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Diode pumped, frequency doubled LiSAF microlaser

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Abstract

A new diode pumped, solid state, Cr:LiSAF/$KNbO_3$ microlaser has been developed which simultaneously produces 50 mW of infrared fundamental power and 0.37 mW power at its second harmonic at 430 nm.

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Compact, low-cost, efficient, blue laser wavelengths are desired for applications such as undersea communications, optical data storage, biotechnology, and spectroscopy. Helium–Cadmium (He–Cd) and Argon-ion (Ar^+) lasers, despite their ideal spatial mode profiles, suffer from extremely low efficiencies and short tube lifetimes, intensifying the development of all solid state blue laser sources. The most promising, most compact, and simplest method to generate solid state blue laser light is directly from a laser diode. However, state-of-the-art InGaN blue laser diodes are limited in output power and have short lifetimes due to catastrophic failure [1]. Blue laser wavelengths can also be generated by frequency doubling the output of 860 nm, GaAlAs laser diodes to 430 nm [2,3]. Despite their compact size, these lasers suffer from poor spatial mode properties. Other approaches to generating blue laser light are by intracavity sum frequency mixing the circulating Nd:YAG laser power with the 809 nm pump beam to obtain 459 nm [4], and by frequency doubling the 946 nm Nd laser line to obtain 473 nm [5].

An alternative method of generating blue laser light is with a diode-pumped microchip laser. Over the past few years, microchip lasers have become reliable as ultracompact sources of high quality near infrared and visible laser radiation [6]. A microchip laser cavity is formed by depositing the appropriate dichroic dielectric mirror coatings directly onto the polished end surfaces of short plane/parallel laser crystals. A composite microchip laser can be formed by optically contacting two or more different plane-parallel materials together. Although short microchip laser cavities operate at the edge of stability, under longitudinal pumping, highly efficient TEM_{00} mode operation can be obtained [7]. Mechanisms such as thermal lensing and gain guiding which help to stabilize the cavity have been studied by many authors [7,8]. One of the most advantageous properties of microchip lasers is their ability to produce remarkably good spatial mode outputs despite the inherently poor spatial mode of a highly astigmatic pump laser diode. Efficient conversion of the infrared laser to the blue is achieved by intracavity placement of the nonlinear crystal optimizing the dichroic coatings at the

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ends of the microchip laser. A composite diode pumped Nd:YAG/$KNbO_3$ microlaser initially demonstrated over 1 mW of 473 nm laser light and with further optimization of the microchip design led to output powers exceeding 25 mW [5].

We report a new diode-pumped composite microchip laser incorporating Cr:LiSAF and $KNbO_3$. When pumped by a visible laser diode, the microchip laser generates both 860 nm near-infrared fundamental output and 430 nm deep blue second harmonic laser output. We have obtained over 0.37 mW of blue laser light from this new microlaser. The colquiriites suffer from many thermo-mechanical problems such as low thermal conductivity [9,10] and thermal quenching of fluorescence [11]. To minimize the thermal problems associated with Cr:LiSAF, we have developed a new thermally-compensated microchip laser architecture. This new architecture, shown in Fig. 1, is designed to remove the pump-induced heat from the Cr:LiSAF as efficiently as possible. The laser cavity consists of a $4 \times 4 \times 1$ mm thick, 5% doped Cr:LiSAF laser crystal, two 9 mm diameter $\times$ 400 μm thick, undoped YAG disks, and a $3 \times 3 \times 1.5$ mm thick A-cut $KNbO_3$ second-harmonic crystal. All components were polished flat and parallel on the two faces normal to the optical axis. The LiSAF crystal was surrounded on both sides by the thin clear YAG disks to help with thermal management by removing the power that is generated from upconversion, thermal quenching of fluorescence, and quantum defect heating [12,13]. YAG is utilized inside the cavity because of its superior thermal conductivity when compared to LiSAF. $KNbO_3$ was chosen as the nonlinear conversion crystal because of its extremely high nonlinearity and its ability to be non-critically phase-matched at slightly above room temperature [14].

The dielectric coating on the pump face of the microlaser is highly transmitting at the pump wavelength (665 nm) and highly reflecting at the LiSAF oscillating wavelength (860 nm). An index matching coating was applied to the center clear YAG disk before the crystals were optically contacted together. The dielectric coating on the output face of the microlaser was also highly reflecting at the LiSAF oscillating wavelength and highly transmissive at the LiSAF second harmonic wavelength (430 nm).

The pump source was a 150 μm stripe width AlGaInP visible laser diode (LDX Optronics) lasing at 665 nm. The diode output was collimated by a high numerical aperture aspheric lens (Geltec 350230B) and expanded six times in the slow direction by a cylindrical telescope. After beam shaping the laser diode output was focused into the LiSAF crystal by a 50 mm focal length plano/convex lens. The focused pump spot had dimensions of 50 μm $\times$ 55 μm ($1/e^2$) as measured by a scanning slit beam profiler (Photon Inc, BeamScan). To prevent thermo-mechanical fracture in both the LiSAF and the $KNbO_3$ crystals, the diode was operated at a 50% duty cycle at a frequency of 100 Hz.

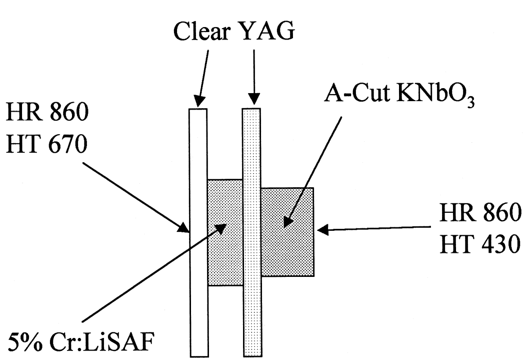

Fig. 1. Scheme of the microlaser design.

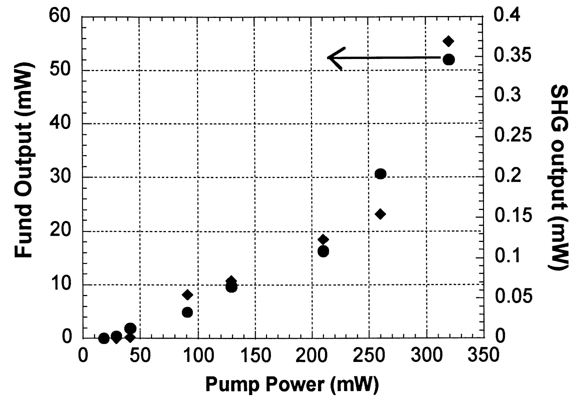

Fig. 2. Fund and SHG output power versus pump power.

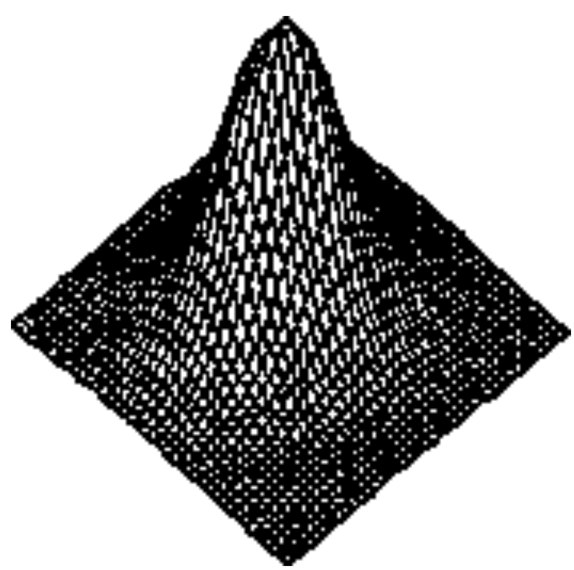
Fig. 3. SHG transverse mode profile.

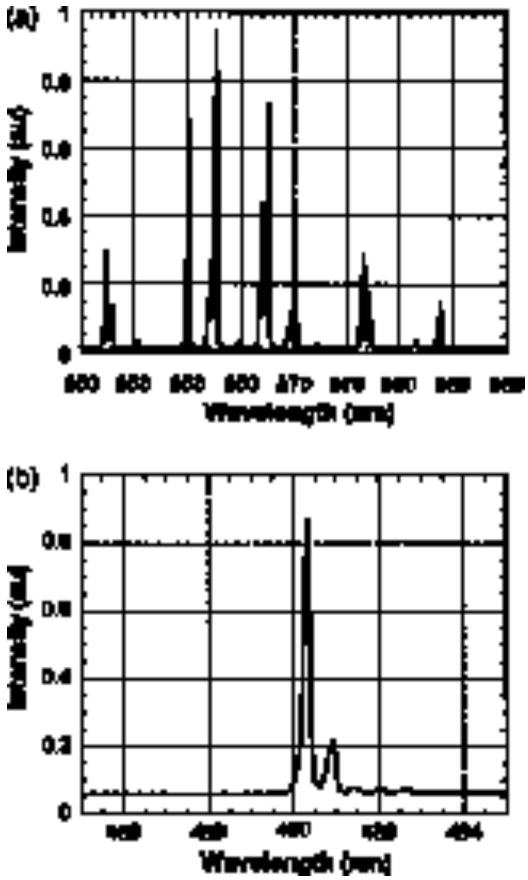

Fig. 4. (a) Fundamental laser spectrum. (b) SHG laser spectrum.

The near-infrared and blue output powers as a function of the pump power were measured and are shown in Fig. 2. The threshold for fundamental wavelength operation was only 18.3 mW of average pump power. The threshold for blue light output was 29.2 mW of average pump power. The fundamental and blue output beams displayed Gaussian (TEM_{00}) beam profiles. Fig. 3 shows the profile of the 430 nm beam as measured with a Spiricon LBA-100A. Phase matching was achieved by adjusting the temperature of the microlaser heatsink with a thermoelectric cooler/thermister combination. At a maximum average pump power of 320 mW, 0.37 mW of blue 430 nm laser output power was obtained. At this same pump power, the microlaser generated over 50 mW of 860 nm near infrared laser power. The fundamental output wavelength spectrum of the microlaser is shown in Fig. 4a. The laser operates simultaneously at over 10 different frequencies between 850 and 880 nm. This multi-frequency operation is typical from broadband lasers such as LiSAF without active wavelength control [15].

When the temperature of the microlaser heatsink was adjusted for maximum second harmonic output, it was possible to select only one of the fundamental laser wavelengths for conversion, as seen in Fig. 4b. Because of the variable pump induced heating, the temperature of the heatsink was readjusted at each pump power level to maintain optimum phase matching conditions [5]. The temperature of the heatsink was found to be extremely critical because both the LiSAF and $KNbO_3$ are sensitive to temperature. If the temperature of the heatsink was adjusted to be too high before the pump power was at full pump power, the blue output power and conversion was initially quite high. However, at full pump power, the LiSAF crystal temperature rapidly increased above the critical temperature of 67°C [11] resulting in a thermal runaway situation in which the upperstate population was severely depleted by detrimental non-radiative transitions inside the LiSAF crystal [12].

In conclusion, we have shown that a Cr:LiSAF, YAG, and $KNbO_3$ matrix can be successfully combined in a composite microlaser to produce a compact, diode pumped, deep-blue laser light source. The design of a new thermally compensating architecture has produced encouraging initial results. Further development of the cavity design should result in multi milliwatt single transverse mode 430 nm output powers.

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