

Diode-pumped alkali lasers aim for single-aperture power scaling

William Krupke

Electrically driving a flowable laser gain medium is key to high output beam quality.

Military directed-energy applications generally require development of compact, efficient, high-power ($\gg 1\text{kW}$) lasers with excellent beam quality. Gas lasers, such as chemical oxygen-iodine devices, have been pursued for these purposes, in part because of their ability to flow the gain medium through the laser resonator to avoid thermo-optical distortions that would degrade beam quality. Nevertheless, chemical gas lasers are burdened by the need for large amounts of highly reactive chemical compounds that are not usually included in military field-supply logistics. This remains a significant impediment to operational deployment.

The development of high-power semiconductor laser-diode pump sources in the past decade has enabled a significant increase in the efficiency, power, and compactness of bulk solid-state lasers, which has attracted the attention of directed-energy researchers for military applications. Diode-pumped bulk solid-state lasers have now been scaled well into the multi-kilowatt regime with excellent beam quality. However, these lasers appear limited to perhaps several tens of kilowatts in a single spatially coherent aperture because of thermo-optical distortions produced in the static gain medium. To overcome this conundrum, I proposed^{1,2} the diode-pumped alkali laser (DPAL) concept to benefit from the attractive efficiency and power-scaling properties of high-power pump-semiconductor-laser diodes, while replacing the solid-state gain medium with a gaseous (vapor) medium to recover convective transport of waste heat from the laser resonator.

The DPAL energy-level scheme is deceptively simple (see Figure 1). Neutral alkali atoms have three active electronic energy levels. In a DPAL, population inversion is produced between the lowest excited $^2P_{1/2}$ level and the ground $^2S_{1/2}$ state, re-

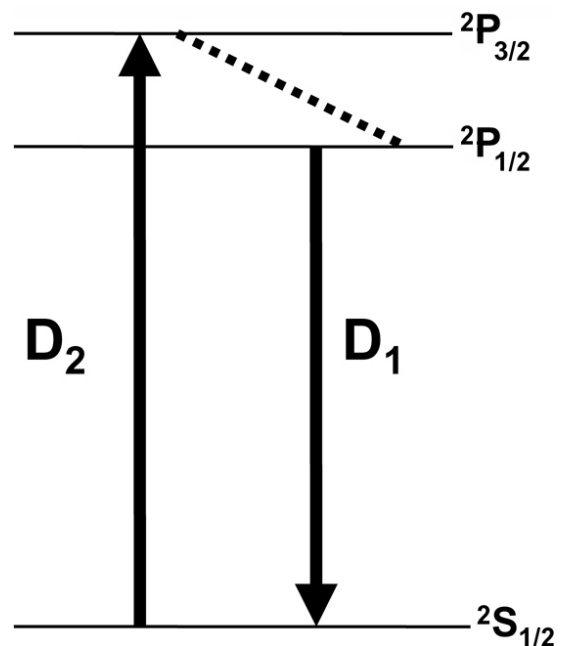


Figure 1. Diode-pumped alkali laser (DPAL) energy levels ($^2P_{3/2}$, $^2P_{1/2}$, and $^2S_{1/2}$) and their transitions (D_1 and D_2).

sulting in laser action in the resonance D_1 transition. This is achieved by pumping the D_2 transition with a semiconductor laser-pump diode: the operating wavelength ranges of highly developed aluminum gallium arsenide (AlGaAs) laser diodes span the range of D_2 transitions of the cesium (Cs), rubidium (Rb), and potassium (K) atoms. To ensure efficient DPAL gain and power conversion, electrons pumped to the $^2P_{3/2}$ level must be relaxed rapidly to the $^2P_{1/2}$ state (usually through collisions with a buffer gas consisting of a rare gas and/or small-mass molecular gas such as ethane or methane). The buffer gas also collisionally broadens the atomic transitions sufficiently to ren-

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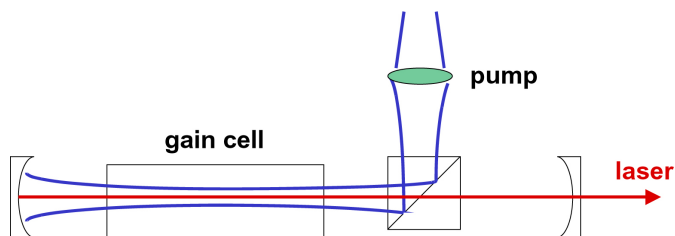


Figure 2. End-pumped DPAL laser geometry.

der them spectrally homogeneous for enhanced absorption of pump radiation. A typical DPAL gain-medium mixture comprises an alkali vapor pressure of a few millitorr (cold temperature of 100–150°C), 100torr of ethane, and 1–2atm of helium. Note that alkali quantum defects—leading to waste heat per excited atom and defined as $1 - (\text{laser wavelength}/\text{pump wavelength})$ —are relatively small (Cs-0.047, Rb-0.019, and K-0.0044) compared to those of well-known solid-state lasers (e.g., Nd:YAG-0.27, Yb:YAG-0.10).

Efficient Cs, Rb, and K alkali resonance-transition lasers have been demonstrated successfully and their observed performance accounted for using a simple plane-wave rate-equation laser model³ and literature spectroscopic and kinetic parameter values. These initial experiments used titanium-doped sapphire or alexandrite lasers as surrogate pump sources. In all cases a classic ‘end-pumped’ optical laser configuration (parallel pump and laser beams) was employed with a static gain medium (see Figure 2). Slope power efficiencies as high as 81% (Cs), 72% (Rb), and 67% (K) have been observed, in accord with expectations. True diode-pumped DPALs have also been developed for Cs and Rb in static gain-medium cells with output powers and slope efficiencies, respectively, as high as 10W and 68% (Cs) and 17W and 53% (Rb).^{4,5}

In each of these experiments the gain medium was static, and waste heat removal from the lasing volume occurred through free convection. Efforts to further increase DPAL average output power have retained static gain media but resort to geometries in which at least one high thermal-conductivity wall is placed close to the pumped active laser volume, as in a circular capillary or a planar waveguide. Calculations suggest that capillaries may be scaled to output powers into the 100W regime, and that 2D waveguides may scale to output powers into the kilowatt range. In scaling to much higher powers, it is anticipated that a flowing DPAL medium will be needed, which will likely be undertaken in the next few years.

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