High-Power, Passively Q-switched Microlaser - Power Amplifier System

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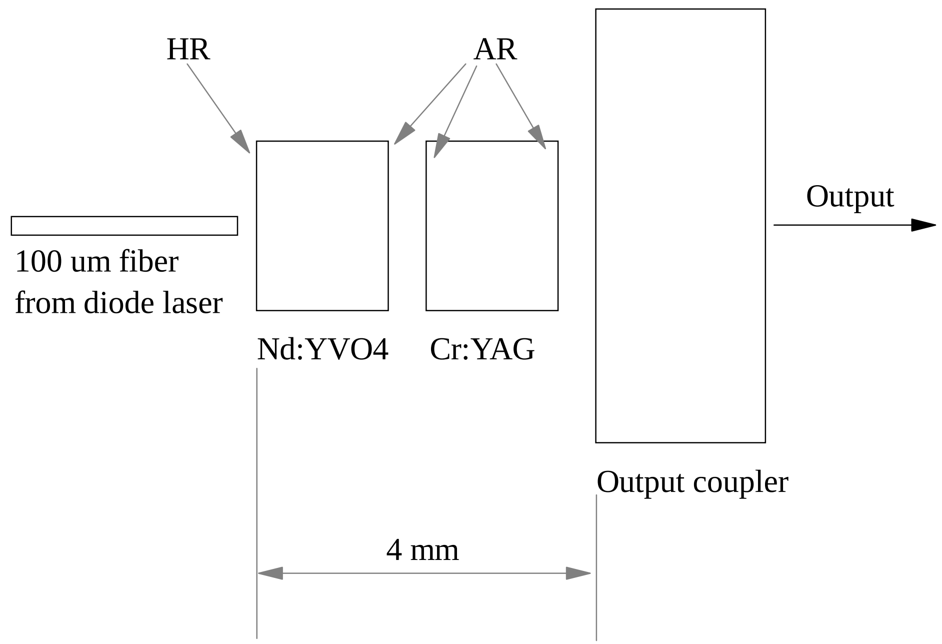
Technical objective

Develop a Subnanosecond-Pulse MOPA System Including diode-laser-pumped, passively Q-switched, 1064-nm Nd-doped microlaser, multipass amplifier and SHG to generate pulses with

- Pulse energy: 150 μJ
- Wavelength: 532 nm
- Pulse rate: 2 kHz
- Pulsewidth ≤ 200 ps

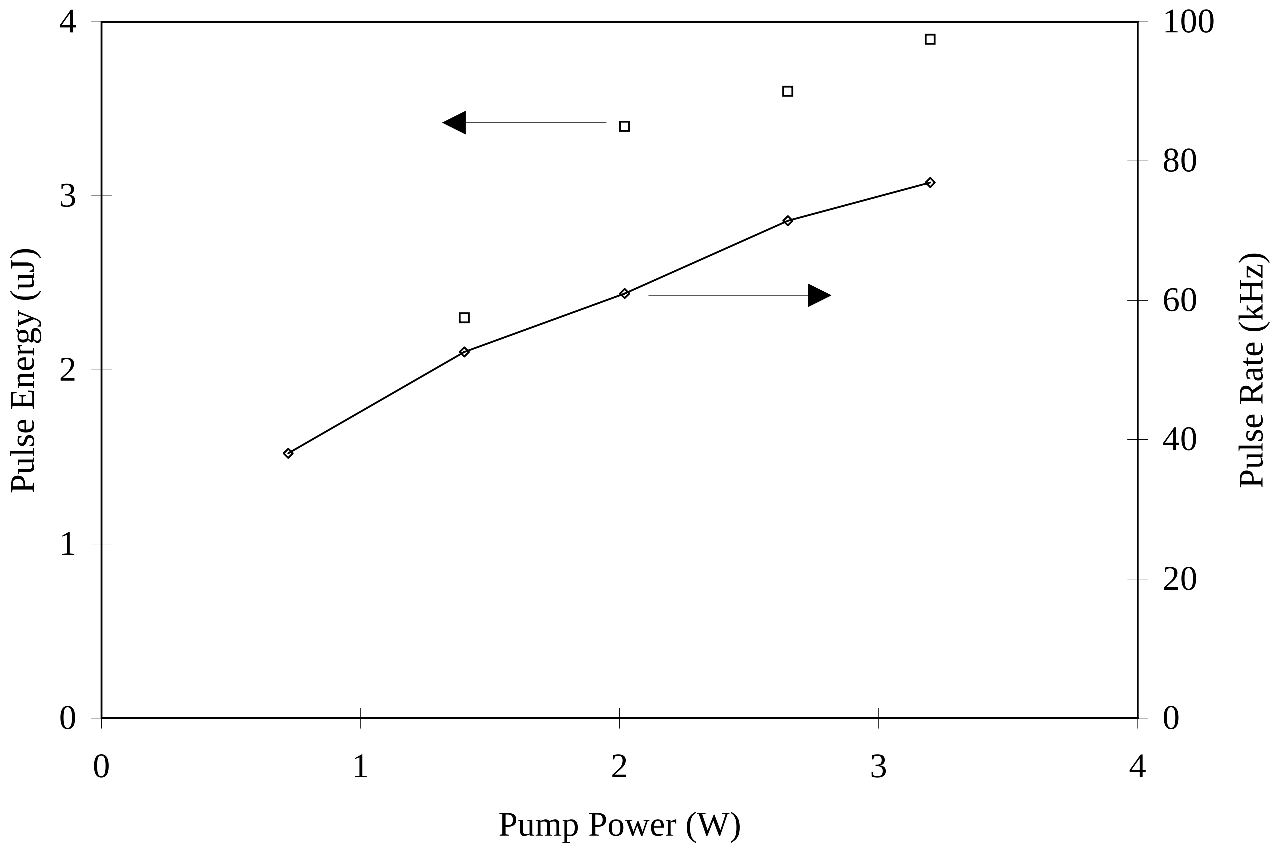
Phase I $Nd:YVO_4$ Microlaser



The laser crystal was a 1-mm thick piece of 3% Nd-doped YVO_4 with the pumped face highly transmitting at the pump wavelength and highly reflecting at 1064 nm while the opposite face was anti-reflection (AR) coated at 1064 nm. No attempt was made to double-pass the pump light through the laser crystal.

The resonator was formed between the pumped face of the crystal and an external mirror placed to < 1 mm of the AR-coated face of the crystal. Using this arrangement we were able to change output coupling transmission and insert the saturable absorber material to Q-switch. Pump induced thermal lensing and gain-guiding in the $Nd:YVO_4$ crystal stabilizes the resonator and the 100 μm diameter pump beam only provides excitation for the TEM_{00}-mode. Hence, we obtained near-TEM_{00}-mode output beam quality.

Pulse energy and rate as a function of pump power



Roc=80%
Tsa=80%

Modeling of Microchip Lasers

Zayhowski and Kelley analysis

$$\tau = \frac{8.1n}{N_0 \sigma c}$$

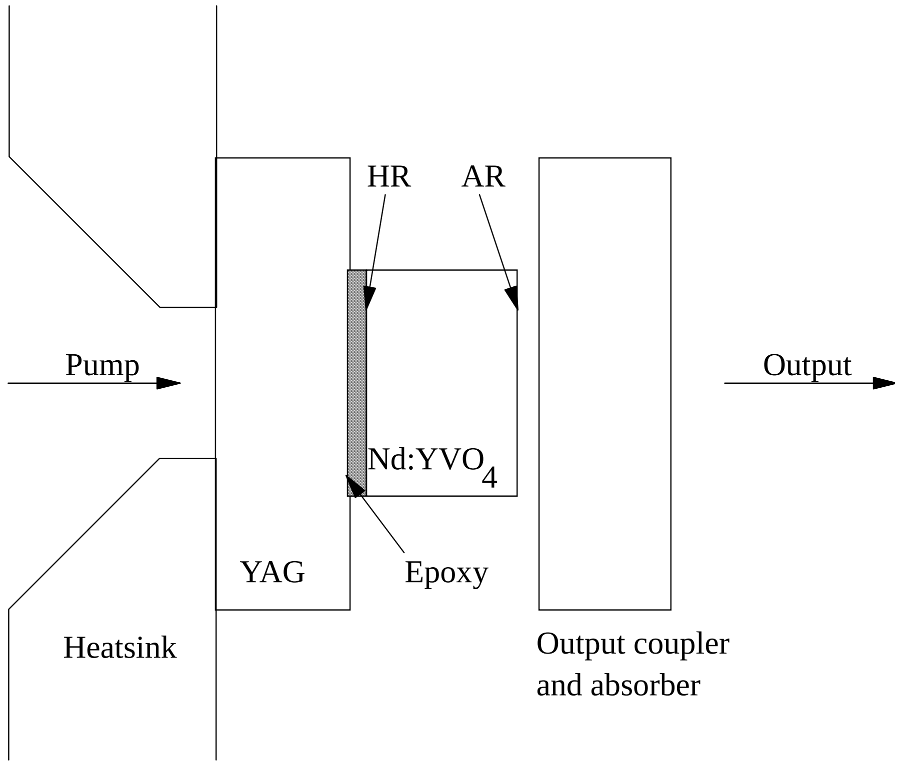
$$E = \frac{N_o \pi r_m^2 l_r h \upsilon}{2}$$

N_0 is the initial population inversion (1.1×10^{18} cm^{-3})
n is the refractive index,
σ is the gain medium emission cross-section (15.6×10^{-19} cm^2),
c is the speed of light, r_m is the laser beam radius (75 μm),
l_r is the round trip path length (3 mm),
h is Planck's constant,
ν is the optical frequency

Experimental and theoretical results for 2-W pumped laser:

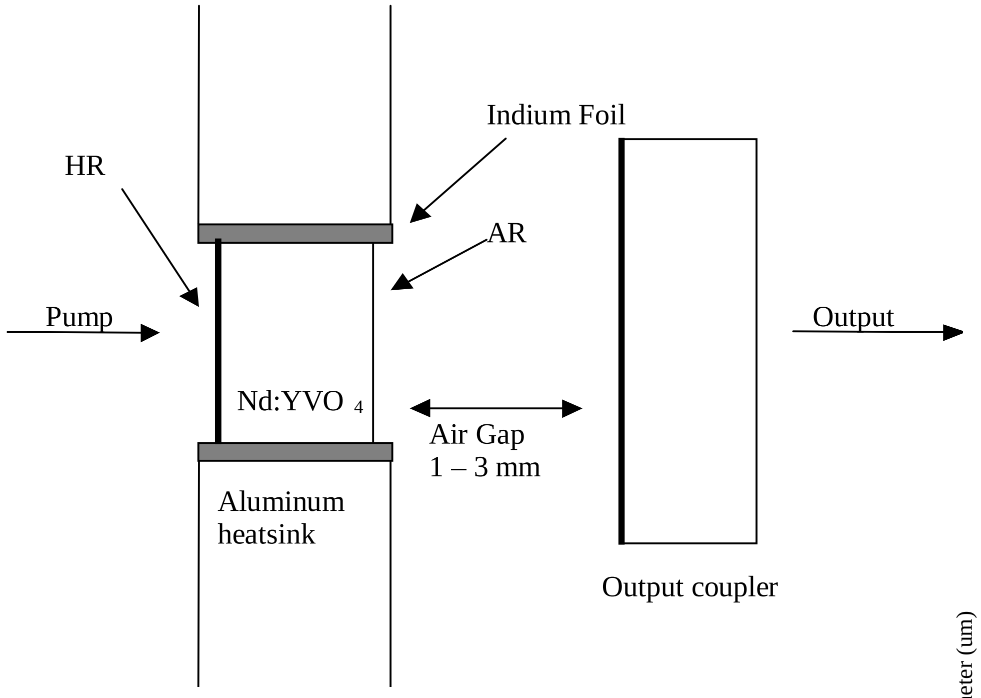
Pulsewidth: 2.5 nsec	315 ps
Pulse energy: 3.4 μJ	6.5 μJ
Average power: 300 mW	

$Nd:YVO_4$ Microlaser Development

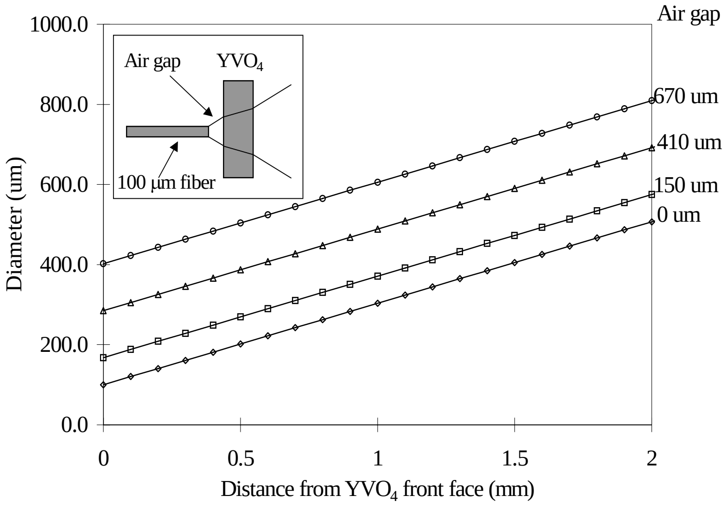


Face-cooled heatsinking with an epoxy bonded or optically-contacted, 3 mm × 3 mm × 1 mm, 1% Nd-doped YVO_4 laser crystal

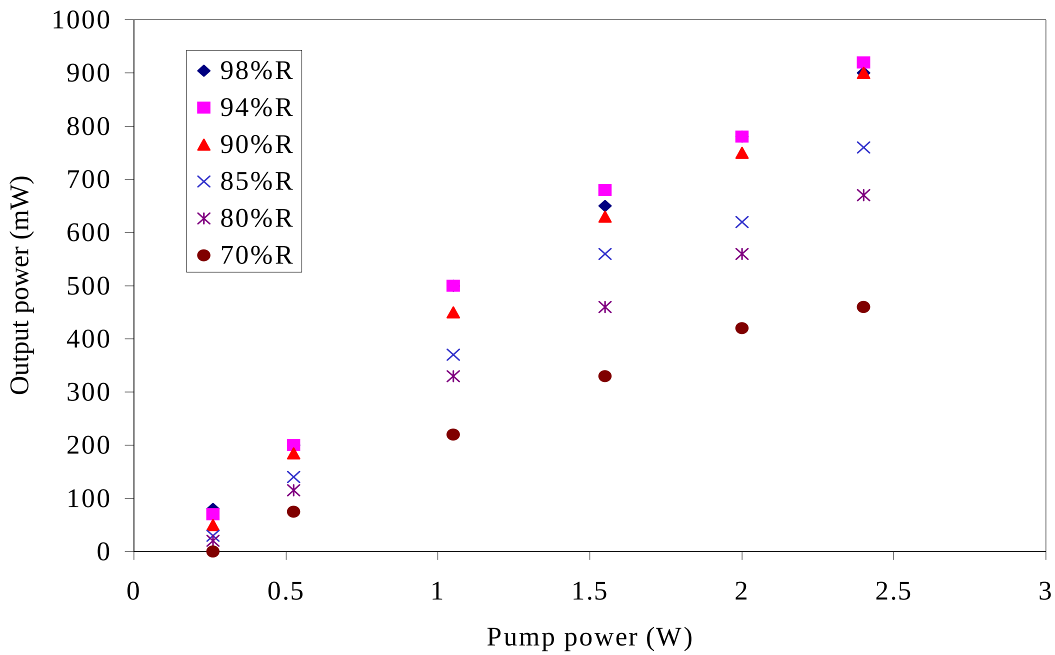
$Nd:YVO_4$ Microlaser with edge-mounted laser crystal heatsinking



Pump beam propagation data in the $Nd:YVO_4$ crystal for 100 μm diameter, 0.22 NA fiber pumping with various fiber-to-crystal air gaps.

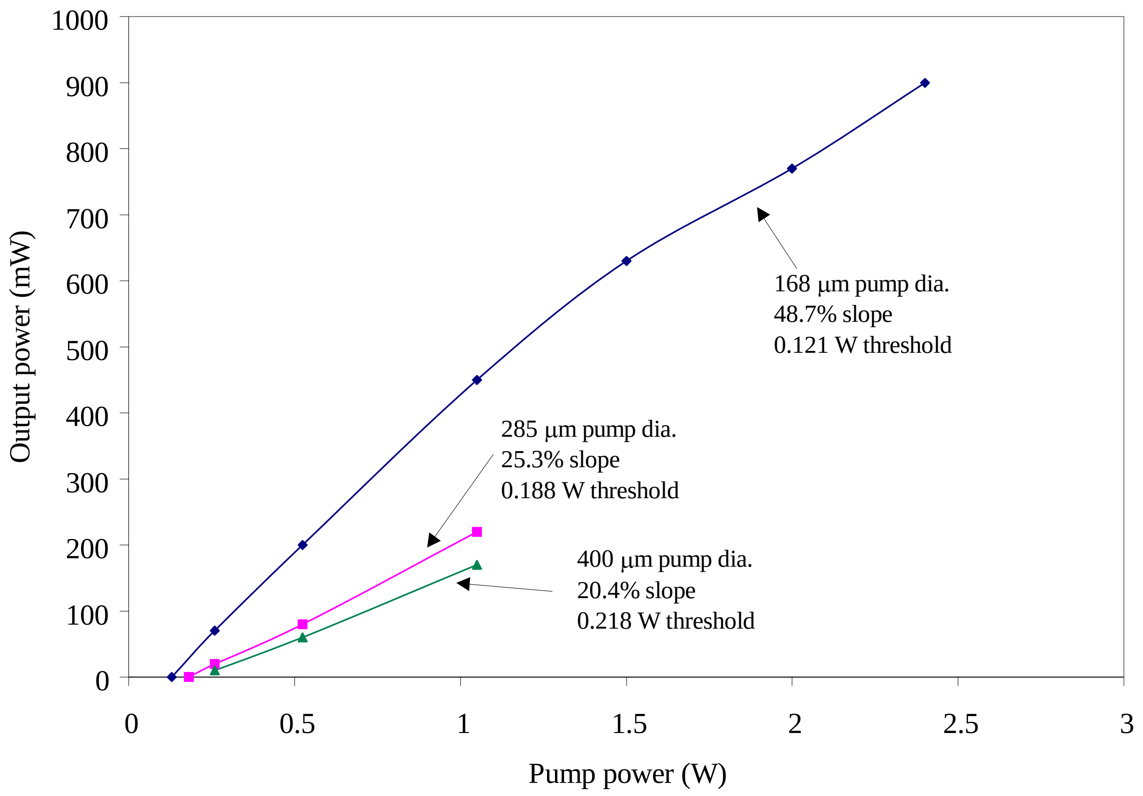


Nd:YVO4 microlaser output power data as a function of output coupling

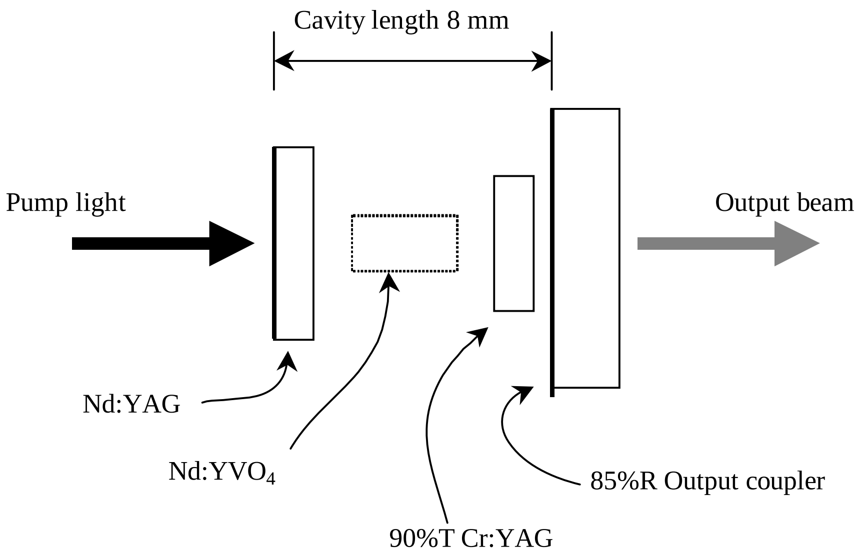


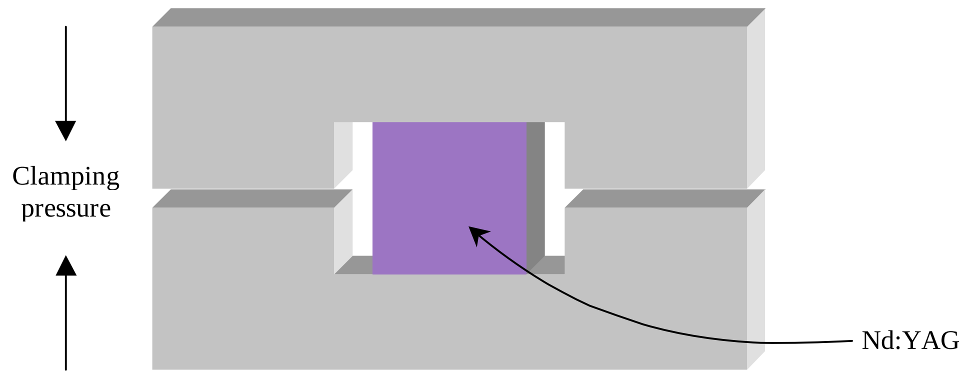
Pump source: OPC-D003-808-HB/100 fiber-coupled diode laser

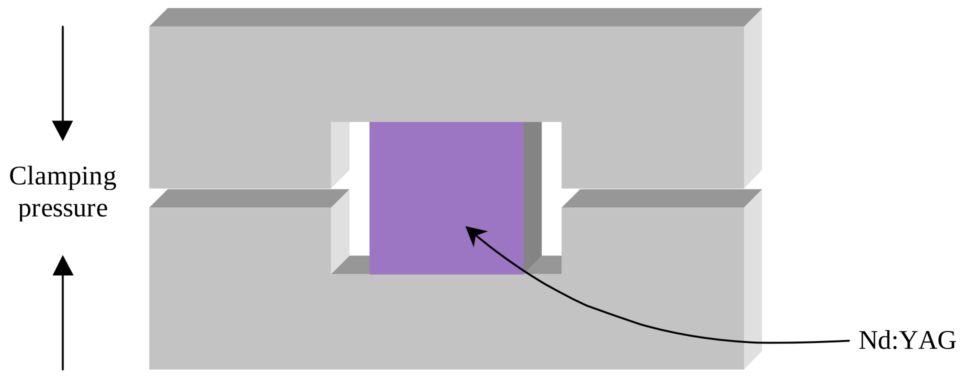
Nd:YVO4 microlaser output data as a function of pump beam diameter

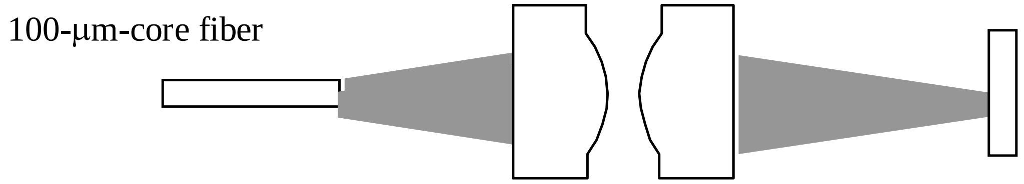


Nd:YAG/Cr:YAG Microlaser Development

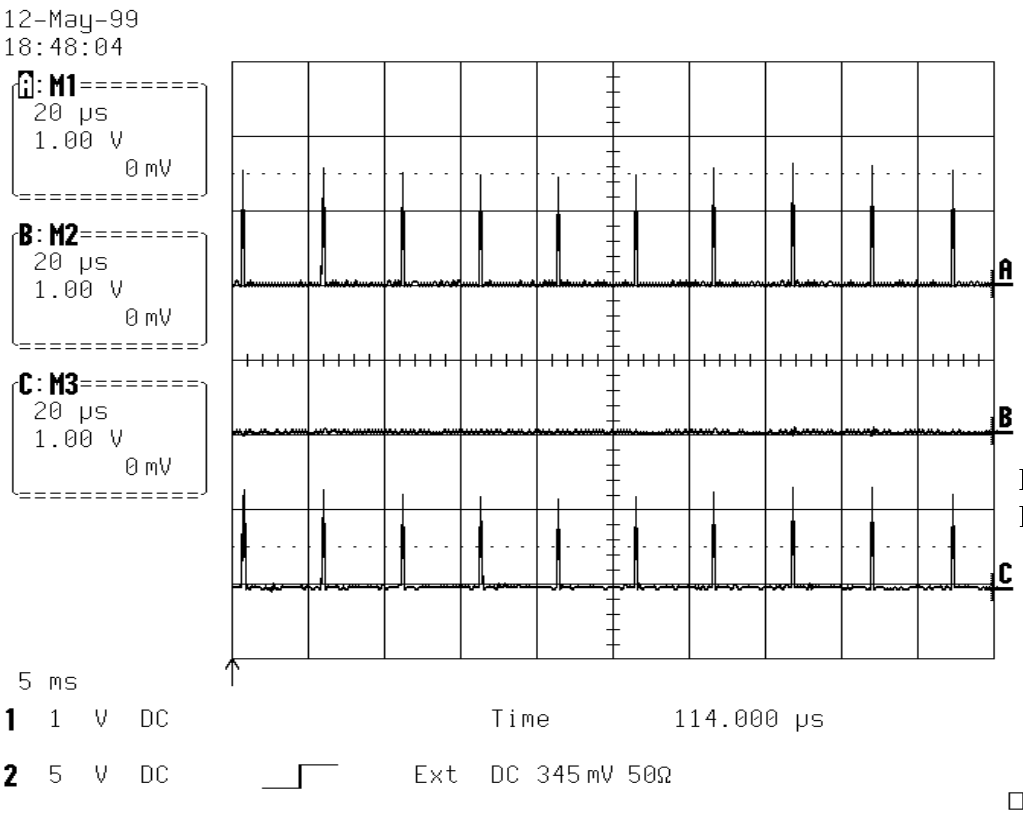





Clamping
pressure
Nd:YAG


100-µm-core fiber

Polarization instability of Q-switched pulses



All Pulses

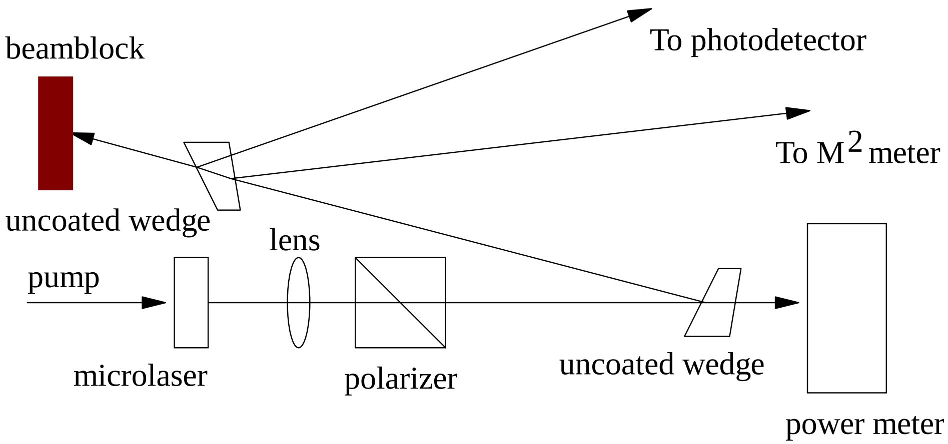
Horizontally Polarized Pulses

Vertically Polarized Pulses

Experimental data and model predictions for Nd:YAG/Cr:YAG passively Q-switched microlasers

Device	Experimental data [21,22]		Model predictions	
	Pulse energy (μJ)	Pulsewidth (ps)	Pulse energy (μJ)	Pulsewidth (ps)
LPMCL-1	4	218	5.1	227
LPMCL-2	4.7	275	4.5	232
LPMCL-3	7	440	5.4	387
LPMCL-4	9	440	7	347
LPMCL-5	14	460	9.1	330
MPMCL-1	30	700	29	622
MPMCL-2	40	1200	40	1244
MPMCL-3	65	2200	59	2486
HPMCL-1	130	390	77	340
HPMCL-2	225	700	127	628
HPMCL-3	200	310	84	253
HPCML-4	250	380	84	358

Pulse duration measurement

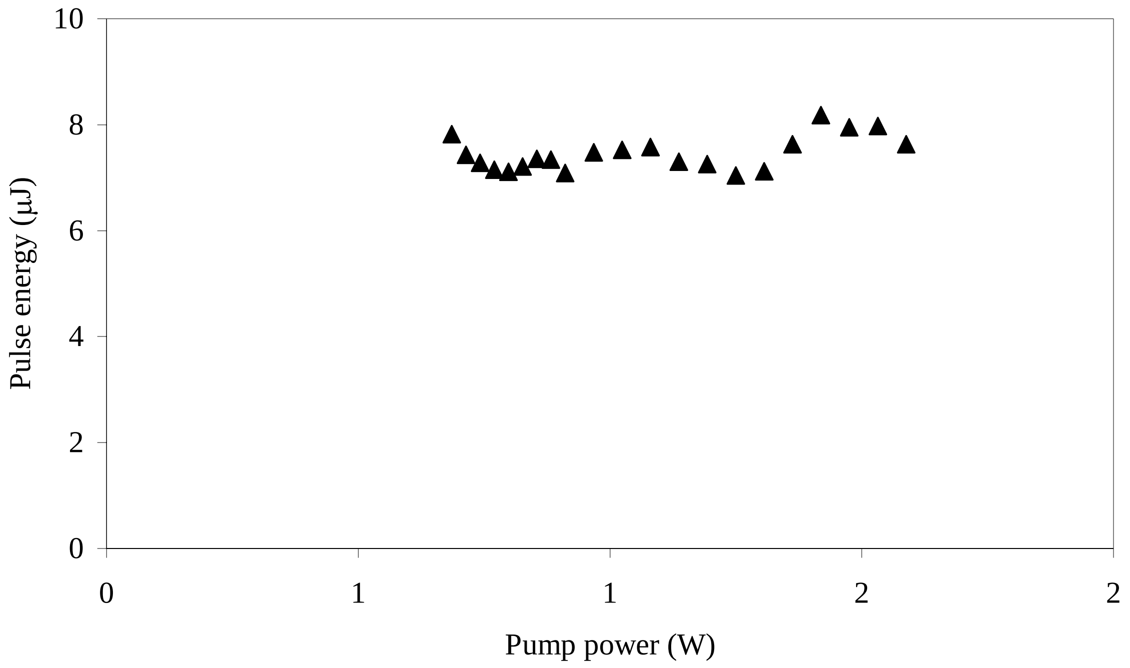


Pulse durations were measured with a Sydor InGaAs photodetector (model IGA80s) and a Tektronix sampling oscilloscope. Light was delivered to the detector with a 60-micron-core multimode fiber. This system was characterized with <2-ps duration pulses from a passively modelocked cw Cr:YAG laser at 1450 nm, and demonstrated a 110-ps (full-width at half-maximum peak height) impulse response time

Synoptics's microchip laser output pulse energy as a function of pump power

1.5x1.5x1.5 mm^3
1.25-mm Nd:YAG
0.25-mm Cr:YAG material

4 μJ pulse energy
<650 psec pulsewidth
TEM_{00}-mode output beam

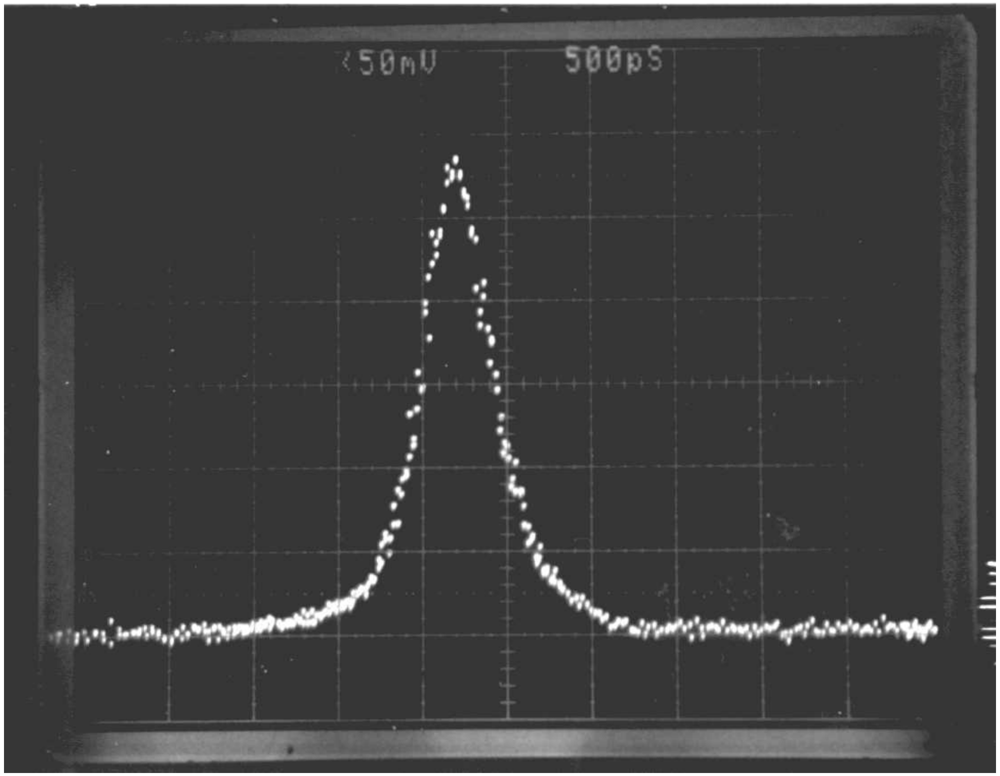


Microchip designs

Microchip design	**Q-Peak-1**	**Q-Peak-2**	**Synoptics**
Nd:YAG doping *t* (mm)	2.8% 0.5	2.8% 0.5	1.9% 1.25
Cr:YAG *t* (mm)	0.25	0.5	0.25
Cr:YAG α (cm^{-1})	5.7	5.7	6.0
R_{oc} (%)	80	80	80
$T_{p\ calcls}$ (ps)	304	204	200
$T_{p\ measur}$ (ps)	700	440	440

Microchip design	Q-Peak-1	Q-Peak-2/3	Q-Peak-1/3	LPMCL-1	LPMCL-2	LPMCL-3
2.8% Nd:YAG t (mm)	0.5	0.5	0.5	0.5	0.5	1
Cr:YAG t (mm)	0.75	0.5	0.25	0.25	0.25	0.25
Cr:YAG α (cm^{-1})	5.7	5.7	5.7	6	6	6
R_{oc} (%)	40	80	80	80	85	85
$T_{p\ measur}$ (ps)	450	450	850	218	275	440
$T_{p\ calcls}$ (ps)	150	204	304	218	224	374

Microlaser output pulse profile



0.7 W pump power at 809.0 nm
440 ps pulse duration

APPLIED PHOTONIC SYSTEMS

Microlaser characteristics

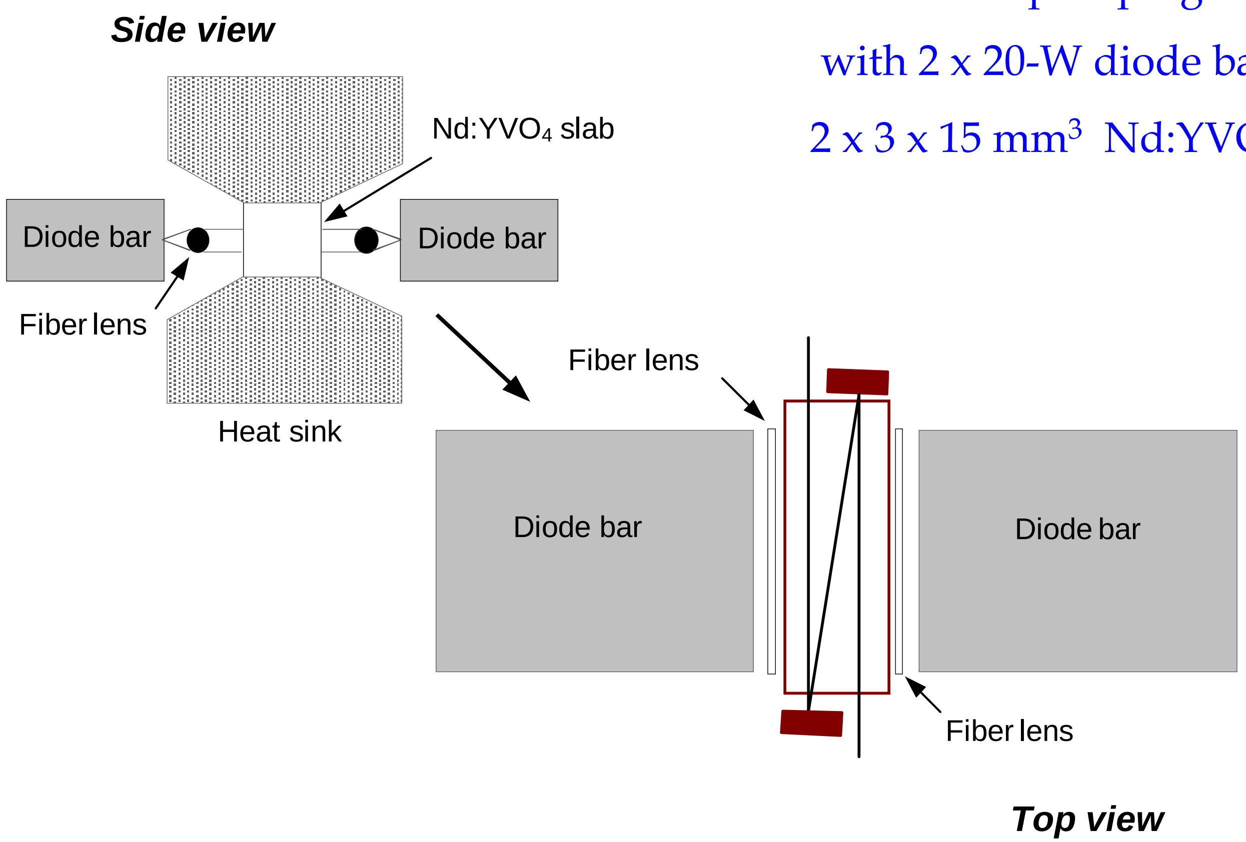
Microlaser parameters	Microlaser 1, 4:3 telescope	Microlaser 2, 2:1 telescope	Microlaser 3, 4:3 telescope
Average power, mW	4.4	3.1	6.4
Pulse energy, μJ	2.2	1.55	3.2
Pulse width, FWHM, psec	700	400-440	400-440
Delay, μsec	90	40	70
Pump pulse width, μsec	120	60	120
Jitter, ns	± 100	± 100	± 100
Drift, 5 min, ns	± 300	± 200	± 200

Optical layout of a multi-pass Nd:YVO4 slab amplifier

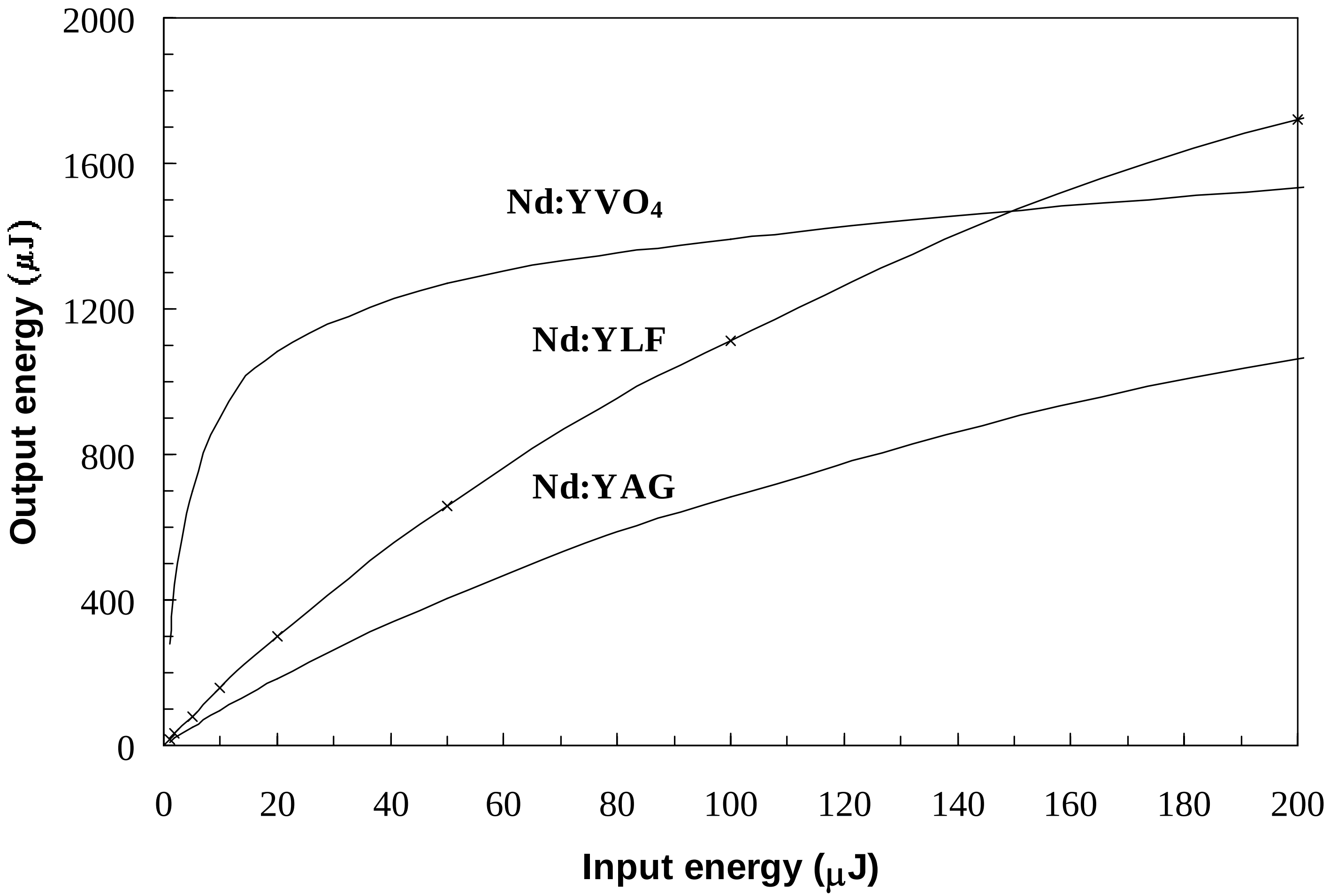
Transverse pumping @808 nm

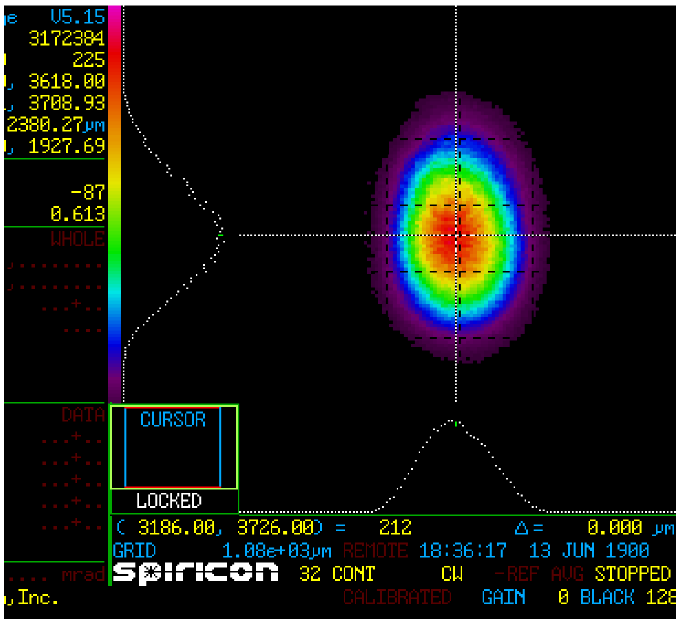
with 2 x 20-W diode bars

2 x 3 x 15 mm^3 Nd:YVO4 slab



Double-pass gain curves for cw-pumped multi-pass slab amplifiers

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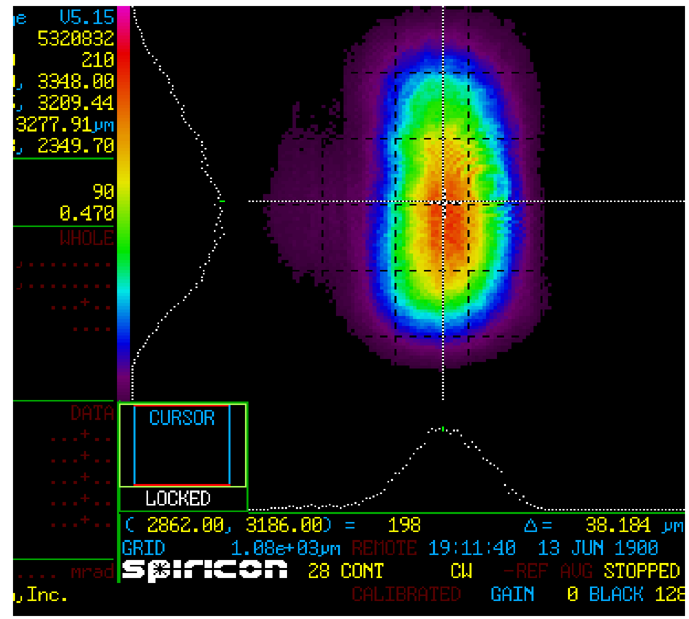
3618.00
3708.93
2380.27μm
1927.69
-87
0.613
WHOLE
DATA
CURSOR
LOCKED
(3186.00, 3726.00) = 212
Δ= 0.000 μm
GRID 1.08e+03μm REMOTE 18:36:17 13 JUN 1900
spiricon 32 CONT CW -REF AVG STOPPED
mrad
, Inc.
CALIBRATED GAIN 0 BLACK 128


V5.15
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3348.00
3209.44
3277.91μm
2349.70
90
0.470
WHOLE
DATA
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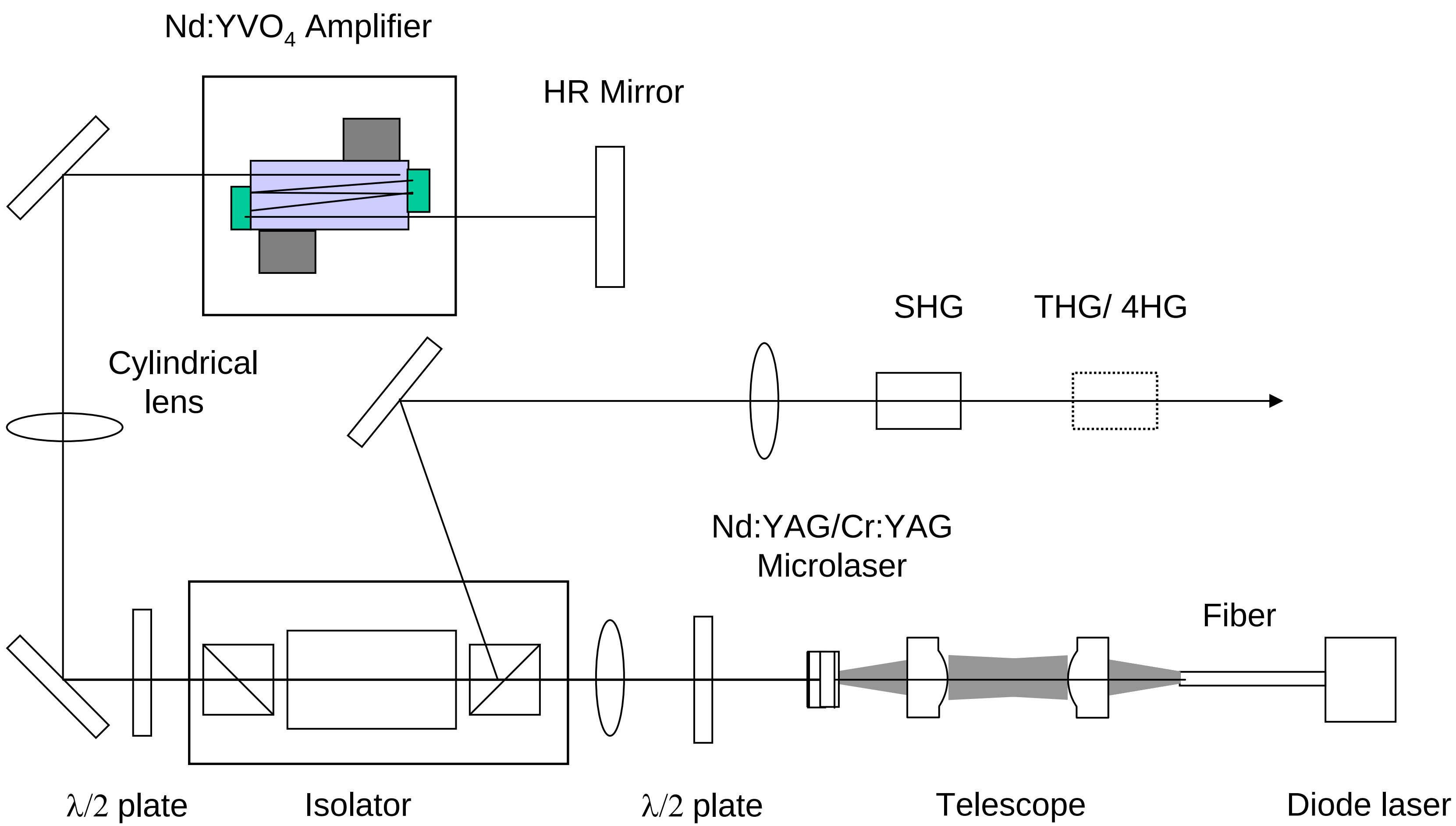
LOCKED
(2862.00, 3186.00) = 198
Δ= 38.184 μm
GRID 1.08e+03μm REMOTE 19:11:40 13 JUN 1900
spiricon 28 CONT CW -REF AVG STOPPED
mrad
, Inc.
CALIBRATED GAIN 0 BLACK 128

Micro-VAM optical layout



Summary

- *A Cr:YAG passively Q-switched Nd:YAG microchip laser that generated 3.2-μJ, 400-ps pulses at a 2 kHz rate*. The microlaser, quasi-cw end-pumped by a 1-W fiber-coupled laser diode, combines high peak power output, good beam quality, and compactness and reliability.
- *An efficient cw transversely-diode-pumped double-pass Nd:YVO4 amplifier.* The amplifier multipass gain module is based on the design developed by Q-Peak for the MPS commercial series of lasers. It combines high-power output, and freedom from optical distortion of the laser material caused by the pumping process. The amplifier *produced 370-ps output pulses of 335-μJ energy at a 2 kHz rate.*
- *A 60-% conversion efficiency second harmonic generator (SHG)* based on a NCPM Type I LBO crystal mounted in a temperature-stabilized oven. The average output power of the 532-nm beam was 400 mW (200 μJ per pulse) that is ~1.3 times the proposed value. The M^2 values characterizing the beam quality were 1.17 and 1.14 in the horizontal and vertical plane, respectively.
- *Third and fourth harmonic nonlinear devices* based on critically-phase-matched LBO and BBO crystals, respectively, operating at room temperature. The output powers at *355 nm and 266 nm were 240 mW and 66 mW, respectively.*

Micro-VAM

US (MIT) Patent "Passively Q-switched Picosecond Microlaser"

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