discrepancy between theory and experiment in cavity length is within 2% and in stability range is within 10%.

In conclusion, multi-reentrant ring laser is demonstrated. We have successfully derived the reentrant condition and get a good agreement with the experimental results for the planar and non-planar ring cavities. The stability criteria have also been analyzed. Long round-trip length can be achieved with short cavity length by using the multi-reentrant ring laser cavities. The ring lasers have potential applications in such as short cavity mode-locked laser and high-sensitivity trace gas detection.

References

1. T.J. Kane and R.L. Byer, "Monolithic unidirectional single-mode Nd:YAG ring laser," Opt. Lett. **10**, 65–67 (1985).
2. M.D. Selker, T.J. Johnston, G. Frangineas, J.L. Nightingale, and D.K. Negus, ">8.5 watts of single frequency 532 nm light from a diode pumped intra-cavity doubled ring laser," in *Conference on Lasers and Electro-Optics*, 1996 Technical Digest Series (Optical Society of America, Washington, D.C., 1996), paper CPD-21.
3. H.Z. Cheng, P.L. Huang, S.L. Huang, and F.J. Kao, "Reentrant 2-mirror ring resonator for generation of a single frequency green laser," Opt. Lett. **25**, 542–544 (2000).
4. T. Beddard, W. Sibbett, D.T. Reid, J. Garduno-Mejia, N. Jamasbi, and M. Mohebi, "High-average-power, 1-MW peak-power self-mode-locked Ti:sapphire oscillator," Opt. Lett. **24**, 163–165 (1999).

CThO13 — 1:00 pm

Simple and Efficient Pumping Scheme for Side-pumped Laser Rods

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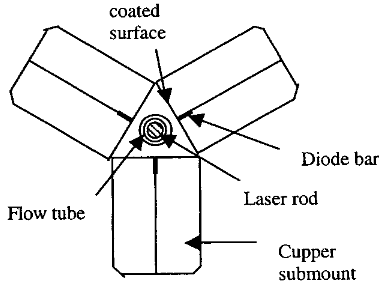
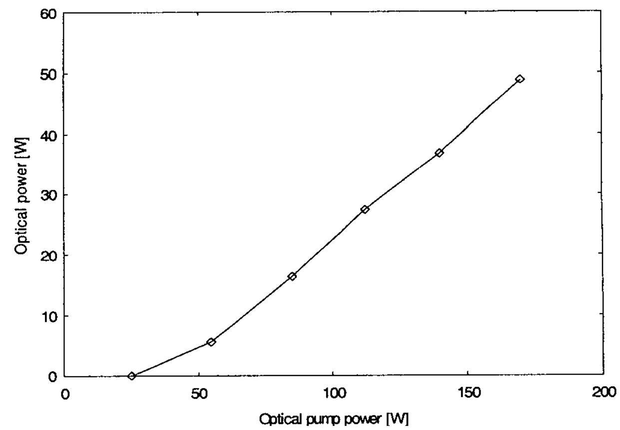
Moderate power lasers (few tens of watts) with relatively good beam quality ($M^2 = 5 - 10$) found many potential industrial applications. Side-pumped geometries with high-power diode-laser bars as pump source have been widely adopted for this kind of lasers. However it is difficult to design a pumping chamber with both high coupling efficiency and good pump power deposition, especially for small diameter rods.



CThO13 Fig. 1. Schematic drawing of laser head.



CThO13 Fig. 2. Laser performance of a 2 mm Nd: YAG rod in a plane-plane cavity.

We circumvent this difficulty by simply putting a reflector directly on the diode bar submount.[1] Namely the cupper mount is polished and gold coated in order to reflect the pump light which has not been absorbed by the first path through the rod, as seen on figure 1. By assembling three such diode bars around a 2 mm laser rod calculations show that up to 75% of the pump power are absorbed by a 1.1% doped Nd:YAG rod. It should be pointed out that no guiding or shaping optics is needed and that this simple and robust scheme is insentive to the alignment of diode bars. The system is scalable by simply adding more diodes around the rod.

If the diodes are at the right distance (from the rod center) as given by the ray tracing simulation[2] the distribution of the pump light is uniform over the rod cross section. Homogeneous pump deposition is important to minimize spherical aberrations due to the non-parabolic temperature gradient in the rod.[3]

To confirm the calculations we constructed a pump chamber using six custom-made 30 W laser diodes emitting at 807 nm from Thalès Laser Diode (France). The cupper submounts are polished and gold coated with a reflectivity of appromately 90%. The 2 mm Nd:YAG rod (doping : 1.1% at. Nd) is ground polished in order to get the best homogeneity. The measured fluorescence is very flat over the rod cross-section, as expected. The plane-plane cavity we used for the experimental work is 25 cm in length and has a 90% reflectivity output coupler. The laser threshold is at 35 W pump power and the laser emits 50 W at 1064 nm for 180 W of pump power. The optical-to-optical efficiency is 37.5% and optical-to-electrical efficiency 10.4%. The beam quality M^2 is equal to 4.8.

In summary we proposed a very simple and cost-effective way to pump laser rods with high power laser diodes. Simulations show that the power deposition can be very homogeneous in order to avoid spherical aberration.

1. P.-Y. Thro and G. Ughetto, "Module de pompage optique d'un laser, comprenant un réflecteur cylindrique à base polygonale", European patent n° wofr0000734, 2000.
2. SPIR, commercial software from Oxalis Laser, France, www.oxalis-laser.com.
3. W. Koechner, *Solid-State Laser Engineering* (Springer, 1999), Chap. 7.

CThO14 — 1:00 pm

Optimization of Passively Q-switched Er: Glass Laser

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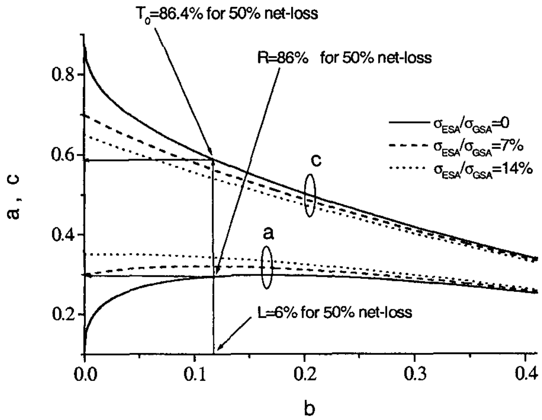
Optimization of the laser performance of the Q-switched lasers resulting in maximal output pulse energy and/or minimal pulse width has got much attention in the recent years.[1,2] Here we present an usable and demonstrative theoretical approach and its practical application to the optimization of the passively Q-switched Er:glass laser emitting in the so called "eye-safe" spectral range around 1.5 µm.

Our theoretical model is based on the analytically solved rate equations which take into account excited-state absorption in the saturable absorber. The optimal contributions of the output loss $a = ln(1/R)/N$ and the initial absorber's loss $c = ln(1/T_0^2)/N$ in the laser's net-loss $N = ln(1/R) + L + ln(1/^2)$ as well as maximal pulse energy were shown to be parametric functions of $b = L/N$, where R is the output mirror reflectivity, T_0 is the small signal transmittance of the absorber, and L is the logarithmical linear intracavity loss.

The theory predictions were compared with experimental results for the flash-lamp pumped Er:glass laser operated at 1.53 µm. Three different mirrors with 91.6, 88 and 79.3% reflectivity were used for output coupling. The laser was passively Q-switched by using three saturable absorbers based on Co^{2+} -doped $LaMgAl_{11}O_{19}$ (LMA) and Co^{2+}-doped spinel $MgAl_2O_4$ (MALO) with 92, 90



CThO14 Fig. 1. Optimal output coupling (*a*-curves) and initial saturable loss (*c*-curves) versus linear loss parameter *b*. The solid, dashed and dotted curves correspond to the values of $\sigma_{ESA}/\sigma_{GSA} = 0, 0.07, 0.14$, respectively. The horizontal and vertical straight solid lines are utility lines for determination of the intersection points.

and 88.6% transmittance at the laser wavelength. These crystals were shown recently to be the most promising saturable absorber Q-switches for 1.5 μm lasers.[3–5] Q-switched pulses with pulse energy up to 11.5 mJ and pulse width of 70 ns were demonstrated in our experiments. The optimal values of T_0 and R as well as output energy and pulse width predicted by the theory are in a good agreement with the experimental results.

The choice of the optimal T_0 and R for the energy maximization of the laser with known value of linear intracavity loss L and laser net-loss N can be done by using Fig. 1. The main trends of the optimization procedure are following: 1) with increasing of the relative linear intracavity loss b the relative optimal saturable loss c is decreased while the output loss a is increased; and 2) for the fixed value of L the relative contribution of the saturable loss c is increased and that of output loss a is decreased with increasing of the laser net-loss. The change of a is negligible in the range of b from 0.1 to 0.3 that results in nearly proportional dependence of the optimal output coupler transmission on the laser net-loss.

The growth of the excited-state absorption (transition from solid through dashed to dotted curves in Fig. 1 corresponds to $\sigma_{ESA}/\sigma_{GSA} = 0, 7\%, 14\%$, respectively) leads to the decrease of the optimal relative contribution of the saturable loss c and the increase of the optimal relative contribution of the output loss a.

In conclusion, the approach to the energy optimization of the passively Q-switched Er:glass laser based on the analytical solution of rate equations is demonstrated. The energy values predicted by the theory are in a good agreement with experimental results for the flash-lump pumped Er:glass laser passively Q-switched with the Co^{2+}:$LaMgAl_{11}O_{19}$ and Co^{2+}:$MgAl_2O_4$ crystals.

References

1. J.J. Zayhowski, P.L. Kelly, IEEE J. Quant. Electr. Vol. 27 (1991) 2220.
2. J.J. Degnan, IEEE J. Quant. Electr. Vol. 25 (1989) 214.
3. K.V. Yumashev, I.A. Denisov, N.N. Posnov, V.P. Mikhailov, R. Moncorgé, D. Viven, B. Ferrand, Y. Guyot, J. Opt. Soc. Am. B, Vol. 16 (1999) 2189.
4. Ruikun Wu, J.D. Myers, M.J. Myers, B.I. Denker, B.I. Galagan, S.E. Sverchkov, J.A. Hutchinson, Ward Trussel, in OSA Trends in Optics and Photonics, Vol. 34, Advanced Solid-State Lasers, H. Injeyan, U. Keller, Ch. Marshall, eds. (OSA, Washington, DC, 2000) 254–256.
5. V.G. Shcherbitsky, A.V. Podlipensky, N.V. Kuleshov, V.I. Levchenko, V.N. Yakimovich, A. Diening, M. Mond, E. Heumann, S. Kück, G. Huber, in Conference Digest of Euro-CLEO/EQEC'01 Focus Meetings (Münich, 2001) p. 51.

CThO15 **1:00 pm**

Experimental Investigation and Numerical Simulation of the Spatio-Temporal Evolution of the Laser Pulses in Q-switched Nd:YAG-Lasers

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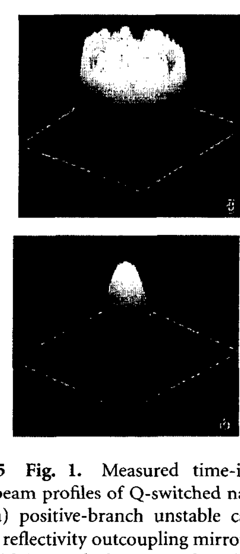
Flashlamp-pumped, Q-switched Nd:YAG-lasers provide high energy nanosecond light pulses at repetition-rates of up to 100 Hz. The wide range of applications covers material processing, optical spectroscopy and pumping of nonlinear frequency conversion processes. For a high energy extraction large diameter laser rods in resonator cavities with large fresnel numbers have to be used. However the drawback of these cavities is a transverse highly multimode beam with more or less poor beam quality. In the past, several methods for an improved laser beam quality have been investigated. Positive-branch confocal unstable resonators in combination with variable reflectivity mirrors hereby have become a standard solution for generating large diameter modes in conjunction with a low beam divergence.

In this paper we report on the two-dimensional measurement of the spatio-temporal dynamics of the pulse formation in Q-switched Nd:YAG-lasers. In our investigation we compare two different resonators. A positive-branch confocal unstable resonator with an gaussian variable reflectivity outcoupling mirror provides 7 ns-pulses in a 8 mm beam with a pulse energy of up to 650 mJ and a near flat-top transverse intensity distribution. The second resonator consists of a stable cavity and a resonator-internal telescope. This system provides 10 ns pulses in a 4 mm beam and a pulse energy of 90 mJ. With an additional amplifier stage the pulse energy is increased up to 350 mJ. An internal mode-aperture discriminates high-order transverse modes, leading to a nearly gaussian transverse intensity distribution (Fig. 1).

For the time-resolved measurement of the spatial beam profiles we used a two-dimensional, fast gated and intensified CCD-camera system with a gating time of 0.25 ns. With a high precision delay the laser pulses were sampled in steps of 1 ns. With this camera-system we can also measure the dynamical development of the beam quality factor M^2 of the laser pulses.

Figure 2 shows the transverse beam profile of the laser pulses at four different times during the pulse formation. In both resonators the oscillation starts with a small spot on the optical axis. But while in the telescopic resonator the spatial beam profile remains gaussian throughout the whole laser pulse, in the unstable resonator the temporal nonuniform depletion of the laser inversion leads to a strong variation of the intensity distribution. Correspondingly during the pulse evolution the beam quality factor M^2 increases in the unstable resonator from a value near 1 to more than 10, where in the stable resonator the M^2 remains about 1.3 throughout the whole laser pulse.

We compare our measurements with the results of a numerical simulation (Fig. 3). The numerical model takes cavity-losses, free-space propagation, diffraction and curved mirror-surfaces into account. Gain depletion is calculated by the rate equations. With an M^2-formalism, based on the 4-sigma method, the temporal behavior of



CThO15 Fig. 1. Measured time-integrated, spatial beam profiles of Q-switched nanosecond lasers. a) positive-branch unstable cavity with variable reflectivity outcoupling mirror. b) stable cavity with internal telescope and mode aperture.