Semiconductor Q-switched, Short-Pulse, High-Power, MHz-Rate Laser

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- SBR characterization:
  Günter Steinmeyer at Max Born Institute (Berlin, Germany)

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Outline

- Motivation
- Technical approaches
- Oscillator design and experiments
- Amplifier design and experiments
- Conclusions

Motivation

- Development of a green laser source for high-speed, high-resolution imaging and ranging applications:
  - Wavelength range: ~0.5 μm
  - Pulsewidth: < 1 ns
  - Spectral linewidth: <1 nm
  - High pulse contrast ratio: > 30-40 dB
  - High repetition rate: 0.1-1 MHz
  - Pulse energy:
    - >10 nJ - oscillator
    - >10 μJ - amplifier
  - System volume: ~1 cub. ft (including electronics)
  - Conductive/air cooling

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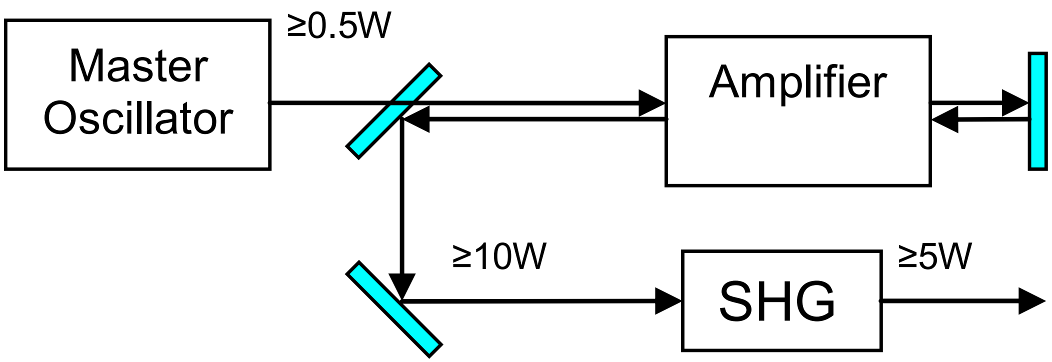
Alternatives

MHz-rate, sub-nanosecond laser sources for can be based on:

- cavity-dumped lasers,
- regenerative amplifiers based on mode-locked lasers,
- directly modulated diode lasers with high gain fiber amplifiers,
- externally modulated lasers,
- ***CW-pumped, repetitively Q-switched lasers***.

Approach



- Oscillator defines:
  - Pulsewidth
  - Repetition rate
  - Time jitter
  - Linewidth
  - Pulse-to-pulse stability
- Amplifier
  - x20-25 gain for 0.5-1 W seed
- SHG
  - 60-70% efficiency

<1-ns master oscillator

Requirements and constraints for a diode-pumped solid state bulk oscillator to generate <1-ns-pulses at high rep. rate (>100 kHz):

- High gain/high pump absorption laser material,
- Saturable semiconductor structure with 0.1-1 ns relaxation time as a passive Q-switch,
- Shortest possible resonator length.

SESAM technology pioneered by Prof. Keller's group at ETH Zürich:

- ~37 ps from a Nd:YVO_4 passively Q-switched oscillator.
- ~ MHz repetition rate
- To achieve the shortest possible length thin laser crystal was sandwiched between the SESAM and the output coupler.

  B. Braun *et al*, Opt. Lett. 22, 381 (1997).

  G.J. Spühler *et al*, JOSA B 16, 376 (1999)

Saturable Bragg Reflectors (SBR)

- SBR structures were designed and several runs grown at MIT
- SBR design was based on the layered structure:
  - AlAs/GaAs Bragg mirror stack providing high reflectivity at 1064 nm,
  - InGaAs quantum-well (QW) absorber clad by GaAs barrier layers,
  - overall Fabry-Perot cavity is anti-resonant at 1064 nm,
  - optional top reflector to form a Fabry-Perot structure.
- Molecular beam epitaxy (MBE) was used to create the AlAs/GaAs Bragg stacks.
- Growth calibrations were carried out to achieve the 1064-nm InGaAs quantum well absorber layer on GaAs substrates
- Characterization included photoluminescence and x-ray diffraction analysis of SBR structures.
- Design and targets:

Substrate material	GaAs
Operating wavelength	1064 nm
Bottom reflector (HR Bragg mirror)	25-layer stack of AlAs/GaAs pairs
Saturable absorber	2-8 InGaAs quantum wells
Saturable loss	~10%
Saturation fluence	35-350 uJ/cm2
Saturable absorber lifetime	>200 ps
Nonsaturable losses	< 0.5%

Modeling/ Characterization/ Experiments

- Modeling of electrical field distribution in fabricated SBR structures
- SBR characterization (Max Born Institute)
- Modeling of temporal characteristics of laser oscillator (pulsewidth and repetition rate)
- Modeling of spatial mode distribution
- Issues to consider:
  - SBR damage threshold
  - SBR long term operation
- Oscillator experiments with various SBRs
  - vs number of QWs
  - vs resonator length
  - vs SBR top reflector
  - vs output coupler reflectivity

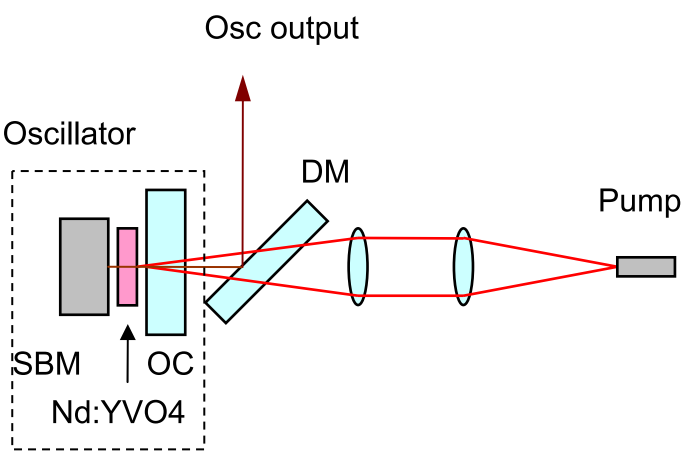
Saturable Bragg Reflectors - Characterization

- Experimental characterization confirmed that the grown SBR structures had a relaxation time of ~0.3-0.9 ns and a low level of non-saturable losses <1.1%.

Sample	Units	MIT-2	MIT-8	Other
# of quantum wells		2	8	6
F_{sat}	μJ/cm²	20.1 (+/-5.3)	29.9 (+/-3.2)	35.5 (+/-3.8)
Saturable loss	%	2.4	7.8	6.1
Non-saturable loss	%	**1.0**	**1.1**	**3.2**
Decay	ps	**100-300**	**600 (+/-300)**	**15**

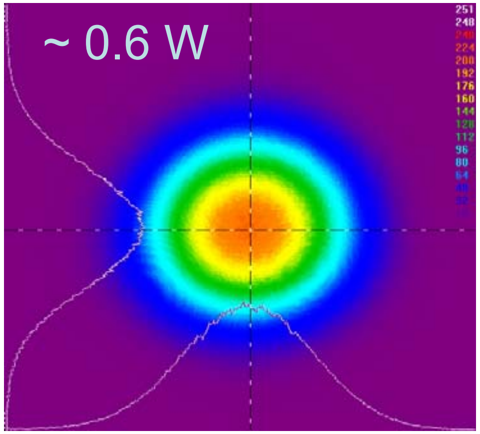
Master Oscillator with SBR

- Typical approach – SBR-xtal "sandwich"
  - Laser crystal – face-cooled through the SBR
  - Short pulses
  - Limited power < ~100 mW
  - Susceptible to mode distortion

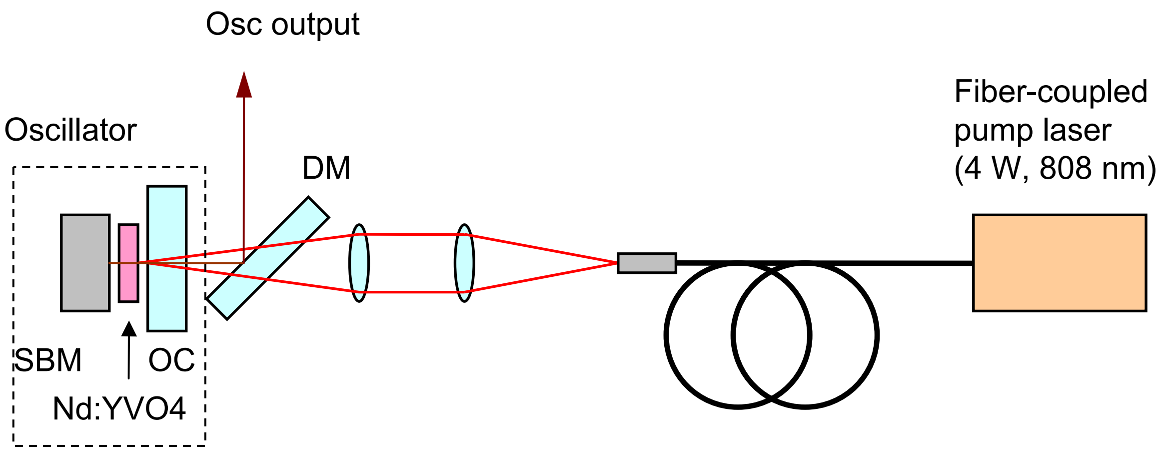


- Our objectives:
  - Increase osc average power to 0.5 – 1 W
  - Preserve beam quality
  - Pulsewidth – ~ 1 ns or less
- We tried two types of "sandwiches":
  - Optical contact
  - "Spin-on glue glass" bonding
- Final choice -> "discrete" design: SBR-air gap-xtal
  - Laser crystal – edge-cooled
  - Longer crystal
  - Lower doping
  - Higher power
  - High beam quality
  - Longer pulses but continuous pulsewidth control

Master Oscillator with SBR



- "Discrete" design: SBR - air gap - xtal
  - ~1 mm thick Nd:YVO_4 xtal
  - 1-2% Nd-doping
  - Laser crystal – edge-cooled
  - Power -> up to 1 W
  - High beam quality (M^2<1.1)
  - SBR with various top reflectors
  - Various output couplers



Master Oscillator with various SBRs

Rep.rate ~ g_0/q

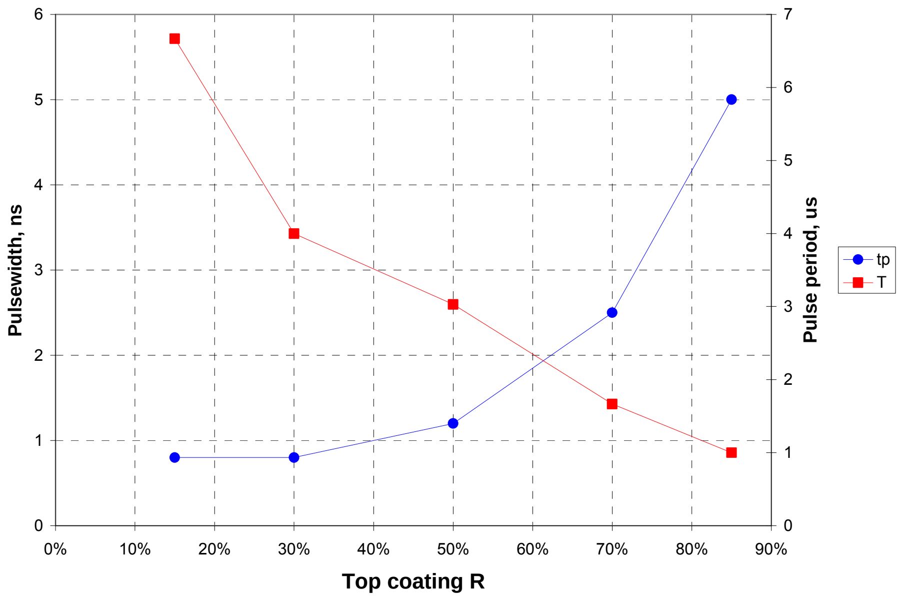
Pulsewidth ~ T_r/q

vs. number of QWs:

	Units	2QW	8QW
Top coating		None	None
Average power	W	~0.6	~0.6
Min pulsewidth	ns	~5	~0.8
Max rep. rate	MHz	~2	~0.25

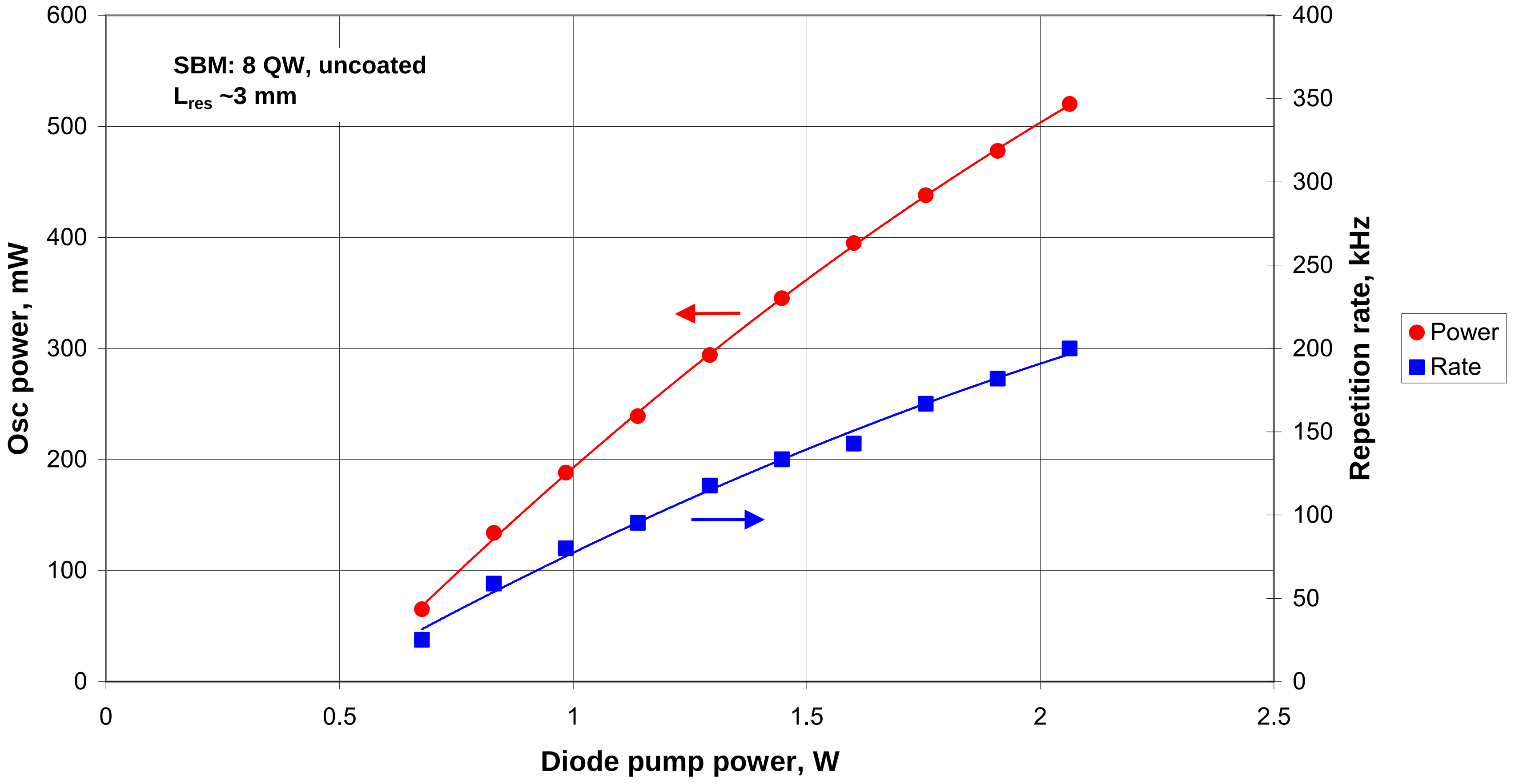
vs. top coating reflectivity:

	Units	8QW SBR				
Top coating (R)	%	15%	~30% (unc)	50%	70%	85%
Average power	W	0.6	0.6	0.6	~0.6	0.6
Min pulsewidth	ns	<0.8	~0.8	~1.2	~2.5	~5.0
Max rep. rate	MHz	~0.15	0.25	0.33	0.6	≥1.0



ASSP'10

Master Oscillator with 8QW SBR (~0.9-ns-long pulse)



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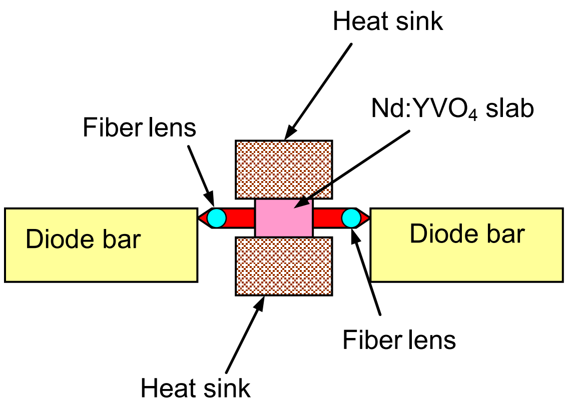
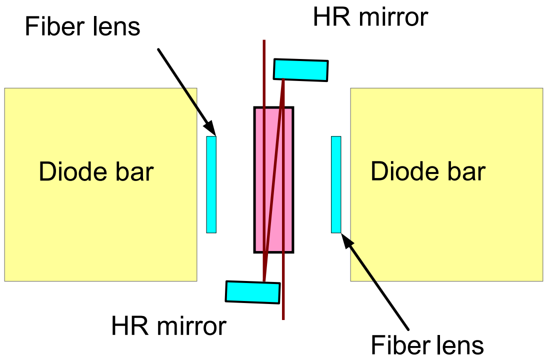
ASSP'10

TE-cooled MPV Nd:YVO_4 amplifier

Side view

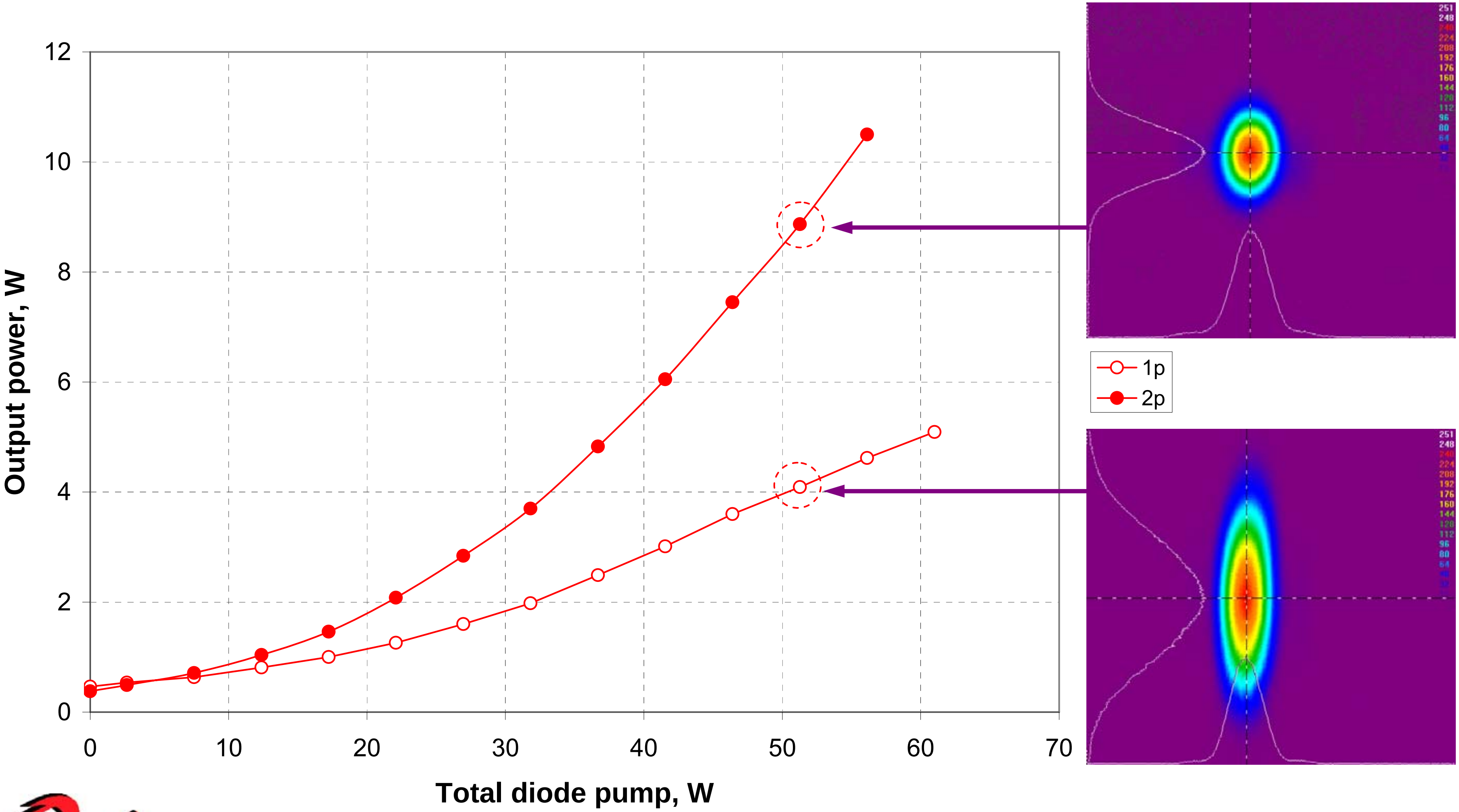


Top view



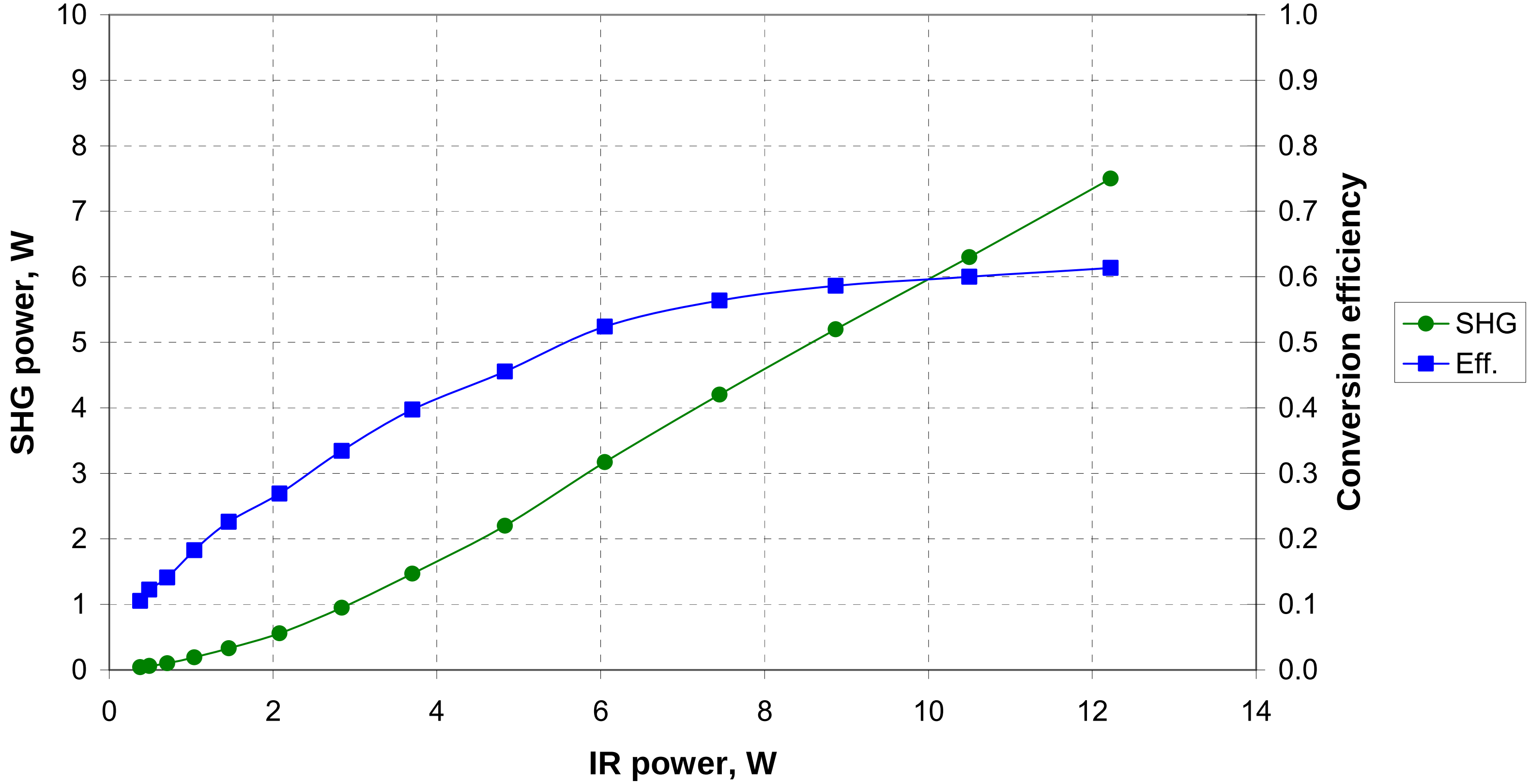
- Multi-pass side-pumped Nd:YVO_4 slab architecture (Q-Peak's MPV technology)
- New development for this effort:
  - Elimination of water cooling
  - Mechanical package suitable for TE cooling
  - Efficient TE cooling with up to 140 W cooling capacity
  - Compact, rugged packaging

TE-cooled MPV $Nd:YVO_4$ amplifier



ASSP'10

SHG Generation – NCPM LBO



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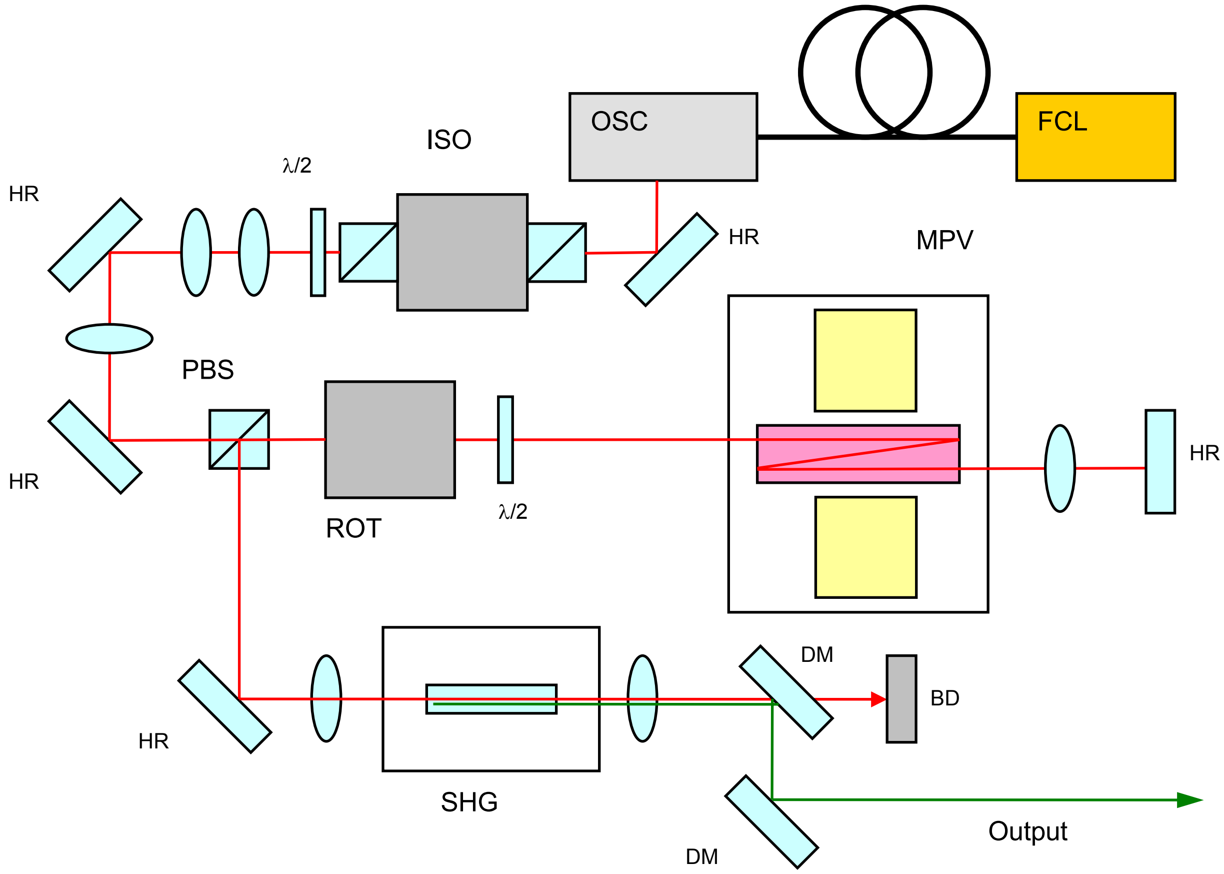
System Layout



ASSP'10

System Performance

System stage	Parameter	Value
Master Oscillator:	Wavelength	***1064 nm***
	Linewidth	***< 0.1 nm***
	Beam quality	***TEM_{00}***
	Pulsewidth	***~0.9 ns***
	Power	***0.52 W***
	Repetition rate range	***20-200 kHz***
	Pulse energy	***>2.6 uJ***
Amplifier:	Power (2-pass)	***Up to 12 W***
	Pulse energy	***>60 µJ***
SHG:	Wavelength	***532 nm***
	Pulsewidth	***~0.8 ns***
	Power	***Up to 7.5 W***

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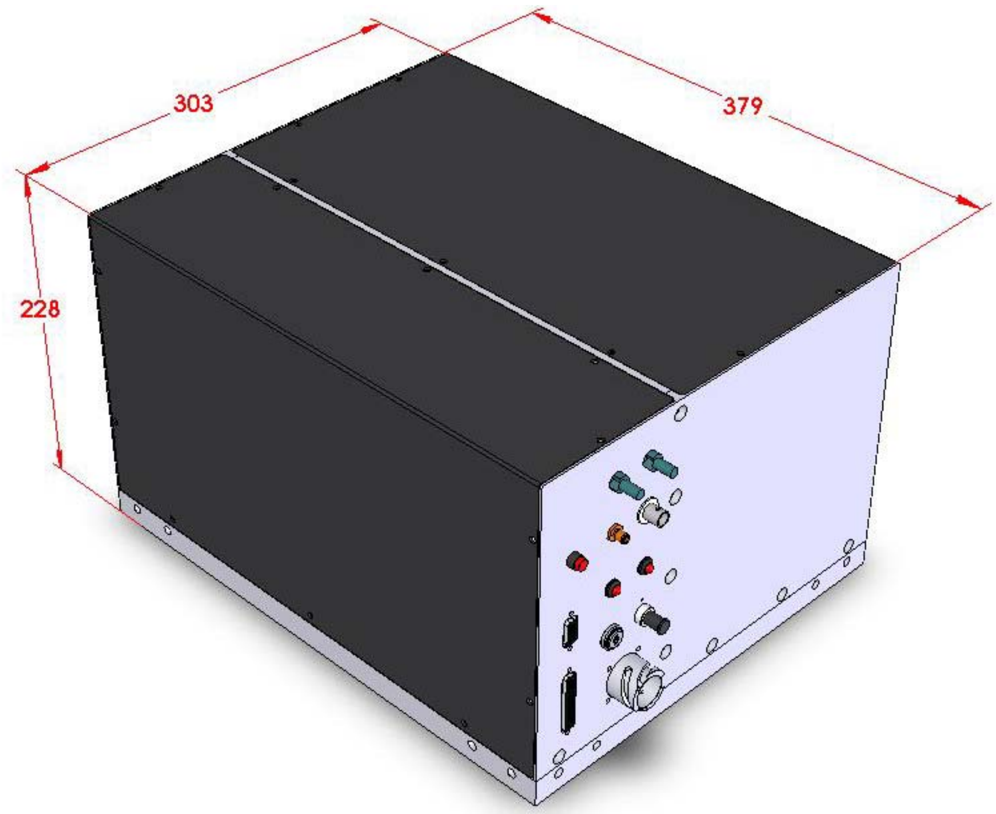
Packaged system

- Inputs:
  - 28 V, 15 A
- Volume:
  - 0.97 cu. ft.



Actual laser system

a)

b)

a) Output panel view, b) Connector panel view

Conclusions

Semiconductor Q-switched, Short-Pulse, 1-um Nd:YVO_4 oscillator:

- Pulsewidth 0.6 - 5 ns
- Average power 0.5 – 1 W
- Pulse energy >0.5 µJ
- Repetition rates in 20 kHz to 2 MHz range
- High beam quality (TEM_{00} beam)

Double-pass Nd:YVO_4 MOPA:

- > 12 W output power at 1064 nm
- > 7.5 W at 532 nm
- Beam quality close to diffraction limited