

Tunable Yb:KYW laser with a volume Bragg grating

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Abstract: We demonstrate a tunable Yb:KYW laser, locked by a volume Bragg grating in a retroreflector geometry. The power was ~1 W within the tuning range from 1032 nm to 1048 nm.
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 OCIS (050.7330) Volume holographic gratings; (140.5680) Rare earth and transition metal solid-state lasers; (140.3480) Lasers, diode-pumped; (140.3600) Lasers, tunable;

1. Introduction

Ytterbium doped lasers have met a lot of interest due to attractive properties such as low quantum defect, wide emission spectrum and an absorption suitable for diode pumping. Among the various host materials that have been investigated the double-tungstate crystals, such as KGW, KYW and KLuW, have shown the highest efficiency [1], while having good mechanical properties. This has led to the realisation of compact lasers with high cw powers [2]. However, the laser wavelength in these materials varies strongly with cavity loss and output power. At the same time, the laser bandwidth is typically quite broad, in the order of a nanometer or more.

In order to obtain spectral control of the laser, a spectral filter can be inserted into the cavity, such as an etalon. However, etalons have drawbacks including insertion loss and limited tuning range. We demonstrate an alternative solution, where we use volume Bragg gratings to lock and tune the laser wavelength. These Bragg gratings are made from a photosensitive glass with a sinusoidal refractive index modulation throughout the volume. Previously, volume Bragg gratings have been used to lock – but not tune – high power diode lasers [3] and various solid state lasers: ErYb:glass [4], Ti:sapphire [5], Cr:LiSAF [5] and Nd:GdVO₄ [6]. In Ref. 7, locking and tuning of an optical parametric oscillator have been achieved by tilting an intracavity volume Bragg grating. However, the used tuning method required repeated cavity realignment.

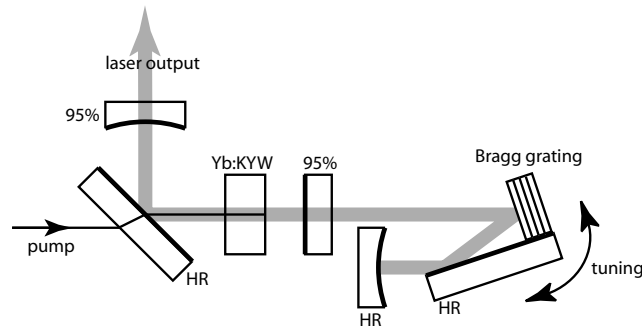


Fig. 1. Laser setup

2. Experimental setup

Tuning of the reflected wavelength from a volume Bragg grating can be achieved by changing the angle of incidence. However, this leads to beam steering, which causes the need for repeated cavity realignment while tuning the laser. A way around this problem is to combine the Bragg grating with an ordinary mirror at a perpendicular angle, thereby creating a retroreflector. Now, the wavelength can be tuned without beam steering and the cavity alignment is preserved [8].

For a plane wave incident on a Bragg grating at an angle, the peak reflectivity should increase slightly with the angle of incidence. Nevertheless, for a gaussian beam with a beam diameter smaller than the grating thickness, this relation does not hold. Instead, the reflectivity drops significantly with increased angle, which is separately investigated in Ref. 9. In our setup, the reflectivity dropped from 97% to between 71% and 87% depending on wavelength, according to the model in Ref 9. This precludes using the Bragg grating in the laser cavity and the grating was placed in an external cavity instead.

Fig. 1 depicts the laser setup. The laser was pumped by a diode bar at 980 nm which was focused into a spot of ~110 μm ($1/e^2$ radius) inside the laser crystal to match the laser mode size. The pump light entered the cavity

through a dichroic mirror at 45° transmitting at the pump wavelength and specified for high reflection (HR) at the laser wavelengths. The maximum pump power at the crystal was 11.5 W. The laser crystal was a 5 at.% doped Yb:KYW crystal of 3 mm length with AR/AR coatings, cut for propagation along the b-axis. The pump absorption was ~90 %. The internal cavity consisted of an R = 95% output coupler with a radius of curvature (ROC) of 100 mm, the dichroic 45° folding mirror, the laser crystal and a plane mirror with R = 95%. The internal cavity had a total optical length of 29 mm. The external cavity, which provided the tuning feedback, was composed of the retroreflector placed on a rotation stage and an HR-mirror with ROC = 100 mm. The retroreflector was constituted by a flat dielectric mirror, specified for HR between 1010 nm and 1050 nm for 63° to 77° angle of incidence, respectively, and the volume Bragg grating. The Bragg grating had a peak reflectivity for plane waves at normal incidence of 97% at 1063.5 nm and a FWHM bandwidth of 0.55 nm.

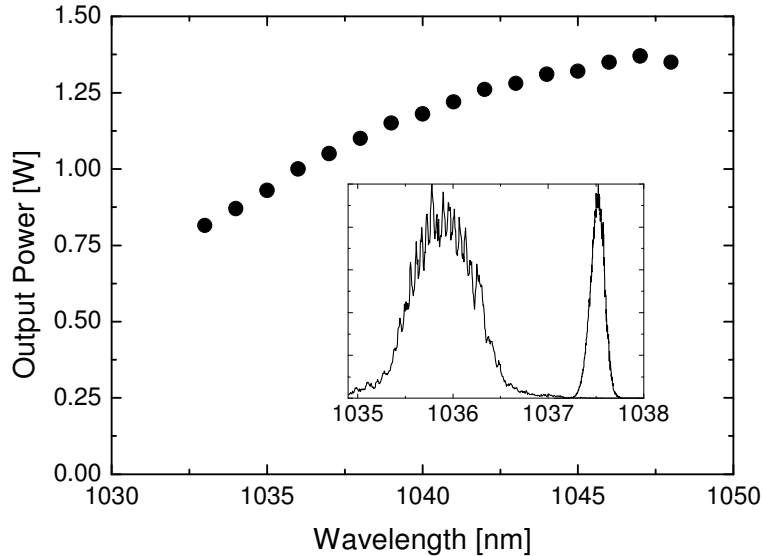


Fig. 2. Laser tuning performance at maximum pump power. The inset shows a typical locked laser spectrum to the right and an unlocked spectrum to the left.

3. Results and discussion

By simply turning the retroreflector, the laser wavelength could be continuously tuned between 1032.5 nm and 1048 nm. The output power increased with longer wavelengths and at maximum pump power it reached a value of 1.37 W at 1047 nm. The bandwidth of the locked laser was 0.18 nm FWHM at full power, to be compared with the grating bandwidth of 0.55 nm. The tuning performance is shown in Fig. 2. Without the feedback from the external cavity, the laser wavelength was about 1036 nm with a bandwidth of ~1 nm. When the laser was tuned beyond the locked range, the laser behavior was the same as without feedback. We believe that the tuning at short wavelengths is limited by a reduced reflectivity for the incoupling mirror, however, the limiting factors are still under investigation. Using the Bragg grating directly at normal incidence, we were also able to lock the laser at 1063.5 nm, though at lower output power due to the lower gain at this wavelength. Still, this shows that the tuning range for Yb:KYW could be extended to more than 1060 nm.

The laser output power versus incident pump power, when locked both at 1038 nm and at 1047 nm, can be seen in Fig. 3. The slope efficiencies were 16% and 22%, respectively. We also measured the M^2 of the output beam, and found a value of 1.0 in both the horizontal and vertical direction. In addition to the main output, there were also two weaker laser beams coupled out through the Bragg grating, due to the reduced reflectivity of the Bragg grating at an angle as discussed above. The total power in these two beams was between 20% and 35% of the main output power, decreasing with increasing wavelength. This explains the power variation in Fig. 2, as well as the different slope efficiencies at different wavelengths, since for longer wavelengths the outcoupling losses in the grating are lower which results in higher output powers. As explained in Ref 9, the transverse mode profile of the beams coupled out through the grating consisted of two lobes separated in the horizontal direction.

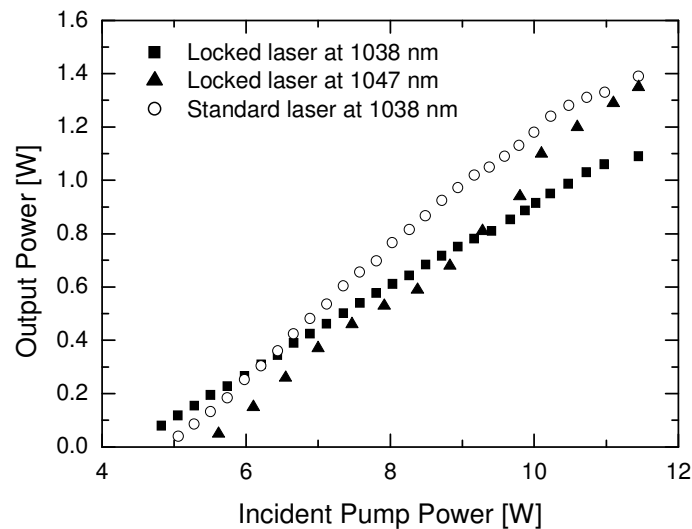


Fig. 3. Output power performance of the locked laser and the standard cavity used for comparison.

For comparison, an ordinary laser based only on the internal cavity was evaluated, with the reflectivity of the flat mirror increased to 99.95% (HR). This laser operated at a wavelength of 1038 nm. Because of the lower cavity losses in this setup, the slope efficiency is higher than for the locked laser at the same wavelength, see Fig. 3. Still, if the 30% of extra power coupled out through the Bragg grating at this wavelength is taken into account, both cases give approximately the same slope.

4. Conclusions

We have demonstrated a novel technique for locking and tuning of the wavelength of solid-state lasers, based on a volume Bragg grating in a retroreflector geometry. To exemplify, we have constructed an Yb:KYW laser that is tunable between 1032 nm and 1048 nm. The output power ranged between 0.8 W and 1.4 W in the tuning interval, while the M^2 -value was 1.0.

5. References

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