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Intensity scaling of an optically pumped potassium laser

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ABSTRACT

A pulsed, optically pumped potassium laser has been demonstrated with output intensity exceeding 7 MW/cm^2. By using a surrogate pump, heat pipe gain cell, and helium pressure of 2500 Torr, the intensity of Diode Pumped Alkali Lasers (DPAL) has been increased by a factor of 38. Bottlenecking due to slow fine structure mixing can be avoided without hydrocarbon buffer gases with as many as 375 lasing photons obtained per potassium atom following a 7.4 ns pump pulse. A slope efficiency of 9.4% is achieved and primarily limited by a mismatch between pumped and cavity mode volumes. Laser performance is well described by a three-level, longitudinally averaged model without ionization.

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1. Introduction

The Diode Pumped Alkali Laser (DPAL) was invented in 2001 [1,2], with the first diode pumping achieved using Cs vapor in 2005 [3]. The three level laser system involves diode laser pumping on the D$_2$ $^2S_{1/2} \rightarrow {}^2P_{3/2}$ line and collisional relaxation to the lower $^2P_{1/2}$ state to achieve lasing on the $^2P_{1/2} \rightarrow {}^2S_{1/2}$ transition. Threshold pump intensities are high $\sim$1 kW/cm^2 [4], slope efficiencies can be as high as 81% [5], and power has been scaled to $\sim$1 kW [6]. Scaling with pump intensity is typically limited to 10–30 times threshold, or $<$40 kW/cm^2 [7–9].

The potassium variant of the DPAL has received less attention due to diode source availability at the shorter wavelength, higher threshold pump intensity and lower gain. However, the K system offers some important advantages associated with the smaller fine structure splitting, including higher quantum efficiency, lower heat load, faster mixing rates and lower pressure, hydrocarbon-free gain cells. Atmospheric transmission for the K laser is good, lying between two rotational lines of the O$_2$ (X-b) system [10]. The first K laser using a surrogate continuous wave (cw) pump and ethane buffer gas achieved 14 mW with 20% slope efficiency in 2007 [11] quickly followed by a similar system with helium buffer gas [12]. A more efficient (64%), pulsed system was scaled to 10 mJ/pulse in 2009 [13]. A diode pumped potassium laser was first achieved in 2011 exhibiting a high threshold of 2 kW/cm^2 at 2240 mW output power [14]. Most recently, a 16 W potassium laser pumped by a 50 W diode stack has been reported with a threshold of 4 kW/cm^2 [15].

Power scaling of DPAL devices can be achieved by increasing the pump intensity or increasing the aperture size (pumped area). Increased pump intensity requires higher fine structure mixing rates to prevent bottlenecking [4]. At higher intensities the effects of nonlinear processes and ionization may become important [16,17]. Several laser demonstrations have examined intensity scaling to 180 kW/cm^2 [7,18]. In the present work we employ a potassium heat pipe and helium pressures of 2500 Torr to dramatically increase the output intensity to 7 MW/cm^2.

2. Experiment

The apparatus for the optically pumped potassium laser is illustrated in Fig. 1. A frequency-doubled Quanta-Ray Pro Series pulsed Nd:YAG laser (10 Hz, 1 J/pulse, 532 nm) is used to pump a Sirah model PRSC-D-1800 dye laser with LDS-765 dye tuned to the K D$_2$ transition at 766.5 nm. The dye laser provides 5.1–7.4 ns pulses (FWHM) as the energy is tuned from 2 to 20 mJ/pulse by varying the Nd:YAG flashlamp energy. The most intense portion of the dye laser beam exhibits an area of about 0.032 cm^2. The intensity of the dye laser and corresponding pulse duration is provided in Fig. 2. At 1.8 mJ/pulse, the pump intensity is 77 MW/cm^2. The dye laser spectral width (FWHM) is ~31 GHz and is ~98% vertically polarized.

The pump laser was directed toward the laser cavity using a polarizing beam splitter or PBS. A small fraction of the light passed through the PBS and scattered off a beam block. The temporal pulse shape of this scattered radiation was detected by a New

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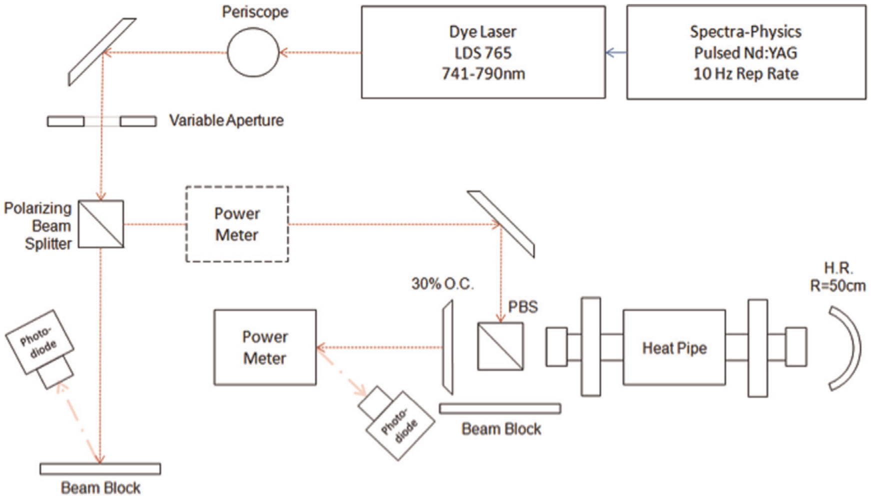

Fig. 1. Experimental apparatus.

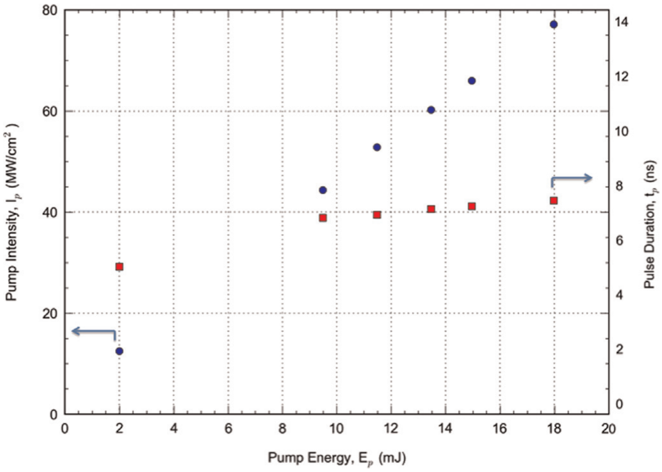

Fig. 2. Dependence of: (●) pump intensity and (🟥) pulse duration on energy per pulse.

Focus Model 1621 visible photo-detector and recorded on a LeCroy Wavepro7300 3 GHz oscilloscope. The majority of the pump laser was reflected off the PBS and traveled in the direction of the DPAL cavity. A Coherent Powermax PM30 power meter could be moved into position to detect the time-averaged power incident on the laser cavity. When this power meter was not blocking the beam, the pump laser reflected off a flat mirror and entered the laser cavity through a second beam splitter.

The laser cavity consisted of a flat 30% output coupler, the PBS, the heat pipe gain cell, and a high reflector with a 50 cm radius of curvature. The distance between the cavity mirrors was 45 cm. The normal incidence Sapphire windows at either end of the heat pipe each had approximately 8% loss before degradation. However, we estimate higher total cavity losses during operation with a threshold gain of 0.08 cm^{-1}. Any light that passed through the laser cavity could be measured in three different ways: a Coherent Powermax PM10 power meter displayed the time-averaged output power, an Ocean Optics HR4000CG spectrometer recorded the spectral frequencies of the output onto a laptop, and a second photodetector recorded the temporal pulse shape on the oscilloscope.

A stainless steel heat pipe 30 cm long and 2.54 cm in diameter contained about one gram of potassium metal. The ends of the heat pipe were cooled to 20 °C using an aluminum water jacket and Neslab RTE-111 chillers to prevent condensation of potassium vapor and damage to the windows. The central section of the heat pipe was enclosed in an aluminum heater block with eight C1E14-L12 heater cartridges controlled by a Watlow single zone heater

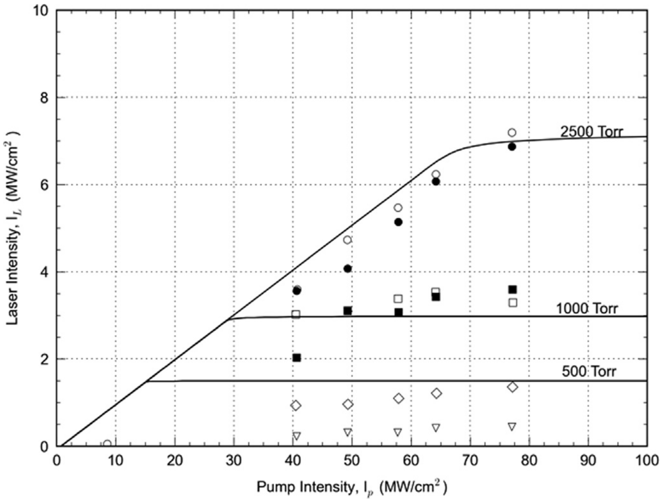

Fig. 3. K Laser intensity as a function of pump intensity for helium pressures of: (▽) 100 Torr, (◂) 500 Torr, (■) 1000 Torr, (□) 1400 Torr, (●) 2000 Torr, and (o) 2500 Torr. Predictions from the theory of Eqs. (1) and (2) at 500, 100 and 2500 Torr are also provided.