A 3.5 μm Continuous-wave Laser Pointer

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Abstract: A handheld, battery-powered intracavity singly resonant optical parametric oscillator (IC-SRO) emitting 3.5 μm, 39 mW CW radiation is demonstrated. The lasing threshold of the IC-SRO (end-pumped by a 808 nm diode) is 120 mW.
OCIS codes: (140.3480) Lasers, diode-pumped, (140.4780) Optical resonators, (190.4970) Parametric oscillators and amplifiers

1. Introduction

Mid-infrared (MIR) is particularly useful in gas sensing [1], biomedical surgery, [2] and free-space communications [3]. Coherent MIR is commonly generated by quantum cascade lasers (QCLs), solid-state lasers, and nonlinear conversion. QCLs are compact, electrically pumped, but with limited output power for wavelengths below 4 μm. MIR solid-state lasers can produce watt-level output at some particular wavelengths determined by quality gain medium (e.g. Cr:ZnSe) or high-power pump source (~1900 nm), which are problematic in spectroscopic applications. In contrast, singly resonant optical parametric oscillators (SROs) pumped by 1064 nm laser and 808 nm diode in tandem routinely generate watt-level coherent MIR over a wide spectral range. However, the required pump power at 808 nm is usually >10W. To reduce the 808 nm pump threshold, the SRO and 1064 nm laser cavities can be integrated to intensify the circulating power at 1064 nm. Several groups have worked on this intracavity pumped singly resonant optical parametric oscillator (IC-SRO), demonstrating 310 mW pump threshold (at 808 nm) [4] or nanosecond output pulse [5]. In this contribution, we reduced the size and pump threshold of IC-SRO by using a 808 nm diode with a symmetric and diverging output beam in close contact with a highly absorptive $Nd:YVO_4$ gain medium. The record low pump threshold (120 mW at 808 nm) enables the system to be handheld and powered by two AA batteries.

2. Theory

The threshold condition of an SRO is formulated as

$$\cosh^2(\Gamma L) R_1 R_2 e^{-\alpha} = 1,\ \ \Gamma^2 = \frac{2\omega_s \omega_p d_{eff}^2 I_p}{n_p n_s n_i \varepsilon_0 c_0^3},$$

where L and d_{eff} are the length and effective nonlinear coefficient of the $\chi^{(2)}$ crystal, R_1 and R_2 are the cavity reflectance values, and $e^{-\alpha}$ is the loss inside the cavity. For a common SRO with 50-mm-long periodically poled lithium niobate (PPLN, d_{eff} =14 pm/V), the threshold pump power at 1064 nm is ~3 W [6]. This threshold can be easily achieved by integrating the SRO cavity inside the 1064 nm laser cavity such that the circulating 1064 nm power can be boosted by hundreds of times.

3. Experiment

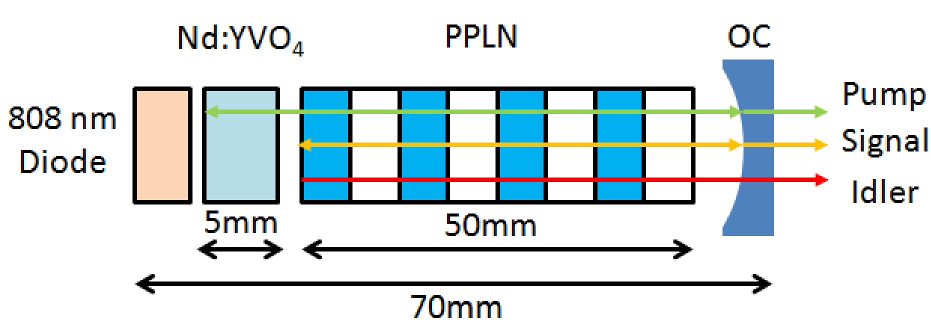

Fig. 1 Schematic of the IC-SRO. OC; output coupler.

The schematic of the end-pumped IC-SRO is shown in Fig. 1. The system pump is a 600 mW c-mount 808 nm laser diode with fast-axis collimation (FAC). Since the FAC output diameter (~200 μm) matches that of the cavity mode, the 808 nm pump diode is in close contact with a 3×3×5 mm^3 a-cut 0.5% doped Nd:YVO_4 (Castech) gain medium with high-reflection (HR) coating at 1064 nm on the input facet. The 50-mm-long PPLN has a poling period of 30.40 μm, supporting an idler wavelength λ_i ~3500 nm. The PPLN input facet coating is HR for the signal (λ_s ~ 1535 nm) and partially reflective (*R*~50%) for the idler, which could dump half of the reversely propagating idler wave from the cavity. The output coupler is a plano-concave CaF_2 lens (R=60 mm), which is HR for 1064 nm and 1535 nm (*R*~99% for both).

The signal wavelength λ_s was measured by an optical spectrum analyzer, from which λ_i is calculated by $1/\lambda_i=1/\lambda_p-1/\lambda_s$. A thermal power meter without and with the insertion of a germanium filter was used in measuring the total power (P_{tot}) and idler power (P_{idl}) emitted from the IC-SRO, respectively. Another silicon power meter measured the residual 1064 nm power (P_{1064}) at the IC-SRO output, from which the signal power can be estimated by $P_{sig}=P_{tot}-P_{idl}-P_{1064}$. Figure 2 shows the ~120 mW threshold pump at 808 nm, and 39 mW MIR (λ_i = 3470 nm) emitted at P_{808}~540 mW (P_{idl}/P_{808} ~7%). The entire system is packaged within a metal case of 85×24×21.5 mm^3 dimension, sufficiently compact to be handheld [Fig. 3(a)]. The idler far-field pattern recorded by an MIR beam profiler is close to TEM_{00} [Fig. 3(b)].

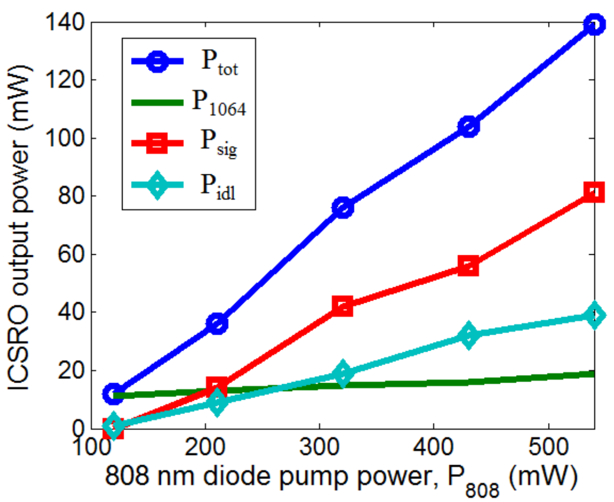

Fig. 2 Output powers P_{idl} (diamonds), P_{1064} (none), P_{tot} (circle) and P_{sig} (square) under different diode pump powers P_{808}.

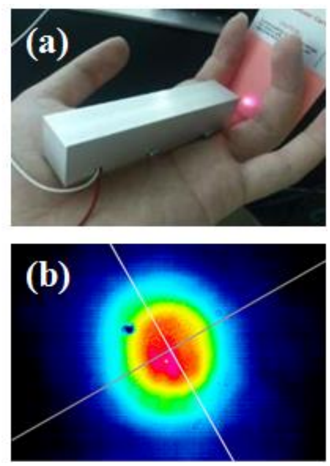

Fig. 3 (a) The real feature, and (b) MIR far-field pattern of the IC-SRO, respectively.

4. Conclusions

An end-pumped CW MIR IC-SRO with compact dimension (85×24×21.5 mm^3) and record-low pump threshold (120 mW at 808 nm) was demonstrated. The system is made of four basic components (diode, gain medium, PPLN and output coupler) with all the required HR coatings deposited on the component end surfaces. The configuration is compact enough to be handheld, battery powered with 39 mW output at 3470 nm and 540 mW pump.

5. References

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