Diode-pumped lasers based on neodymium-doped materials now dominate application areas such as surface marking, wafer inspection, via drilling, and pumping titanium-doped sapphire (Ti:sapphire) laser oscillators and amplifiers. In comparison to their lamp-pumped predecessors, diode-pumped lasers provide advantages such as high reliability, output stability, low maintenance requirements, compact size, and low utilities consumption.

Each of the neodymium-doped materials offers different capabilities, depending on its optical and thermo-mechanical properties. Neodymium-doped vanadate (Nd:YVO₄), for example, is well-suited to delivering modest pulse energies at relatively high pulse repetition rates, while neodymium-doped yttrium lithium fluoride (Nd:YLF) is better for providing higher pulse energies at low repetition rates, appropriate for pumping kilohertz-class Ti:sapphire amplifiers. Commercial Nd:YLF laser systems have now been refined to a high level of reliability, performance, and ease of maintenance. This last attribute is particularly important for applications requiring long-term, hands-free operation.

Nd:YLF is characterized by a low degree of thermally induced lensing, strong natural birefringence, two orthogonally polarized lasing lines, and—particularly important to its application in pumping kilohertz Ti:sapphire amplifiers—long upper-state lifetimes compared to other neodymium-based materials. Specifically, Nd:YLF laser transitions at 1.047 µm and 1.053 µm have upper-state lifetimes of around 490 µs and 540 µs, respectively, versus 230 µs for neodymium-doped yttrium aluminum garnet (Nd:YAG) and around 90 µs for Nd:YVO₄. This substantial difference is the key to the use of Nd:YLF in kilohertz-class, high-pulse-energy lasers.

In a typical Q-switched laser, the optimal pumping time is roughly one to two times the spontaneous lifetime. Nd:YLF can be pumped for about 1 ms before the stored optical gain reaches a plateau due to spontaneous upper-state emission. In contrast, the energy storage in Nd:YAG reaches a maximum after pumping for only about half this time. More optical energy can thus be stored in Nd:YLF than Nd:YAG or Nd:YVO₄.

A common misconception exists that the long upper-state lifetime of Nd:YLF renders it an inferior material for use at high repetition rates. In reality, in an Nd:YLF laser optimized for 1-kHz operation, the output power drops only imperceptibly at pumping rates as high as 15 kHz (see figure). Several commercial Nd:YLF lasers exist based on cavities designed for optimum
As a laser material, Nd:YLF is well suited to kilohertz-repetition-rate applications, for which it delivers higher pulse energies than other neodymium-based materials. In conjunction with diode pumping and ultra-stable laser architectures, this has led to lasers with reliability levels that were unthinkable just a few years ago. An external modulator selects a 2-ns slice from this pulse in order to generate pulses of electrons that match the 2-ns “bunch time” of the accelerator. Depending on the quantum efficiency of the specific photocathode material, the target is irradiated with only 30 to 50 µJ/pulse.

The SLAC Ti:sapphire laser also includes a birefringent filter used to tune the output wavelength to that appropriate for the photocathode material. This is relevant because the laser system is also used to support a research program designed to measure the spectral response of different photocathode materials.

Physicist Axel Brachmann of SLAC explains the benefits of a high-reliability, all-solid-state laser: “Our operating conditions require a ‘set and forget’ type of laser system. The laser operates 24 hours, seven days a week over extended periods of time (several months continuously). Moreover, the laser is located in an interlocked location that cannot be readily accessed without disrupting all electron-source activity. The Q-switched Nd:YLF laser continues to meet this high-reliability need. In fact,” he continues, “the laser performs to specifications with the only interruptions being routine maintenance activities such as pump-diode replacements, which are typically performed once a year.”

The group closely monitors the pulse-to-pulse statistics of the laser, says Brachmann, since significant variations would lead to unacceptable changes in the electron generation process. During a typical 24-hour period, with a mean output of 2.99 mJ, the system operates with a standard deviation of only 0.42%.

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