VIII-D Development and Research of Advanced Tunable Solid State Lasers

Diode-pumped solid-state lasers can provide excellent spatial mode quality and narrow linewidths. The high spectral power brightness of these lasers has allowed high efficiency frequency extension by nonlinear frequency conversion. Moreover, the availability of new and improved nonlinear optical crystals makes these techniques more practical. Additionally, quasi phase matching (QPM) is a new technique instead of conventional birefringent phase matching for compensating phase velocity dispersion in frequency conversion. These kinds of advanced tunable solid-state light, so to speak Chroma Chip Lasers, will assist the research of molecular science.

In this projects we are developing Chroma Chip Lasers based on diode-pumped-microchip-solid-sate lasers and advanced nonlinear frequency conversion technique.

VIII-D-1 Frequency-Doubled Tunable Yb:YAG Microchip Laser for Holographic Volume Memories

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Holographic volume memories have provoked a great deal of controversy.[1] Angle and wavelength-multiplexed recordings have excellent potential for a large storage capacity.[2,3] However, large cumbersome light sources prevent the research of holographic data storage systems. Lately, we developed diode-pumped single-frequency and tunable Yb:YAG microchip laser.[4] In this work, we have demonstrated multiplex recording by using an intracavity frequency doubled Yb:YAG green laser.

The experimental configuration is shown in Figure 1. The frequency-doubled Yb:YAG laser consists of 400-μm thickness YAG doped with 25 at.% Yb^{3+} ion assembled on a sapphire substrate. Because the internal surface of the Yb:YAG microchip has partial reflectivity for laser wavelength, this microchip acts as an mode selection etalon. For tuning, a 1 mm thickness quarts plate was inserted into the laser cavity as a birefringent filter. A 2 mm KTP crystal was cut for type-II second-harmonic (SH) phase matching ($\theta = 90°$, $\phi = 50°$). In the frequency doubled Yb:YAG laser, tuning from 514.8 to 525.7 nm (10.9 nm, 12.4 THz) and maximum SH output power of 112 mW were obtained with single-axial-mode.

The recording medium was a 1% Fe-doped $LiNbO_3$ (Fe:LN) single crystal ($3 \times 3 \times 5$ mm). The *c*-axis of the crystal was parallel to the grating vector of the hologram. A reference beam *R* and a signal beam *S* irradiated opposite sides of the crystal, both at an angle θ_0 of 10°. A pattern mask with a 10×10 mm^2 character image, two lenses (diameter: d = 1-inch, focal length f = 75.5-mm), the Fe:LN crystal, and a CCD camera made a Fourier-transform holographic system. We recorded and reconstructed two successive wavelength-multiplexed holograms by using light of two wavelengths that were 0.31 nm apart which corresponds to the FSR of 400-μm Yb:YAG microchip.

References

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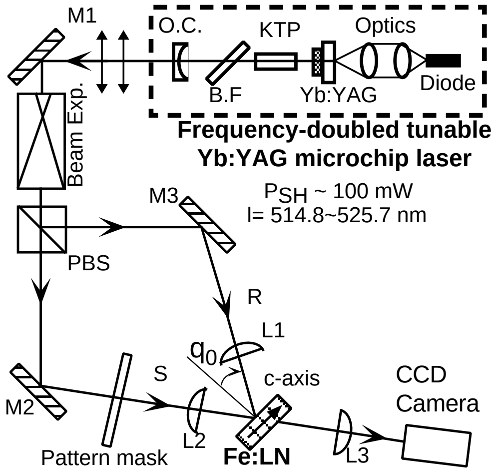

Figure 1. Holographic recording system by using intracavity frequency-doubled Yb:YAG microchip laser.

VIII-D-2 Design Criteria for Optimization of Fiber-Coupled Diode Longitudinally-Pumped Laser Using Pump-beam M² Factor

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For optimization of longitudinally-pumped solid-state lasers, a model which consider the pump-beam propagation described by its M^2 factor is proposed. Analytical functions for the optimum focusing-position, the optimum pump spot-size, the minimum threshold pump power and the maximum overlap efficiency are given. A simple output to input power relation and previous formula provides a straightforward procedure to design the optimum laser resonator, the coupling-optics and to evaluate the laser output power.

A slope efficiency of 57% with a 53% optical-efficiency at maximum 8-W pump-power was obtained from a fiber-coupled longitudinally-pumped Nd:YAG medium. A very good agreement between experiments and theory was obtained.

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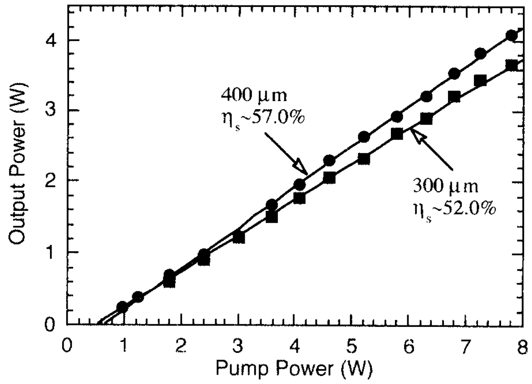

Figure 1. Output power as a function of pump-power.

VIII-D-3 Highly Nd^{3+}-Doped YAG Ceramic for Microchip Lasers

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Nd:YVO_4 offers highly efficiency miniature or microchip lasers due to its high absorption and emission cross-sections.[1-4)] However, its poor thermo-mechanical properties prevent high power laser operation. Much effort has gone into laser material research to find a high absorption coefficient laser medium with high thermal shock parameters. Lately, a high optical quality Nd:YAG laser material of polycrystalline ceramic has been reported.[5)] In this paper, we have demonstrated a highly efficient oscillation in a Nd:YAG ceramic microchip laser.

The YAG ceramic allows highly neodymium-ion doping to overcome low absorption cross-section. The absorption coefficient of the single Nd:YAG crystal was 3.45 cm^{-1} at 808 nm, while the 9.1 at.% Nd:YAG ceramic has about 10 times higher absorption. The absorption coefficient of the 4.8 at.% Nd:YAG ceramic was 11.7 cm^{-1}. This result indicates that Nd:YAG ceramic has advantages in a microchip or miniature laser system as well as Nd:YVO_4. The thermal conductivity of Nd:YAG ceramic decreases with Nd concentration and thermal conductivity of the 9.1 at.% doped YAG ceramic was 9.0 W/mK.

The 4.8 at.% Nd^{3+} doped YAG ceramic was cut to a 847 µm thickness for microchip laser experiments. The plan-concave resonator configuration has an output mirror radius of 100-mm and a resonator length of 50-mm. The 808 nm pump beam was focused to a diameter of 100 µm in the medium. Figure 1 shows an output power of Nd:YAG ceramic laser as a function of input power. A performance of 0.9 at.% Nd:YAG single crystal also plotted in order to compare. As a result, the maximum output power of Nd:YAG ceramic laser was four times higher than conventional Nd:YAG single crystal laser because the YAG ceramic has over five times higher Nd^{3+} ion doping level. Conventional ceramic laser has highly scattering loss which prevent the highly efficient laser oscillation. We are estimating an internal loss of laser cavity from the slope efficiency.

In summary, we developed highly Nd-doped YAG in ceramic for high power microchip laser. Four times higher laser output power in YAG ceramic compared with conventional YAG single crystal was demonstrated.

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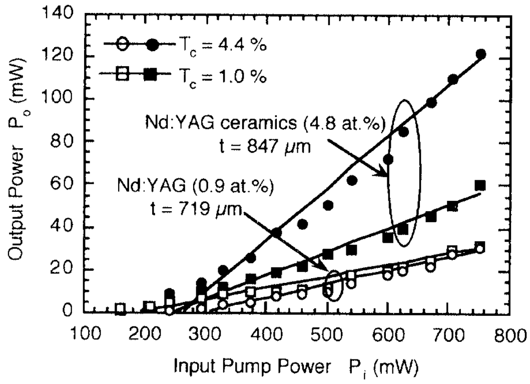

Figure 1. Input-output power characteristics of a diode-pumped Nd:YAG ceramic laser.

VIII-D-4 Nondestructive Characterization of Quasi-Phase-Matched Wavelength Converter

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We devised an observation technique of 180° domains in ferroelectric crystals by using Second Harmonic Generation (SHG) Microscope. The phase reversal of the SH wave accompanying inversion of spontaneous polarization is exploited to visualize domains. Interference between SH waves converts the phase information to the SH contrast. Domain mapping is achieved in $LiNbO_3$ and $LiTaO_3$ with nonlinear coefficients d_{33} and d_{22} under the microscope, which enables characterization of a periodically-poled structure in quasi-phase-matched wavelength converters in a nondestructive way. The validity of the technique is proved by another characterizing tool of destructive etching.

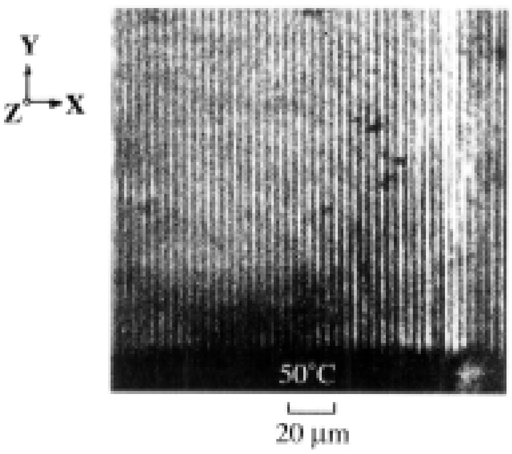

Figure 1. Photo of a Z-cut QPMLT device.