Coupled-Cavity, Single-Frequency Yb:YAB Yellow Laser

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Abstract: CW single-longitudinal-mode output in the 1120-1140 nm range and self-frequency-doubling into the yellow spectral region has been observed in Yb:YAB. Excellent agreement between experiment and modelling of yellow output in a single-crystal solid-state-laser system is observed.

OCIS codes: (140.3480) Lasers diode-pumped; (140.3570) Lasers, single-mode; (190.2620) Frequency Conversion

1. Introduction

Diode-pumped solid-state microchip lasers in the blue-green spectral region have many applications including data storage, visible display devices, laser printing, bio-fluorescence, underwater communications, and medicine. Lasers that are also able to access the yellow region are attractive for a wider range of applications including dermatology and sources for general spectroscopic studies. For such systems, self-frequency-doubling (SFD) lasers (solid-state laser devices based on a non-linear host material) are attractive since an additional non-linear crystal is not required. The SFD device produces visible radiation by internal frequency doubling of the infrared laser lines. The $YAl_3(BO_3)_4$ (YAB) [1] host has recently been identified as one of the most promising SFD type of laser system [2].

The compactness of microchip lasers often allows single-frequency output, since the longitudinal mode spacing can usually be made to be broader than the gain bandwidth. Microchip lasers have traditionally had Nd^{3+} as the active ion, since it has a relatively narrow gain bandwidth. However, to obtain efficient absorption of the pump light, the concentration needs to be increased considerably, with detrimental effects on the visible output due to increased re-absorption losses. Due to the simple energy level scheme, Yb^{3+} based laser crystals do not suffer from visible re-absorption. Yb devices also have other advantages over Nd such as broad tunability, high quantum efficiency, reduced thermal load and the absence of excited state absorption.

2. Experimental

A flat-flat resonator was used to investigate a monolithic microchip laser as depicted in Figure 1. The cavity comprised of a flat input mirror (IP) coated for HR at 1040 nm and HT at 977 nm, and a flat output coupler (OC) coated HR at 1040 nm and partially transmitting in the visible (~70-80%). The Yb:YAB crystal (3x3x1mm) was cut for phase-matched-operation at 1064 nm at normal incidence and was mounted in a temperature controlled copper block. The crystal was AR coated at 1040 nm on the input face and uncoated on the output face for coupling to the air space etalon between the crystal and the OC. The Yb concentration in the YAB crystal was approximately 8 at.% resulting in ~70% absorption in the 1 mm long crystal. The total cavity length of ~1.3 mm was dominated by the laser crystal with air spaces of approximately 300 μm between the IP and the crystal, and ~50 μm between the crystal and the OC. The pump source was a 1.6W fibre-coupled InGaAs diode laser. The output from the pump fibre (50 μm core, 0.2 NA) was focused to a spot size of ~100 μm in the laser crystal. Using this arrangement we have obtained laser operation in the ranges of 1030-1090 nm and 1115-1141 nm. Outputs of 220 mW at 1060 nm with a slope efficiency of ~22% and SFD green output of ~6mW, and 22 mW at 1135 nm with a slope efficiency of 3.4% and <1 mW SFD yellow output has been observed.

3. Coupled Cavity Systems

One approach to achieving single-frequency operation in gain media with broad gain spectra such as Ytterbium (Yb) has been with coupled-cavity configurations. With this method, single frequency microchip lasers have been obtained with the broadband systems Cr:LiSAF [3], Tm:YAG [4], and Tm:Ho:YLF [5]. No report has been made of

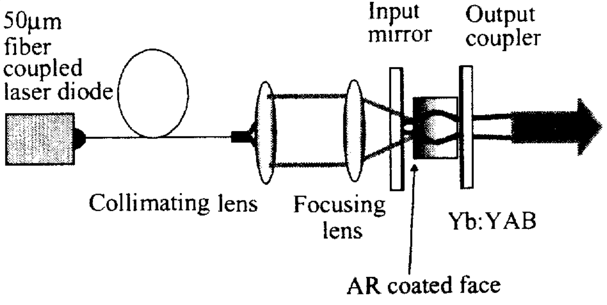

Fig 1. Laser cavity schematic

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this approach for an Yb laser, much less an Yb SFD laser.

We have extensively modelled coupled cavity laser resonators for Yb:YAB laser operation using a model based on the matrix formalism of Pedersen [6]. The allowed resonances of the entire structure are complex functions of the length of each coupled cavity, the reflectivity of the mirror surfaces, and the laser gain. For Yb:YAB we chose the laser crystal to be 1 mm in length for optimal pump absorption. This results in many closely spaced resonances (separation ~0.28 nm) across the gain bandwidth of the laser.

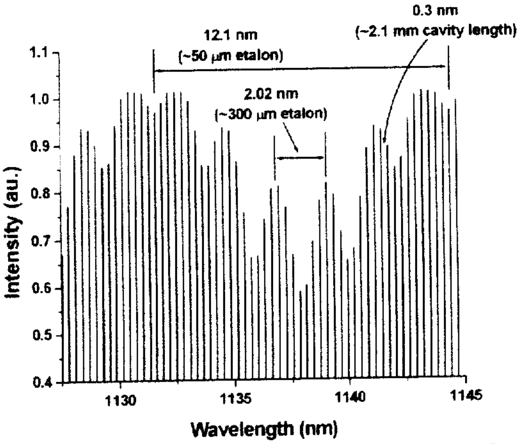

Fig 2a. Results from the modelling of the Yb:YAB coupled-cavity resonator.

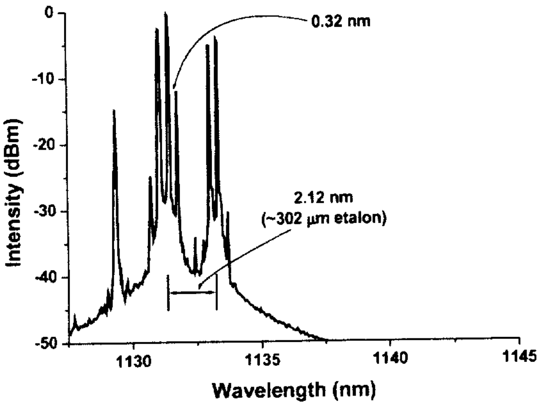

Fig 2b. Free-running output of the Yb:YAB laser

We modelled the Yb:YAB laser operating at 1130 nm with four surfaces incorporating the IP with 98% reflection, a 300 μm air space to the AR coated face of the YAB crystal, which had approximately 2% reflection at this wavelength, the 1 mm YAB crystal with gain, the uncoated output face of the crystal (~8% Fresnel reflection), and a 50 μm air space to the OC with ~99% reflection. The results of this calculation are shown in Figure 2a compared with the continuous-wave laser output observed experimentally shown in Figure 2b. The laser spectra were recorded on an optical spectrum analyser (Anritsu MS9030A) which has a resolution of ~0.1 nm. The agreement between the allowed resonances of the cavity and the laser output is excellent. The finesse of each of the etalons in the present configuration is very low resulting in very weak coupling between each of the etalons. This means that the frequency discrimination for SLM is also weak resulting in the multi-longitudinal mode output observed at high powers.

4. Temperature Tuning

In coupled cavity resonators, the reflection and phase coefficients of the coupled cavities are strongly dependent on the separations of the resonator mirrors. The lasing frequency as a function of temperature, the temperature tuning curve, can be calculated using the known response of the Yb:YAB laser material to temperature. Two factors are taken into account as being dependent on the temperature of the laser crystal: the thermal length expansion, and the change of refractive index. The IP and OC of the laser cavity are thermally isolated from the laser crystal, so as the

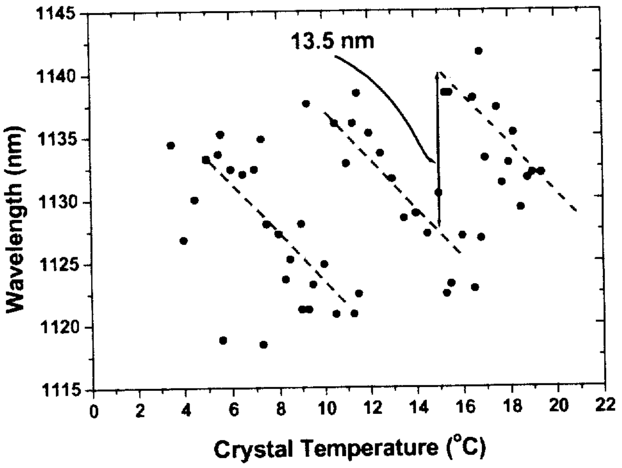

Fig 3. Experimental (●) and theoretically predicted (O) temperature tuning curve of the Yb:YAB laser at 1130 nm

crystal is heated via the temperature controlled mount the length of the crystal increases, the length of the air-space etalons is consequently reduced. Continuously tunable operation was observed between 1120-1141 nm, see Figure 3. Since the laser was operated at maximum pump power, the free-running output often consisted of two mode-groups separated by ~13.5 nm. This is consistent with coupling to a 47 mm air-space etalon. Also, the tuning along a particular branch of the curve is consistent with the free-spectral range of this etalon. Agreement with the predictions of the coupled-cavity model are again excellent. Laser operation has been seen to 1115 nm, but when the laser is tuned to shorter wavelengths, it reverts to the gain peak at 1090 nm.

5. Single Frequency Operation

The parameters of the present laser cavity result in very low finesse etalons, hence the coupling between them is very weak resulting in many closely spaced resonances that are allowed in the cavity with similar line strengths. Hence, in the 1020-1090 nm region of the emission spectrum of Yb:YAB where the gain is very high, it is extremely difficult to achieve SLM operation. However, beyond 1100 nm where the gain of the laser is quite low and trailing off to zero, at low incident pump powers it is possible to achieve SLM lasing output as seen in Figure 4a where 1.8mW of single frequency output was obtained with instrument limited resolution. Even though the Yb:YAB crystal was phase-matched for SFD at 1064 nm, we were still able to see frequency doubled output at 569 nm in a SLM. It is expected that the conversion efficiency would be greatly improved with a crystal cut for phase-matching at this wavelength.

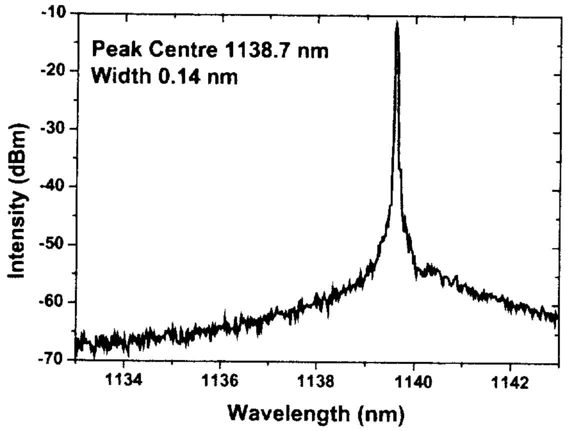

Fig 4a. Single longitudinal mode output of coupled-cavity Yb:YAB laser

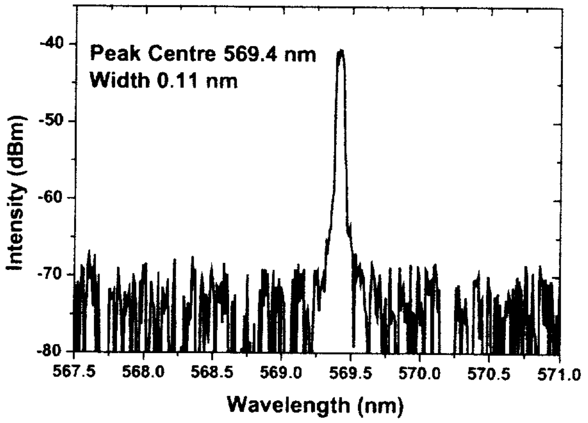

Fig 4b. Single longitudinal SFD yellow output

We are currently working on increasing the coupling between the etalons in our laser cavity by increasing the reflectivity of the uncoated Yb:YAB face. This will give us much better mode discrimination and we should be able to achieve higher power SLM operation at 1140 nm, and also at the peak of the Yb:YAB gain curve at 1040-1060 nm, and the corresponding SFD wavelengths.

6. Conclusions

Continuous-wave single longitudinal mode operation in the 1120-1140 nm range has been observed in a coupled-cavity Yb:YAB microchip laser. Self-frequency doubling of this radiation was also observed in the visible yellow spectral region. We believe this to be the first report of yellow laser output in a single-crystal solid-state-laser system. This radiation was successfully temperature tuned over 13.5 nm corresponding to the free-spectral-range of the 50 μm coupled etalon. Excellent agreement between the experimentally observed laser characteristics and coupled-cavity modelling was also found. Experiments with higher finesse cavities are planned to increase the single longitudinal mode output power, and the range of wavelengths over which SLM operation is possible.

7. References

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