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High peak power generation in thermally bonded Er\(^{3+}\), Yb\(^{3+}\):glass/Co\(^{2+}\): MgAl\(_2\)O\(_3\) microchip laser for telemetry application

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Abstract
The highest ever reported peak power generation of 7.68 kW in thermally bonded active medium Er\(^{3+}\), Yb\(^{3+}\):glass with saturable absorber Co\(^{2+}\): MgAl\(_2\)O\(_3\) was achieved. The sample was a quasi-continuous wave pumped by a fiber coupled laser diode operating at 975 nm wavelength. The generation threshold was 319 mW and slope efficiency was 9.63%. A comparative analysis of the generation of different output coupler transmissions is presented.

Keywords: thermally bonded laser, microchip laser, erbium laser

(Some figures may appear in colour only in the online journal)

1. Introduction
Lasers generating at a 1.5 \(\mu\)m wavelength have attracted considerable interest due to their many potential applications. In the last two decades, many papers have been published demonstrating pulsed as well as continuous wave (cw) operation of such lasers [1–9]. One of the most interesting applications is telemetry, where these lasers are used in range-finders and lidar systems [10, 11]. In such application high peak power, high quality of the output beam and small laser dimensions are the most important parameters. The last two parameters are relatively easy to achieve in the case of microchip lasers. However, high peak power in such lasers is difficult to achieve, which convinced many scientists to conduct research in the field of different active media, saturable absorbers and different configurations of these two elements. The use of glass doped with erbium and ytterbium ions as the active medium and MgAl\(_2\)O\(_3\) crystal doped with cobalt ions (MALO) as the saturable absorber proved to be an efficient way to generate relatively high peak power, but it was still limited to 2.2 kW or less [12–14]. One of the useful ways to increase the peak power is to join the active media rigidly to the saturable absorber. This approach enables very short pulses to be generated because of the shortest possible length of the resonator. Moreover, the heat damage threshold of the active media is significantly increased due to high thermal conductivity of MALO. Additionally, the need for separate alignment of the active media and MALO is avoided and the stability with respect to mechanical vibration is increased [14].

A very effective rigid joint method is thermal bonding, which is already a very well-known technology. In this letter, however, we present the highest peak power, ever reported, of a passively \(q\)-switched microchip laser using glass doped with erbium and ytterbium ions, which was thermally bonded with saturable absorber MALO doped with cobalt ions.

2. Experimental setup and results
The spectroscopic and mechanical parameters of the glass active medium used for the experiment are presented in table 1. The spectroscopic parameters of MALO crystal were measured using the procedure described in [15]. It was assumed that there is no excited state absorption in MALO crystal [16]. The saturation characteristics along with the approximation using Avizonis–Grotbeck’s equation [17] are presented in figure 1. The main parameters of MALO are presented in table 2. The glass active medium and MALO crystal with lengths of 1.9 and 1.4 mm, respectively, were thermally bonded making one monolithic sample with cross section dimensions 4 \(\times\) 4 mm. Then both sides of it were polished to make them plane parallel. The saturable absorber was polished to the thickness of 0.29 mm with the small signal transmission equal...
The small signal transmission value of MALO was chosen taking into account the optimization procedure presented in [18, 19]. To achieve laser generation, a dichroic plane-parallel input mirror with antireflection coatings at 975 nm on both sides (AR@975 nm) and high reflection coatings at 1535 nm (HR@1535 nm) on one side was used. As output couplers, different mirrors with partial transmission at 1535 nm (PT@1535 nm) were used. The output couplers also had high reflection coatings at 975 nm (HR@975 nm) on one side and antireflection coatings at 1535 nm (AR@1535 nm) on the other side. Generation investigations were carried out for two different reflections of the output plane-parallel couplers ($R = 97.64\%$, 98.70%). The reflections of the output couplers were also chosen taking into account the optimization procedure presented in [18, 19]. The length of the resonator was equal to the length of the active media and the saturable absorber, which was 2.19 mm. To pump the sample, a fibre coupled laser diode was used. The laser diode operated at 975 nm wavelength at a room temperature of 25 °C. To avoid the damage of the glass by heat a quasi cw regime with a period equal to 20 ms and a duty-cycle of 50% was applied.

The experimental setup is presented in figure 2. The characteristics of the average output power versus the average pump power incident on the active medium are presented in figure 3. $P_{\text{pump}}$ was limited to 392 mW so as not to damage the sample.

The experimental setup is presented in figure 2. The characteristics of the average output power versus average pump power incident on the active medium $P_{\text{pump}}$ for different reflection of the output couplers $R$ are presented in figure 3. $P_{\text{pump}}$ was limited to 392 mW so as not to damage the sample.

To compare the results for different output couplers, the generation parameters for $P_{\text{pump}}$ equal to 375 mW are presented in table 3. The highest peak power $P_p$ of 7.68 kW and the highest pulse energy $E_p$ of 22.40 µJ were achieved for the output coupler with the reflection equal to 97.64%. Pulse width $\tau_p$ was almost the same for both output couplers. Slope efficiency $\sigma$ was nearly two times higher for the output coupler

### Table 1. Parameters of the glass active medium.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal expansion coefficient (20–300 °C)</td>
<td>71.8</td>
</tr>
<tr>
<td>(x10^{-7}K^{-1})</td>
<td></td>
</tr>
<tr>
<td>Thermal conductivity (20–700 °C)</td>
<td>0.745</td>
</tr>
<tr>
<td>(W m^{-1} × K^{-1})</td>
<td></td>
</tr>
<tr>
<td>Ytterbium concentration (x10^{21} cm^{-3})</td>
<td>1.73</td>
</tr>
<tr>
<td>Erbium concentration (x10^{19} cm^{-3})</td>
<td>8.90</td>
</tr>
<tr>
<td>Absorption coefficient (cm^{-1})</td>
<td>19.41</td>
</tr>
<tr>
<td>Emission cross section (x10^{-20} cm^{2})</td>
<td>0.80</td>
</tr>
<tr>
<td>Refractive index</td>
<td>1.53</td>
</tr>
</tbody>
</table>

## References

[18, 19]
with the reflection equal to 97.64%, while the threshold $P_{th}$ was a little lower for the output coupler with the reflection equal to 98.70%. The pulse repetition rate $f$ in both cases was close to 1 kHz.

The results of the laser generation for the output coupler with the reflection equal to 97.64% are presented in table 4. For different average pump power, the laser generated pulses with relatively stable peak power and very stable pulse width. The pulse width was equal to 2.92 ns, which is shown in figure 4. The laser for both output couplers generated only one longitudinal mode in the whole range of the average pump power. The exemplary spectrum is shown in figure 5.

The far-field distribution of the beam intensity for the output coupler with the reflection equal to 97.64% is presented in figure 6. The blue square frame around the intensity distribution of the beam is caused by the aperture and should not be taken into consideration. Thus one can see that the beam is characterized by the near Gaussian distribution. The measurement was carried out for the average pump power equal to 375 mW.

### Table 3. Results of the investigation for the average pump power equal to 375 mW.

<table>
<thead>
<tr>
<th>$R$ (%)</th>
<th>97.64</th>
<th>98.70</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_p$ (kW)</td>
<td>7.68</td>
<td>3.65</td>
</tr>
<tr>
<td>$E_p$ (µJ)</td>
<td>22.40</td>
<td>10.58</td>
</tr>
<tr>
<td>$\tau_p$ (ns)</td>
<td>2.92</td>
<td>2.90</td>
</tr>
<tr>
<td>$\sigma$ (%)</td>
<td>9.63</td>
<td>5.21</td>
</tr>
<tr>
<td>$P_{th}$ (mW)</td>
<td>319</td>
<td>286</td>
</tr>
<tr>
<td>$f$ (kHz)</td>
<td>0.98</td>
<td>1.22</td>
</tr>
</tbody>
</table>

### Table 4. Results of laser generation for the output coupler with the reflection equal to 97.64%.

| $P_{pump}$ (mW) | 337.5 | 356.5 | 375 | 392 |
| $\tau_p$ (ns) | 2.92 | 2.92 | 2.92 | 2.92 |
| $P_p$ (kW) | 6.78 | 6.10 | 7.68 | 6.69 |
| $f$ (kHz) | 0.657 | 0.833 | 0.980 | 1.087 |

### 3. Summary

As presented in this article, peak power equal to 7.68 kW is the highest ever reported in the case of passively $q$-switched microchip lasers using glass doped with erbium and ytterbium ions thermally bonded with saturable absorber MALO. Such good results may suggest that the small signal transmission of the saturable absorber and the reflection of the output coupler used to build the microchip laser are close to optimal values. According to some previously reported results, microchip lasers with such high peak power can be used successfully in teledetection applications [11].
Acknowledgments

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References


Figure 6. Far-field distribution of the beam intensity.