Argon-Laser Replacement for Microscopy Finally Arrived

At 488 nm, Diode Gain Material Allows Direct Modulation at Lowest Noise Level

Direct semiconductor emission in the range of 488 nm seemed to be impossible, but now a solution has finally arrived. The world's first diode laser was shown in April at the Analytica in Munich. An output power of up to 20 mW on a very small footprint is available with no additional cooling or high voltage requirement. As direct replacement for the 10,000 or more Argon ion laser units used ever year in biophotonical applications, this promises to change the instrumentation landscape. Such a laser is particularly suited for integrators that strive for much reduced noise figures, reduced heat generation, and smaller footprint.

Fig. 1: New 488 nm direct diode laser with smallest footprint and direct modulation capabilities as part of the Toptica laser family

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New Laser Sources are Making Their Way into the Microscope

Gas lasers were the backbone of laser microscopy only a few years ago. Although very little liked, their use was a must since they were the only class of lasers that delivered to the microscope the requested colours in conjunction with the right beam quality. In an attempt for more than 30 years the quest was out to substitute this class of laser sources by alternatives. As it turned out, gas lasers are not as bad as their reputation: the combination of spectral stability, long coherence length, and impeccable beam quality was a hard nut to crack for other laser schemes. New laser sources could only make their way into the microscope based mainly on formerly not available laser wavelengths but hardly ever where able to replace the Helium-Neon, Argon ion or other gas lasers.

A Quest for Stability and Miniaturisation

As a consequence of the Argon ion laser being the only acceptable laser around in the blue-green spectral region, dyes/fluorophores were developed that not only perfectly matched the available colour spectrum of this laser but also were proven to be biocompatible, making it even harder to find alternative solid state or diode laser replacements. Very sophisticated compensation mechanisms for beam pointing stability, intensity noise, and modulation characteristics needed to be added to pursue the applications in the life science field. The size and high power dissipation/inefficiency in the end were still some of the remaining issues. Neither water- nor air-cooled operation are acceptable in the quest for stability and miniaturisation, but also better unit up-time and lifetime are limited as a generic problem for gas lasers.

For years commercial companies in the field worked very hard to come up with reliable alternative solutions, either based on diode-pumped solid state lasers (DPSSL) mainly based on Nd:YAG crystal material. They were integrated into various colour-optimised resonators to produce an optical wavelength in the near infrared (NIR) spectral range that was then consequently transferred by an extra- or intra-cavity nonlinear process to the visible spectral region. Solid state laser systems are technologically challenging, their spectral coverage offers only discrete spectral lines as it is the case with gas lasers, adding new but again fixed spectral lines like their already established gas laser counterparts. Due to the nonlinear character of the light generation, noise and drift issues were and are plaguing these lasers up to date. Direct modulation or switching is no option neither with gas nor solid state lasers. Instead unwanted acousto- or electro-optic modulators are needed for high level integration.

A Hard Time to Reach the Visible Part of the Spectrum

Semiconductor lasers, the most successful laser class of all, on the other hand had a hard time to reach the visible part of the spectrum too. The bread-and-butter material systems of the semiconductor (InP, GaAs) due to their band gap structure are for fundamental reason not capable of producing visible light, offering again nonlinear frequency conversion as the only escape adding issues similar as given above for DPSSL. Only recently, in a nearly heroic effort the world of diode lasers has changed when a new semiconductor material named Gallium Nitride (GaN) entered the commercial laser scene for the first time in 1998 [1]. With

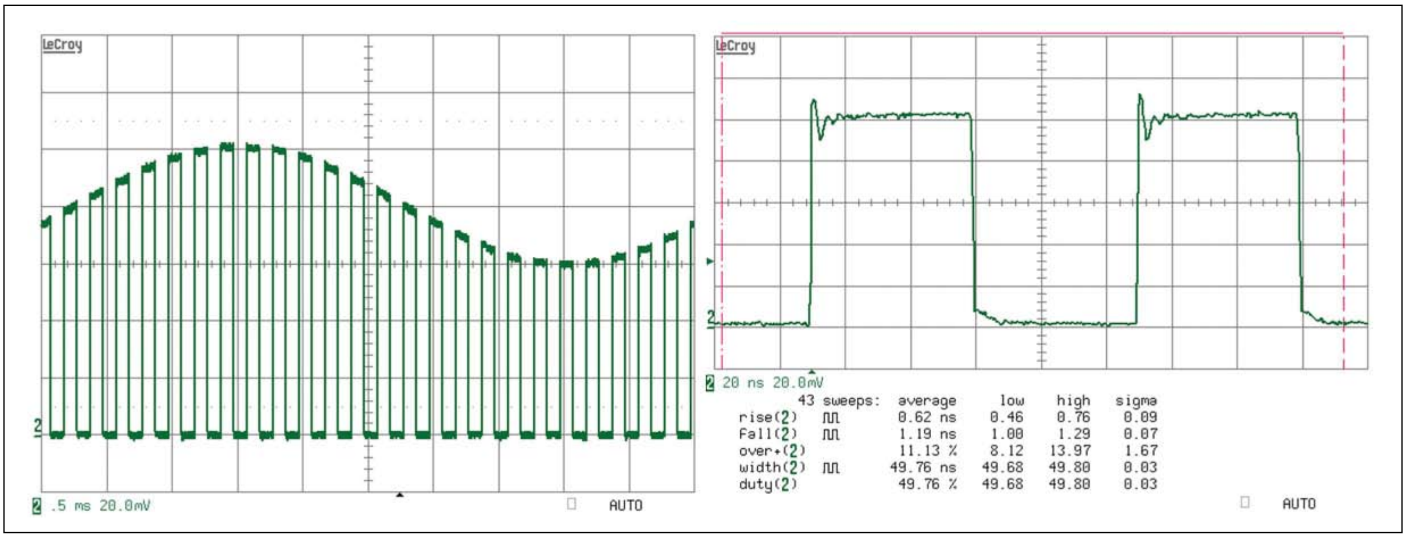
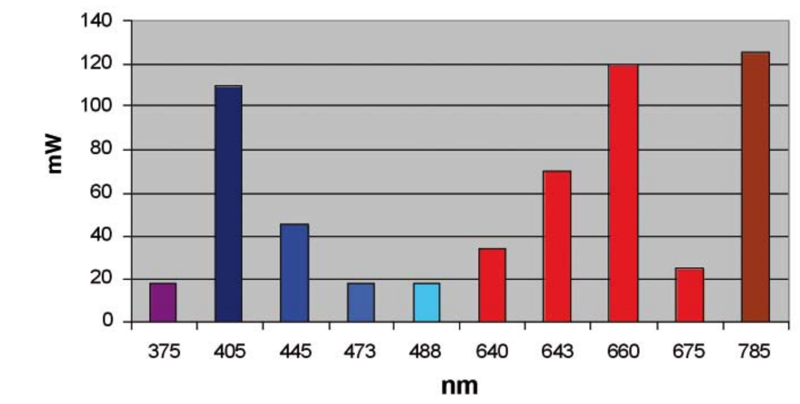


Fig. 2: Direct digital output modulation (sub ns rise and fall time, up to 250 MHz), and a superposed analogue modulation up to 2 MHz (@ 30 % mod. depth) and can be realised now at 488nm without any need for external modulators.

the main target being the third generation of optical data storage (Blu-ray) the technology was refined mainly for operation at 405 nm and has matured in a remarkable speed. The GaN material system allowed also extensions into the shorter wavelength region (370 nm) and via 445, 473 now even 488 nm is available as excitation source for confocal microscopy, and high throughput / high content screening (HTS / HCS). It took a while to add the requested spatial beam quality ($M^2 < 1.2$) to the diodes but then diode laser based products like the Toptica iBeam and iPulse were warmly welcomed by the microscopists. The direct modulation capability (up to 250 MHz) is one of the strongest arguments for laser diodes when replacing gas lasers in these spectral regions, but also for the first time intelligent digital communication with the laser directly was possible. No warm-up time, laser light only when needed, sub nanosecond pulse rise time, coherence control and other features like multilevel operation, digital asynchronous modulation as an integral part of the laser source suddenly offered new opportunities for system integrators. Concerns about life times for the new material were ruled out quickly (well beyond 10,000 hours effective laser-on-time) making this one of the strongest points in the sales process. Beam quality (wavefront < lambda/20), beam pointing at a new level (< 10 µrad/K) and minimum intensity noise and drift (< 0,5 % over 48 hours) are now paving the way of this very small footprint lasers into actual devices in the blue and green region. Single mode fiber coupling efficiencies of 75 % are routinely achieved using proprietary fiber coupler technique.



	375 nm	405 nm	445 nm	473 nm	488 nm	640 nm	643 nm	660 nm	675 nm	785 nm
Output Power Free-beam	18 mW	110 mW	45 mW	18 mW	18 mW	34 mW	70 mW	120 mW	25 mW	125 mW
Output Power Fiber (SM)*	12 mW	40 mW	32 mW	12 mW	12 mW	25 mW	50 mW	85 mW	18 mW	90 mW

Fig. 3: Overview of available diode laser wavelengths and there output power levels

"488 nm diode lasers are a revolution to this industry, and will change the microscopes fast." was one of the first reaction of visitors, when they saw the new laser source in early April. In particular, laser integrators showed strong interest and first product qualification has already started with key customers.

Toptica will integrate the 488 nm semiconductor also into other established products realising wavelength tuning (485 to 490 nm), high frequency modulation (speckle suppression) and linewidth narrowing (< 1 MHz ≙ 0,8 femto meter) at this wavelength. Therefore more applications (digital microscopy, interferometry, ellipsometry) will be able to benefit from the diode-based aquamarine laser. Toptica offers 488nm light from tunable fiber lasers for some time [2], but now to make continuous wave diode laser light for 488nm available is an important milestone for the company and an important contribution to the biophotonics market.

References

[1] Kaenders W. and Nakamura S.: Laser Focus World 35 (4), (1999)

[2] Lison F. *et al.*: Physik Journal 4 (6), 72 (2005)

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