured by involving the 1064-nm beam in the interaction that produces 491-nm emission as well.

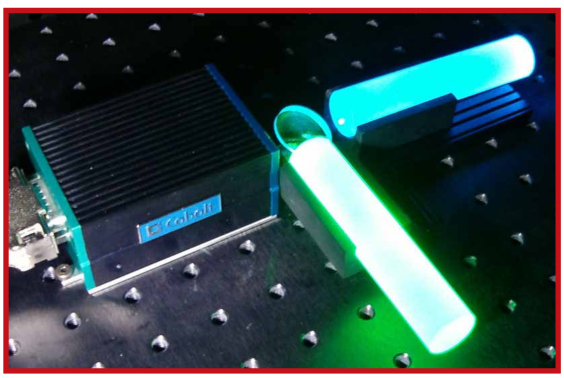

Figure 3. The dual line laser provides output at 491 and 532 nm. The two lines are separated by a beamsplitter and demonstrated by illumination in glass rods.

The periodically poled crystal is a key component in the multiline laser design. It is possible to achieve multiple frequency conversion processes in a single crystal by placing multiple successive quasi-phase-matching gratings into it, each with a different grating period, along the direction of propagation. The grating structure is created in a lithographic process, followed by applying a high-voltage electric field that alters the ferroelectric field of the crystal in an accurately controllable periodic way.

Using two or more gratings in one crystal minimizes the number of optical interfaces, reducing the complexity of the laser's design and its production cost. So far, Cobolt's device is available in a dual-line version, emitting at 491 and 532 nm (Figure 3). There is, however, the potential to add a 457-nm line from the same laser cavity. The concept could also be applied to produce red wavelengths; e.g., by frequency doubling an $Nd:YVO_4$ laser with a 1340-nm wavelength. Thus, it should be possible to realize an RGB laser source using only one pump laser and with all three colours propagating in the same beam.

The Calypso provides 20 mW of output at both wavelengths. It has very low noise (<0.3% rms) and is extremely compact. It is suitable for displays and for high-sensitivity and high-throughput bioanalytical instrumentation, specifically addressing applications that require excitation of fluorescence marker dyes. Other uses include full-colour image systems, such as motion picture video displays, and printing reprographics.

Manufacturers of confocal microscopes and flow cytometry equipment already affirm that the multiline laser opens up a new dimension in the development of compact and efficient next-generation analytical instruments. □

*Contact: Jenni Nordborg; e-mail: jenni.nordborg@cobolt.se; or Håkan Karlsson; e-mail: hakan.karlsson@cobolt.se, both of Cobolt AB, fax: +46 8 545 91 231; or **circle 99**.*