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Power degradation due to thermal effects in Potassium Diode Pumped Alkali Laser

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ABSTRACT

This paper presents results of our study of the performance of a Potassium DPAL operating in pulsed mode with pump pulses from 0.05 to 5 ms long at different pump powers and alkali cell temperatures. The experiments showed the DPAL output power degradation in time with a characteristic time in the range from 0.5 ms to 4.5 ms. We attribute the power degradation to heating of the vapor. The recorded spectrum of the side fluorescence indicates that multi-photon excitation, energy pooling collisions and ionization are also present.

1. Introduction

There has been extensive research into Diode Pumped Alkali Lasers (DPALs) during the past decade because of their potential for efficient scaling to high powers while maintaining a high quality output beam. These lasers are often called "Hybrid Lasers", because they combine most of the important features of Diode Pumped Solid State Lasers (using efficient diode laser pumping) and high power Gas Lasers (excellent optical quality of the gain medium and thermal management). There are 4 alkali atomic vapors: Cesium (Cs), Rubidium (Rb), Potassium (K) and Sodium (Na) which have each been demonstrated lasing using optical pumping [1–4], and the first three of them demonstrated efficient lasing with diode laser pumping. The best results for diode laser pumping were achieved with Cs and Rb DPALs [5–7] including the demonstration of 1 kW output power with optical efficiency about 50% in continuous wave (CW) regime for Cs DPAL [8]. Regarding the optically pumped K laser, the best results were obtained only with so called "surrogate" (not diode laser) pump source, a pulsed (275 ns pulses) Alexandrite laser: Optical-to-optical efficiency of 57% for K laser has been demonstrated [9,10]. The experiments on CW pumping of K vapor with diode lasers were also performed, but slope efficiency higher than 25% was not attained [11]. On the other hand, in our recent experiments with pulsed K DPAL [12] we have demonstrated 52% slope efficiency and 30% optical efficiency. Additionally, these pulsed results indicate the existence of performance limiting effects, perhaps ionization and thermal (lensing, convection, etc.) effects, when operating in CW mode. In this paper we present the results of our experiments on study of the time resolved efficiency degradation in K DPAL with static gain cell pumped by pulses with duration up to 5 ms.

2. Experimental setup and results

A diagram of the experimental setup is presented in Fig. 1. An L-shaped laser cavity with longitudinal pumping of the gain medium was used with a polarizing beam splitting cube (PBS) inside the cavity that allows separation of the pump and lasing beams that have orthogonal polarizations. The 1 cm long K vapor cell had AR coatings on both sides of the cell windows to minimize losses in the cell for both the operation wavelength (770 nm) and the pump (766 nm). The cell was filled with metallic K and 600 Torr of helium at room temperature before being sealed. The sealed cell was assembled inside an oven that could control the cell temperature while keeping its windows at about 5 °C higher temperature than the cell body to prevent potassium condensation on the windows.

The gain medium was pumped by a line-narrowed diode laser stack operating at 766 nm. The stack emission line width was less than 20 GHz (FWHM) and centered at 766 nm. The stack operated in pulsed mode with variable pulse duration in the range from 0.05 ms to 5 ms and repetition rate of 4 Hz. Such a rep rate provides enough time to minimize the heat contribution from the previous pulse. It is shown below that the required time for this is about 200 ms.

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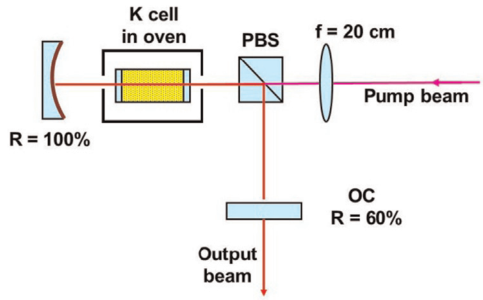

Fig. 1. Diagram of the experimental setup.

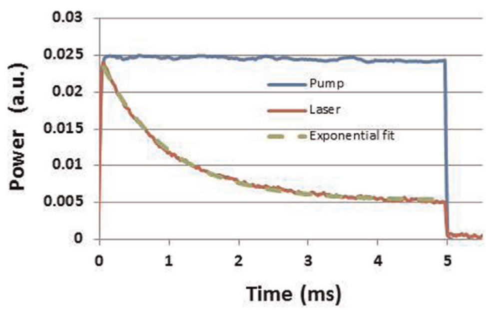

Fig. 2. Pump and lasing pulses for a pump power of 73 W and a cell temperature of 185 °C along with an exponential fit (dashed line) to the decaying lasing pulse.

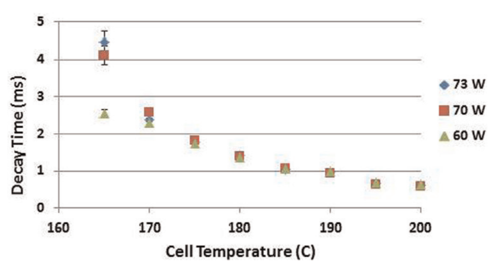

Fig. 3. A plot of the decay time with respect to the K cell temperature for different values of pump pulse power.

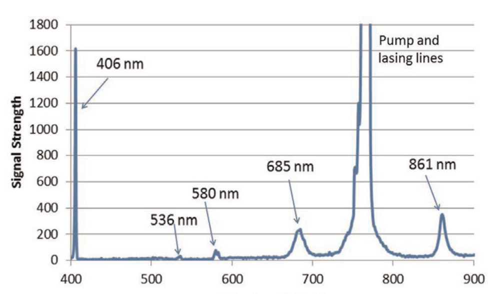

Fig. 4. Side fluorescence spectrum from the pulsed, static-cell K DPAL.

The stack's output beam had a close to rectangular cross section with a vertical to horizontal sides ratio of about 4:1. To correct the beam and make it close to square shape before focusing into the gain medium, we used a system of cylindrical and spherical lenses with an effective focal length of 20 cm. The beam was focused into the center of the K vapor cell and aligned collinearly with the laser cavity axis to provide longitudinal pumping. Such a combination of cylindrical and spherical focusing lenses provided a satisfactory pump beam size matching to the laser cavity mode size in the gain medium. The pump beam in the center of the K vapor cell had dimensions of 0.3 mm × 0.7 mm (FWHM), while the calculated FWHM of the laser cavity mode at the same point was 0.4 mm. The stable 40 cm long laser resonator was constructed of a 50 cm radius concave mirror with 99.9% reflection at 770 nm and 766 nm and flat output coupler with an experimentally optimized 60% reflection at 770 nm.

In our experiments we recorded both the pump and lasing pulses while varying the pump power in the range from 40 W to 80 W and the K-cell temperature in the range of 165–200 °C. Fig. 2 displays typical shapes of the pump and lasing pulses. The pump pulses in all experiments had a nearly rectangular shape, while the lasing power decayed to the level corresponding to CW mode of operation with a characteristic time from 0.5 ms to several ms depending on the cell temperature and pump power. The shape of the decaying pulse could be fitted by the exponential function:

$$P = P_{cw} + P_0 \exp[-t/\tau], \qquad (1)$$

where P_0+P_{cw} is the initial peak power, P_{cw} is the asymptotic continuous wave power and τ is the decay time. A typical fit built using this approach is shown in the Fig. 2.

The results of measurements of the decay time τ using the fit function (1) for different pump powers and K cell temperatures are presented in Fig. 3. The standard error is typically smaller than the symbol used to represent each data point but for those data which had low signal at 165 C the error bars are clearly visible. The trend in the data clearly indicates a decrease of the decay time with increasing cell temperature from 4.5 ms at 165 C to about 0.5 ms at 200 C for all power levels (excluding one point at 165 C and 60 W pump power, which is close to lasing threshold for this temperature). Also these data reveal that the decay time has a weak dependence on the power. It slightly decreases as the power is increased.

The DPAL power degradation in time observed in these experiments can be attributed to several parasitic processes in the gain medium, such as a temperature rise because of energy deposition from spin–orbit relaxation [13] which leads to convection, thermal lensing and alkali metal redistribution. Additionally, non-thermal effects which can degrade laser performance include energy pooling and ionization. Some of these processes can destroy the stability of the laser cavity (e.g. thermal lensing). Others can decrease density of the active lasing species: neutral alkali atoms and, thus, lower pump absorption and the gain. One more parasitic process connected with a temperature rise of the liquid K [14] is

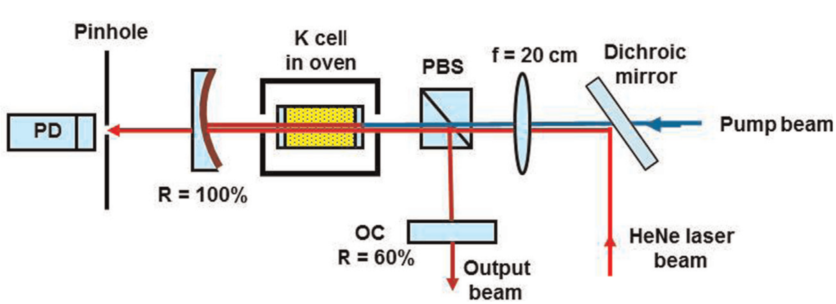

Fig. 5. Experiment with probe HeNe beam demonstrating thermal lensing in the alkali gain medium, when it is pumped and lasing.