High-power diode laser pumps for alkali lasers (DPALs)
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ABSTRACT

We present performance data of recent high-power laser diodes emitting at typical pump wavelengths for alkali vapor lasers: 852 nm for cesium, 780 nm for rubidium, 766 nm for potassium, and 670 nm for lithium atoms. Due to different approaches in alkali laser systems, we report on usual pumps at these non-standard wavelengths with typical line widths of a few nm used for collisional and pressure broadened gas absorption lines as well as on wavelength stabilized laser diodes using volume Bragg gratings (VBGs) for systems with narrow gas absorption lines. The detailed characterization of laser diodes available at DILAS includes power, efficiency, spectral data, and lifetime results. While bars at 6xx and 7xx nm are limited in optical output power due to the strong in-built strain, especially the bars at 852 nm with a small in-built strain have the biggest potential in terms of pump power. The power conversion efficiency in cw operation is as high as 60% at 100 W. Higher power and operation at increased heat sink temperatures up to 50°C are possible depending on lifetime requirements.

Keywords: High-power diode lasers, DPAL, laser pumps, reliability

1. INTRODUCTION

Diode pumped alkali vapor lasers (DPALs) have attracted increasing attention in the last decade because of their potential to achieve high power at near-infrared wavelengths: 895 nm with cesium lasers, 795 nm with rubidium lasers, and 770 nm with potassium lasers. Their main attraction stems from a combination of effective diode pumping, low quantum defect, and scalability to high power. DPALs combine the advantages of semiconductor laser diodes such as high power and efficient operation with those of gas lasers as for example high beam quality or the absence of stress birefringence. Furthermore, the aperture (transverse dimension) of gas lasers can be scaled readily. These systems create a laser that is compact and efficient, while working well at high temperatures and high powers. Moreover, DPALs are electrically driven and easily scalable lasers with excellent thermal management and lightweight packaging. Output powers in the tens of kilowatt may one day be feasible.

Optically pumped alkali lasers have a number of desirable features compared to solid state or fiber lasers. The quantum efficiency is high (e.g., 95.3% for Cs, 98.1% for Rb and 99.6% for K as compared to 76% for a 1.06 µm Nd:YAG laser) which is very important not only for an increase of the overall laser efficiency, but also for minimizing problems caused by waste heat. If one wants to scale a solid state laser to very high power, beam distortions introduced by the thermal effects with potential for irreversible laser material damage and intrinsic efficiency limitations due to the sizable quantum defect become a serious issue. Fiber lasers are limited by optical damage at high intensities and by nonlinear effects. The alkali vapor gain medium does not have these limitations. Since laser media is essentially gas, in addition to the promise of high efficiency, there is no issue with damage, beam distortions are noticeably lower, and scaling to high power can be alleviated by flowing alkali vapor through the laser cell. The gain media in DPALs provide an excellent optical quality that allows the generation of a high brightness beam with diffraction limited divergence.

The minimum waste heat necessary for an upper laser level excitation is the quantum energy defect. Table 1 lists the quantum energy defects \((E_2 - E_1)/E_2\) (see e.g. Fig. 1) for the two most practical diode pumped solid state lasers (Nd:YAG and Yb:YAG), along with the corresponding values for alkali atoms. Potassium, rubidium, cesium and lithium are of particular interest because they can be pumped with laser diodes utilizing III-V compound semiconductor material systems. From Table 1, it can be seen that the alkali atoms possess quantum energy defects that are 2-15 times smaller than that for the solid state laser ions. The amount of waste heat produced for each alkali atom excited will be reduced by the same factor compared to Nd:YAG and Yb:YAG lasers.

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Table 1. Summary of level energies \((E_2 - E_0)\) and \((E_1 - E_0)\) for the \(n^3P_{1/2}\) and \(n^3P_{3/2}\) levels, respectively, the energy difference \(\Delta E = E_2 - E_1\), the wavelengths of the \(D_2\) (pump) and \(D_1\) (laser) transitions, and the quantum energy defects \(\Delta E/E_2\) for the alkali atoms and the two most practical diode pumped solid state lasers (Nd:YAG and Yb:YAG).

<table>
<thead>
<tr>
<th>Laser Entity</th>
<th>(n)</th>
<th>(\lambda_{\text{pump}}) (nm)</th>
<th>(E_2 - E_0) (eV)</th>
<th>(E_1 - E_0) (eV)</th>
<th>(\lambda_{\text{laser}}) (nm)</th>
<th>(\Delta E) (meV)</th>
<th>(\Delta E/E_2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nd(^{3+})</td>
<td>6</td>
<td>808</td>
<td>1.5344</td>
<td>1.1652</td>
<td>1064</td>
<td>369.2</td>
<td>0.24</td>
</tr>
<tr>
<td>Yb(^{3+})</td>
<td>4</td>
<td>941</td>
<td>1.3176</td>
<td>1.2038</td>
<td>1030</td>
<td>113.8</td>
<td>0.086</td>
</tr>
<tr>
<td>Cs</td>
<td>6</td>
<td>852</td>
<td>1.4546</td>
<td>1.3859</td>
<td>894.3</td>
<td>68.7</td>
<td>0.047</td>
</tr>
<tr>
<td>Rb</td>
<td>5</td>
<td>780</td>
<td>1.5890</td>
<td>1.5596</td>
<td>794.8</td>
<td>29.4</td>
<td>0.0185</td>
</tr>
<tr>
<td>K</td>
<td>4</td>
<td>766</td>
<td>1.6171</td>
<td>1.6099</td>
<td>770.1</td>
<td>7.2</td>
<td>0.0044</td>
</tr>
<tr>
<td>Na</td>
<td>3</td>
<td>589</td>
<td>2.1044</td>
<td>2.1023</td>
<td>589.8</td>
<td>2.1</td>
<td>0.0010</td>
</tr>
<tr>
<td>Li</td>
<td>2</td>
<td>670</td>
<td>1.8479</td>
<td>1.8479</td>
<td>670.1</td>
<td>0.04</td>
<td>0.00002</td>
</tr>
</tbody>
</table>

The alkali lasers have also many advantages compared to chemical lasers. They do not use large quantities of hazardous materials and could be constructed in a closed cell, eliminating the need for vacuum pumping and discharge of chemicals. Finally, an easy change of the alkali number density and the buffer gas composition is possible to optimize the laser performance. All these advantages open a wide range of directed energy or power beaming applications for DPALs in civil (i.e. for the processing of photovoltaic cells or underwater communication), space (i.e. electrical power supply for space stations or propulsion systems) and military area (laser weapons).

The system analysis of DPALs is complicated due to the three level laser system with a common ground level for pump and laser light. Scaling DPALs to high power can cause a number of problems in the alkali medium such as absorption cross-section reduction, chemical reactions between alkali atoms and buffer gasses or absorption saturation. This will bleach the medium, causing a spatial pump absorption distribution to be quite different from Beer’s law. In the case of a high power DPAL, the stimulated transition will compete with pumping and, therefore, make lasing and pumping intrinsically connected. Since these are nonlinear processes, the analysis of laser performance requires numerical simulation.

In this paper, we will report on the performance of pump laser diodes at 766 nm, 780 nm and 852 nm available at DILAS, which should allow further power scaling of recently existing potassium, rubidium and cesium lasers, respectively. We will also present data for laser diode arrays at 670 nm that can be used for the first demonstration of a lithium DPAL.

2. PHYSICAL BASICS OF DPALs

2.1 Principle function of alkali lasers

![Energy level diagram of the ground \(n^3S_{1/2}\) \((E_0)\) and the first two excited electronic levels \(n^3P_{1/2}\) \((E_1)\) and \(n^3P_{3/2}\) \((E_2)\) of alkali atoms indicating pump and laser transitions: \(n = 6\) for Cs; \(n = 5\) for Rb; \(n = 4\) for K; \(n = 3\) for Na; \(n = 2\) for Li.](image_url)

As a class, the neutral alkali vapor atoms (Li, Na, K, Rb, and Cs) manifest the same rather simple low-lying electronic structure, due to their possession of a single valance s-electron. This electron gives rise to a \(^3S_{1/2}\) ground level and to \(^3P_{1/2}\) and \(^3P_{3/2}\) first and second excited levels split by a relatively small energy due to spin-orbit interaction. These levels form
a classic pure "three-level-laser" scheme. Figure 1 shows the basic energy level scheme of alkali lasers. In Table 1 and Fig. 1, \( n \) stands for the principal quantum number for the ground configuration of each alkali atom (\( n = 6 \) for Cs; \( n = 5 \) for Rb; \( n = 4 \) for K; \( n = 3 \) for Na; \( n = 2 \) for Li). In an alkali laser, the vapor gain medium is excited at a pump wavelength matching the wavelength of the \(^{2}\!P_{1/2} - ^{2}\!P_{3/2}\) electric-dipole-allowed transition (usually called the D\(_2\) transition) given in Table 1. After rapid kinetic relaxation of pump excitation to the excited \(^{2}\!P_{1/2}\) electronic level by a buffer gas (much faster than \(^{2}\!P\) spontaneous emission rates in the range of \(3 \times 10^7\) s\(^{-1}\)), laser emission takes place on the \(^{2}\!P_{1/2} - ^{2}\!S_{1/2}\) transition (usually called the D\(_1\) transition). A typical buffer gas mixture might be 1-2 atm of helium and about 0.1 atm of a light molecular gas such as ethane.\(^7,10\)

### 2.2 Special requirements for DPALs

The main problem in using of laser diode arrays for alkali laser pumping is to match their emission linewidth to the absorption line of the alkali atom. A typical absorption line of pure alkali vapors is smaller than 0.01 nm (or about 500 MHz), whereas commercially available laser diodes operating in continuous wave (cw) mode can generate more than hundred watts of laser power in near-IR with a typical linewidth of several nm (or about 1 THz). There are two approaches for an efficient matching of the laser diode emission to the alkali atomic absorption: (1) the use of a high-pressure buffer gas\(^12\) and/or increased gas temperature to broaden the alkali absorption line and (2) the narrowing of the laser diode's linewidth using external cavities with volume Bragg gratings (VBGs)\(^13\) or surface diffracting gratings.\(^14\)

The spectroscopic properties of the D-line transition of the alkali vapor atoms\(^15\) as well as collisional effects of all of the rare-gases and selected molecular gases on the spectroscopic and population kinetics of excited alkali atoms including spectral broadening of the D-line transitions,\(^16\) collisional mixing rates of excited \(^{2}\!P_{1/2,3/2}\) alkali atoms,\(^12\) and inelastic quenching rates of excited alkali atoms\(^17\) have been widely studied. To broaden the alkali absorption line to about 1 nm, the corresponding pressure of the buffer gas must be about 25 atmospheres. This high pressure can create other deleterious problems in alkali vapors like a reduction of absorption cross-section, a requirement of higher operating temperatures or the stimulation of chemical reactions between alkali atoms and the buffer gas. Thus, a combination of these two approaches - laser diode line narrowing and buffer gas pressure increase - seems to be the most promising way.

Several methods utilizing different kinds of external cavities with wavelength sensitive elements have been developed (see e.g. Refs.\(^13,18,19\)) that significantly narrow the diode laser linewidth. A well-known approach is the use of external cavities with volume Bragg gratings (VBG) resulting in typical linewidths of about 100 GHz with a few tens of watts output power.\(^13\) More promising results have been obtained with holographic plane reflection gratings. Using this technique, Babcock et al. reached a laser diode linewidth of 64 GHz with 30 W output power and 47 GHz with 12 W output power.\(^13\) In a more recent work, Zhdanov et al. reported about a laser diode line narrowing to 11 GHz using an external cavity with a holographic plane grating.\(^8\)

Another technological factor affecting the linewidth of a laser bar cavity with an external grating as output coupler is the so-called laser bar "smile", i.e. the bending of the line of emitters in transverse direction due to in-built and mounting induced strain (see Fig. 2). As a result, the incidence angle \( \theta \) of the radiation from different emitters onto the grating varies causing differences in the reflected wavelength for each emitter. The smile contribution to the linewidth of a 1-cm laser bar in an external cavity with a grating is given by\(^18\)

\[
\Delta \lambda = \lambda \cot \theta / (M_{f,AC}) ,
\]

\( \lambda \): wavelength

\( \cot \theta \): cotangent of the smile angle

\( M_{f,AC} \): finesse of the external cavity

\( \Delta \lambda \): linewidth contribution due to smile

**Figure 2. Definition of smile size x (peak to valley).**
where $x$ is the smile size (peak to valley) and $f_{\text{FAC}}$ is the FAC focal length. Usual values of the smile size for commercially available laser bars are in the range of 2-10 µm, that, together with short focal length of typical FAC (about 1 mm or less), gives $\Delta \lambda$ about several hundred GHz. To decrease the laser radiation linewidth according to Eq. (1), one should use laser bars with less smile, higher magnification $M$ and longer focal length FAC. As an example, the smile contribution $\Delta \lambda$ to the linewidth of a laser bar with 1 µm smile operating at 852 nm and equipped with an AR coated plano-convex cylindrical lens with a focal length of $f = 9.7$ mm (that is about one order of magnitude larger than a typical FAC) is about 8 GHz. A similar consideration has to be done for the lateral beam divergence.

Since the introduction of diode pump concept for alkali lasers in 2001 and the first demonstration of a DPAL in 2002, the achieved power levels have steadily increased from several mW to more than 48 W using a diode laser system with 250 W output power at 780 nm. Supplying more powerful diode laser systems at the pump wavelengths given in Table 1 with reduced line widths can increase the output power of DPALs by several orders of magnitude within the next few years.

3. LASER BAR PERFORMANCE

In the following, we present performance data of laser bars suitable for pumping of various alkali lasers. All these bars have an emitter pitch of 500 µm and can also be used for fiber coupling. For the particular application in DPALs, we focus on laser bars mounted on standard micro-channel coolers. Although laser bars mounted with AuSn promise a longer lifetime at higher optical powers with view on the stability of solder interface, we used only indium soldered laser bars due to requirement of a minimum smile (see section 2.2). The smile size (peak to valley) of all mounted laser bars mentioned in sections 3.1-3.3 is less than 0.9 µm.

3.1 Laser bars at 852 nm for Cs laser pumping

An efficient cesium vapor pumping requires a laser diode wavelength of 852.1 nm. The investigated laser bars have a lateral fill factor of 30% with a cavity length of 2000 µm. The emitter width is 150 µm. The width of a full laser bar is 10 mm corresponding to 19 emitters/bar. The laser structure is based on an Al free quantum well (QW) embedded in GaAsP spacers showing TE polarized emission during laser operation. As already mentioned, these laser bars were mounted on DILAS standard micro-channel coolers using indium soft solder. Figure 3(a) shows the optical output power and power conversion efficiency vs. forward current at a heat sink temperature of 20°C right up to the thermal roll-over (TRO). The laser diode array was driven in cw mode, achieving a thermal resistance of 0.34 K/W for the laser bar. TRO occurs at 205 A and 195 W (i.e. at about 10 W per emitter). No events of critical optical mirror damage (COMD) were observed up to currents of 220 A, exceeding the TRO point. The maximum power conversion efficiency at 20°C is more than 60% at 78 A which corresponds to an optical output power of 83 W. Up to 155 A and 165 W, the power conversion efficiency is clearly above 55%. Figure 3(b) depicts the temperature dependence of the power-current characteristics of the same laser bar between 25°C (blue line) and 40°C (red line).
value of $T_j = 200$ K. At a heat sink temperature of 40°C, the maximum power conversion efficiency drops to 54.4% at 79 A and 75 W.

Figure 4. (a) Optical spectrum of a 852 nm laser bar with 30% fill factor and a cavity length of 2000 µm at 125 W taken in cw operation at a heat sink temperature of 20°C. (b) Dependence of the lateral and vertical beam divergence on optical output power for the same laser bar at 20°C. The given values show the divergence data for 95% power content.

Figure 4(a) shows the optical spectrum taken in cw operation at 125 W. The spectrum peaks at 852.2 nm with a line width of 2.9 nm. All line widths in Sec. 3 are given for a power content of 90%. The dependence of the lateral beam divergence on optical output power for the same laser bar at 20°C is depicted in Fig. 4(b). The slow-axis and fast-axis divergences increase with forward current and reach 8.8° and 40.7° at 120 W, respectively. This divergence data and all following in Sec. 3 are given for 95% power content.

Figure 5. Step stress reliability test on six 852 nm diode lasers bars in cw operation at a heat sink temperature of 20°C.

A step stress reliability test was performed on a batch of six laser diode arrays in cw operation at a heat sink temperature of 20°C. The test power was increased in 20 W steps from 80 to 120 W after 500 hours of operation for each power level. Jumping from 80 to 120 W, we observed a slightly increasing degradation rate (see Fig. 5). The penalty for higher optical output powers is the long-term stability of the indium solder interface. Nevertheless, the performance of the investigated 852 nm bars is impressive and can be useful for a significant improvement in cesium laser’s development.
3.2 Laser bars at 780 nm for Rb laser pumping

Figure 6. Optical output power and power conversion efficiency vs. forward current of 780 nm laser bars at a heat sink temperature of 20°C. (a) TM emitting bar with 30% fill factor and a cavity length of 1000 µm. (b) TE emitting bar with 20% fill factor and a cavity length of 2000 µm.

Laser diode arrays at a wavelength of 780.0 nm are necessary for the pumping of rubidium lasers. Figure 6 shows the power-current characteristics and the dependence of power conversion efficiency on forward current at a heat sink temperature of 20°C for two different types of diode laser bars. The electro-optical performance of a TM emitting laser bar based on a tensile strained GaAsP QW with 19 emitters per bar and a cavity length of 1000 µm is depicted in Fig. 6(a). The emitter width is 150 µm corresponding to a lateral fill factor of 30%. The threshold current for these devices is $I_{th} = 6.5$ A; the slope efficiency is $\eta = 1.27$ W/A. Up to an output power of 110 W, no COMD events were observed. The maximum power conversion efficiency at 20°C is more than 60% at 61 A or 68 W, respectively. Figure 6(b) shows the power-current characteristics of a TE emitting laser bar based on a compressive strained InAlGaAs QW with 19 emitters per bar and a cavity length of 2000 µm. For these laser bars, the lateral fill factor is 20%. In comparison with the shorter TM emitting bars, the performance of the bars based on a compressive strained quaternary QW is worse. The threshold current for these devices is $I_{th} = 14.6$ A; the slope efficiency is $\eta = 1.15$ W/A. The maximum power conversion efficiency at 20°C reaches 46.7% at 70 A or 60 W, respectively.

Figure 7. (a) Optical spectrum of a 780 nm laser bar with 30% fill factor and a cavity length of 1000 µm at 60 W taken in cw operation at a heat sink temperature of 20°C. (b) Dependence of the lateral and vertical beam divergence on optical output power for the same laser bar at 20°C. The given values show the divergence data for 95% power content.

Due to the better performance, the following data is only given for the laser bars based on a tensile strained GaAsP QW. Figure 7(a) shows the optical spectrum taken in cw operation at 60 W. The emission wavelength is 780.2 nm at 60 W in cw operation; the spectrum has a linewidth of 2.2 nm. For output powers between 41 and 79 W, the slow-axis divergence increases strongly from 7.8° to 10.4°, whereas the fast axis divergence shows only a slight increase up to 52.6W [see Fig. 7(b)].
The result of an ongoing reliability test carried out in constant current mode on four 780 nm diode lasers bars in cw operation at a heat sink temperature of 20°C is shown in Fig. 8. The observed slight power degradation can be reduced and the available output power of low-smile indium soldered laser bars can be increased beyond 60 W using 780 nm laser bars with longer cavity.

3.3 Laser bars at 766 nm for K laser pumping

Laser diode arrays at a wavelength of 766.1 nm are required for an efficient potassium vapor pumping. At this wavelength, we have investigated the electro-optical performance of two different types of laser bars with the same lateral structure: 19 emitters per bar, 20% fill factor and 2000 µm cavity length. The laser structures are based on a compressive strained quaternary InGaAlAs QW [see Fig. 9(a)] and a tensile strained GaAsP QW [see Fig. 9(b)], respectively. In contrast to the described laser bars at 780 nm described in Sec. 3.2, the different laser structures at 766 nm show a comparable performance. The maximum power conversion efficiency is about 57% at 60 A. The GaAsP based laser structure shows a slightly smaller threshold current of $I_{th} = 6.5$ A compared to 8.3 A for the TE emitting bar, whereas the slope efficiency of the compressive strained laser structure of $\eta = 1.24$ W/A is slightly larger compared to 1.20 W/A for the TM emitting structure. A reliability test on both structures carried out at a heat sink temperature of 20°C in constant current mode at 60 W in cw operation showed a significant difference in the degradation rate by a factor of >10. Thus, we will focus on the more reliable structure based on a tensile strained GaAsP QW in the following.
Figure 10. (a) Typical spectrum of a 766 nm laser bar with 20% fill factor and a cavity length of 2000 µm based on a GaAsP QW taken in cw operation at 50 W and at a heat sink temperature of 25°C. (b) Dependence of the lateral beam divergence on optical output power for the same laser bar at 25°C. The given values show the divergence data for 95% power content.

Figure 10 shows a typical emission spectrum at 50 W in cw operation as well as the dependence of lateral beam divergence on output power for such laser diodes. The emission spectrum peaks at 766.3 nm and has a line width of 2.3 nm. The vertical beam divergence remains almost constant at 53.4° in the illustrated power range, whereas the slow-axis divergence shows the expected increase from 6.6° to 7.7° between 40 and 75 W. Recently, we started a reliability step stress test in order to find the maximum output power level with a reasonable life time; this data will be published later.

3.4 Laser bars at 670 nm for Li laser pumping

The pump wavelength of the $D_2$ transition in a lithium vapor is 670.0 nm. This type of alkali lasers was not demonstrated so far. In contrast to the data presented in Sections 3.1-3.3, we realized at 670 nm only conduction-cooled diodes with AuSn mounted bars so far. From the measured wavelength shift, the thermal resistance for this diode laser package can be calculated to $R_{th}=1.2$ K/W.

Figure 11. Optical output power and power conversion efficiency vs. forward current of a 670 nm laser bar with 20% fill factor and a cavity length of 1500 µm, mounted with AuSn on a CS mount. The measurement was carried out at a heat sink temperature of 20°C. (a) Result for cw operation. (b) Result for qcw operation with a repetition rate of 20 Hz and a duty cycle of 1%.

The laser structure is based on a compressive strained InGaP/AlInGaP QW. The investigated laser bars have a lateral fill factor of 20% with a cavity length of 1500 µm, an emitter width of 100 µm, and 19 emitters per bar. Figure 11 shows the comparison of the optical output power and power conversion efficiency vs. forward current in cw operation [see Fig. 11(a)] and in qcw mode with a repetition rate of 20 Hz and a duty cycle of 1% corresponding to a pulse width of 500 µs [see Fig. 11(b)]. In cw operation, the TRO occurs at 48 A and 35 W. Up to currents of 53 A and exceeding the TRO point, no events of COMD were observed. The maximum power conversion efficiency is about 39% at 36 A which corresponds to an optical output power of 29.5 W. The threshold current and the slope efficiency are $I_{th}=10.4$ A and $\eta = 1.27$ W/A, respectively. The much better electro-optical performance in qcw operation of 670 nm laser bars...
illustrates their strong dependence on junction temperature. For 500 µs wide pulses, the maximum power conversion efficiency increases to 48% at 47 W, and the TRO is not reached at 100 A or 100 W. It is obvious, that water-cooled packages of bars at 670 nm will show a better performance compared to the cw data presented above.

Figure 12. (a) Typical spectrum of a 670 nm laser bar with 20% fill factor and a cavity length of 1500 µm taken in cw operation at 20 W and at a heat sink temperature of 20°C. (b) Dependence of the lateral beam divergence on optical output power for the same laser bar at 20°C. The given values show the divergence data for 95% power content.

Figure 12(a) shows a typical emission spectrum taken in cw operation at 20 W. The emission wavelength is 670.2 nm at 20 W in cw operation; the spectrum has a linewidth of 1.3 nm. For optical output powers between 2.5 and 24 W, the slow-axis divergence increases strongly from 7.8° to 10.7°, whereas the fast axis divergence shows only a slight increase up to 55.6 W [see. Fig. 12(b)]. A reliability test was carried out on six single emitters (100 µm × 1500 µm) with 1.5 W. All devices survived 5000 h. Reliable operation at 35 W seems to be possible with 670 nm laser bars in a water-cooled package.

4. SUMMARY

We have reported on performance data of high-power diode laser bars available at DILAS with non-standard wavelengths necessary for an effective pumping of various alkali lasers. DPALs are easily scalable lasers with excellent thermal management and lightweight packaging. They have attracted increasing attention in the last decade because of their potential to achieve high output powers at near infrared wavelengths beyond the power limitations of recent solid-state or fiber lasers.

The achievable output power from diode laser pump sources for different alkali lasers depends on the pump wavelength. At 852 nm for an effective pumping of cesium lasers, we can reach the highest output power with more than 100 W per laser bar in cw operation. Nevertheless, other pump wavelengths for Rb, K and Li lasers are not less interesting. Although the available output power from laser bars at 780, 766 and 670 nm decreases with increasing photon energy, the corresponding alkali lasers are able to compensate the lower pump power by increasing efficiency due to smaller quantum energy defects.

For all these non-standard wavelengths, work is ongoing to improve the materials, processes and structures for better power conversion efficiencies, higher output powers and smaller emission spectra. Even better results can be expected in the near future.

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