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Intensity scaling for diode pumped alkali lasers

Glen Perram

Diode pumped alkali metal vapor lasers offer significant promise for high average-power performance and laser-weapon applications.

Laser weapons may find broad military applications against many types of targets from tactical to strategic missions on the ground, sea, air, and in space. The highest priority and nearest term applications are the defense against ballistic missiles, cruise missiles, rockets, artillery, and mortars. Recent progress in developing diode-pumped solid-state lasers has been dramatic and enables electrically driven systems. However, thermal management and associated beam quality issues continue to stress the design and may limit employability and effectiveness.

A new class of optically pumped laser, the diode-pumped alkali metal vapor laser (DPAL), was proposed by W.F. Krupke and colleagues in 2003.¹ Radiation from unphased diode lasers is absorbed in the near IR by atomic potassium, rubidium, or cesium. The gain cell for a DPAL system using a heat pipe design is illustrated in Figure 1. Collisions with rare gases or hydrocarbons induce energy transfer and populate the upper laser level. Lasing is achieved at 770–894nm. The quantum efficiency is very high, 95–99%, the gain medium is small even for high power applications, $\sim 10\text{cm}^3$, and the broadband (1–3nm), low brightness ($M^2 \sim 1000$) diode-pump photons are converted to a single coherent beam. Thermal loads can be rejected in a slow flow (10m/s), closed loop cycle, promising very high beam quality ($M^2 \sim 1$). Recently, a closed-loop transverse-flow cesium laser achieved 1kW of laser output power.² The optical-to-optical efficiency in this device was 48%.

Early DPAL laser demonstrations were limited to pump intensities of a few times threshold, reducing optical efficiency. For efficient operation, the system needs to be pumped with diode intensities of greater than $10\text{kW}/\text{cm}^2$. Two years ago, we demonstrated linear scaling of a rubidium laser to 32 times threshold.³ In our present work, we explore scaling to pump intensities of $>100\text{kW}/\text{cm}^2$. The collisional relaxation between the pumped and upper laser levels must be fast in order to prevent bottlenecking for these high-intensity conditions. Bottlenecking

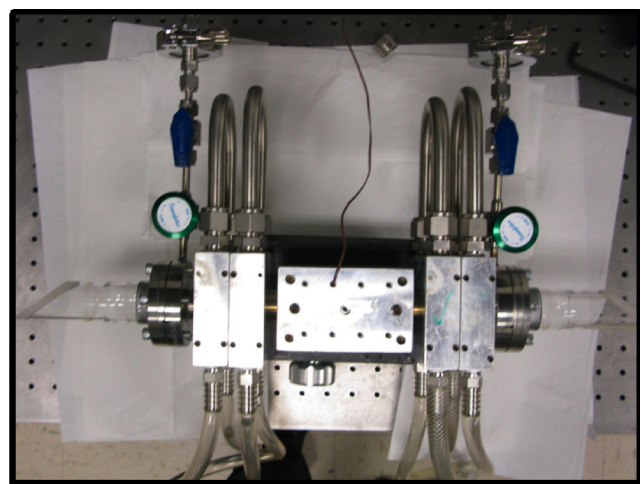


Figure 1. Diode pumped alkali metal vapor laser (DPAL) gain cell with Brewster windows.

limits the excitation rate and prevents further scaling of output power. Each alkali atom in the laser medium may be required to cycle as many as 10^{10} pump photons per second.

We demonstrated a rubidium laser using a pulsed dye laser at pump intensities exceeding $3.5\text{MW}/\text{cm}^2$ (>1000 times threshold). More than 250 photons are available for every rubidium atom in the pumped volume during each pulse. For modest alkali atom and ethane spin-orbit relaxer concentrations, the gain medium can only process about 50 photons/atom during the 2–8ns pump pulse. Any additional pump photons are not absorbed and wasted. At 110°C and 550 Torr of ethane, the system becomes bottlenecked. The system efficiency based on absorbed photons approaches 36% even for these extreme pump conditions. To alleviate the bottlenecking, we employed a heat-pipe reactor for a potassium DPAL. At 320°C with 2500 Torr of helium only, the pulsed potassium laser achieved a $1.15\text{MW}/\text{cm}^2$ peak intensity and 9.3% optical-to-optical efficiency.

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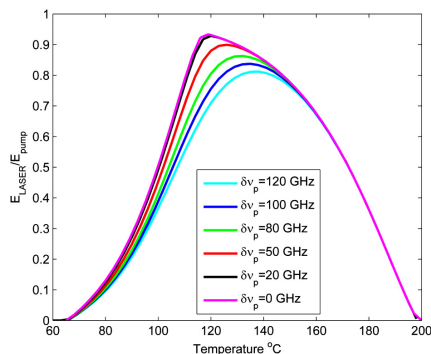


Figure 2. Optical-to-optical efficiency (E) for a rubidium DPAL.

We also developed a three-level analytic model by considering the steady-state rate equations for the longitudinally averaged number densities.⁴ By assuming a statistical distribution between the upper two levels, we achieved the limiting solution for a quasi two-level system. For properly designed gain conditions, the quasi two-level solution is usually achievable and represents ideal performance. We identified a second limiting solution for strongly bleached conditions where the atom recycle rate, limited by spin-orbit relaxation, fully specifies the output power. Performance in the intermediate regime depends significantly on the pump bandwidth relative to the atomic absorption line width and requires numerical simulation (see Figure 2). Absorption well into the wings on the atomic profile can be used by increasing alkali concentration, but it imposes an increased pump intensity threshold.

Our DPAL development path comprises two strategies, high-pressure gain cells (>10 atmospheres) and diode bars with modest spectral narrowing (>100GHz), or low-pressure gain cells (~1 atmosphere) and diodes with dramatic spectral narrowing (~10GHz). In both cases, the pump spectral width can be larger than the atomic absorption profile and still yield efficient operation. The DPAL slope efficiency decreases with increasing pump bandwidth for a given alkali concentration. However, increasing the alkali concentration to obtain similar absorption can restore much of the performance. The threshold pump intensity does increase for higher alkali concentrations. All absorbed photons above threshold can be converted to output photons in the quasi two-level limit if the cavity is lossless and the resonator extraction is ideal, meaning there are no scattering losses. When the DPAL output intensity is measured against absorbed pump photons, rather than incident pump intensity, a single performance curve is observed.

The hybrid DPAL system combines efficient diode pumping with the good beam quality and superior thermal characteristics of gas lasers. We have demonstrated the scaling of DPALs

to pump intensities of greater than $1\text{MW}/\text{cm}^2$ with good efficiency. Future experiments will be designed to scale intensity for continuous-wave (steady) laser pump sources.

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Glen Perram has served with the institute faculty since 1989. His research interests include high-power lasers, laser material interactions, and remote sensing of battlespace combustion events.

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