Power-scalable internal frequency doubling scheme for continuous-wave fiber lasers

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ABSTRACT

We describe a simple power-scalable concept for efficient second harmonic generation in a cladding-pumped continuous-wave fiber laser. Our approach makes use of an internal resonant enhancement cavity to increase the intracavity power and second harmonic conversion efficiency without the need for active cavity length control and stabilization. This technique has been applied to a cladding-pumped Yb-doped fiber laser yielding 15 W of linearly-polarized continuous-wave green output (at 540 nm) for 90 W of absorbed diode-pump power (at 975 nm). The internal conversion efficiency of the laser with respect to the fundamental power entering the enhancement cavity was >63%. The prospects for further improvement in performance with respect to conversion efficiency and output power will be discussed.
Keywords: fiber laser, ytterbium, continuous wave, visible laser, green laser, second harmonic generation

1. INTRODUCTION

High power laser sources emitting in the visible spectral region have a diverse range of applications in areas such as laser processing of materials, projection displays, medicine and sensing. For the continuous-wave (cw) operating regime the most popular approach for generating visible output is via intracavity second harmonic generation in a diode-pumped 'bulk' solid-state laser. This approach exploits the relatively low resonator losses and hence high intracavity powers that can be achieved in these lasers to yield high second harmonic conversion efficiency and output powers in multi ten-watt regime [1]. However, scaling to higher powers is rather more challenging due to the effects of heat generation in the laser medium which lead to degradation in beam quality and increased resonator loss. Fiber lasers benefit from a geometry that is relatively immune to the effects of heat generation in the core and hence offer a route to much higher power levels in the near-infrared wavelength regime via the use of cladding-pumped architectures [2], and hence offer the prospect of much higher power levels in the visible regime via nonlinear frequency conversion. Unfortunately, the technique of intracavity second harmonic generation is not well-suited to cladding-pumped fiber lasers, since they have rather high resonator losses. One solution to this problem is to employ the technique of external resonant cavity second harmonic generation. This approach has been successfully applied to cw fiber sources [3], but suffers from the drawback of added complexity since a single-frequency fiber master-oscillator power-amplifier is required and the master-oscillator and/or resonant cavity lengths must be actively stabilized to ensure that the resonance condition is maintained at all times.

In this paper we present an alternative scheme for efficient second harmonic generation in cladding-pumped continuous-wave fiber lasers. Our approach makes use of a simple fiber laser resonator containing an internal resonant enhancement cavity with a nonlinear crystal for second harmonic generation. The fiber laser automatically lases on axial modes which are simultaneously resonant in the enhancement cavity and main cavity. As a result, the intracavity power in the enhancement cavity is increased to many times the cw power that can be extracted from the fiber laser alone, leading to high second harmonic conversion efficiency. In contrast, to external resonant frequency doubling, this approach does not require a single-frequency fiber source and there is no need for active cavity length stabilization since the fiber laser can only lase on axial modes which are resonant in the enhancement cavity. We have applied this technique to a cladding-pumped ytterbium(Yb)-doped fiber laser to achieve efficient nonlinear frequency conversion of near-infrared (fundamental) output at ~1080 nm to the green output at ~540 nm.

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2. EXPERIMENTAL SET-UP AND RESULTS

The experimental configuration (shown in Fig. 1) comprised a double-clad fiber with a polarization-maintaining Yb-doped core in a simple standing-wave resonator. Feedback for lasing was provided by a diffraction grating at one end of the fiber, and by an external cavity containing a resonant enhancement cavity at the opposite end of the fiber. A simple four-mirror 'bow-tie' cavity design was employed for the enhancement cavity with a Brewster-angled LiB_3O_5 (LBO) crystal placed in an oven and cut for type I non-critical phase matching. Pump light was supplied by a fiber-coupled diode source at 975 nm and coupled into the end of the Yb-doped fiber adjacent to the diffraction grating. The diffraction grating was used to select the operating wavelength and narrow the emission spectrum to lie within the phase matching bandwidth for second harmonic generation.

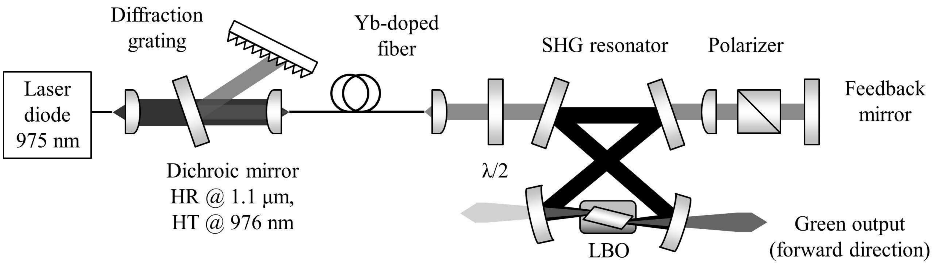

Figure 1. Schematic of the experimental set-up

With this set-up, we obtained 15 W of CW second harmonic output (at 540 nm) in the forward direction (Fig. 1), corresponding to 19 W generated inside the LBO crystal, for 90 W of absorbed diode pump power (at 975 nm). The output power in the reverse direction was <100 mW. The internal conversion efficiency of the laser with respect to the fundamental power entering the enhancement cavity was >63%. The output was linearly-polarized with a beam propagation factor (M^2) <1.25. The laser was tunable over the range of 540-560 nm (for a 20 m long Yb-doped fiber) and over the range 520-550 nm (for a 10 m long fiber) by adjusting the grating angle and the oven temperature to maintain phase matching. The output power stability (rms noise over 100s) was measured to be <0.7%. These preliminary results were obtained with a non-optimal set-up due to limited availability of components. The prospects for further improvement in performance in terms of output power, conversion efficiency and range of operating wavelengths will be discussed.

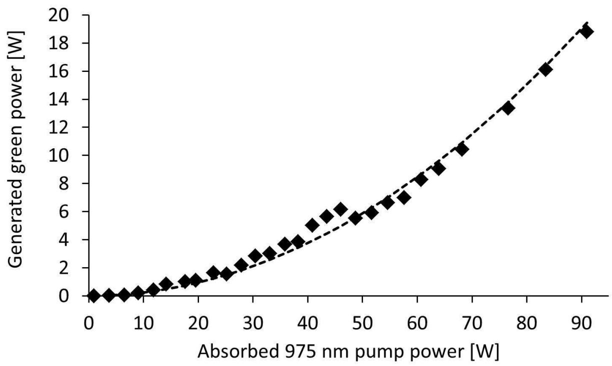

Figure 2. Generated second harmonic power at 540 nm as a function of absorbed diode pump power at 975 nm

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