Development of 10 kHz multi-mJ fs Pulse High-efficiency Yb:YAG Laser

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Abstract

We are developing a high-efficiency Yb:YAG regenerative amplifier for industrial applications. Optical-to-optical efficiencies have been theoretically calculated to determine efficient amplification conditions. Experimental results show an output pulse energy of more than 2 mJ before compression at a 10-kHz repetition rate with an optical conversion efficiency of 17.8%.

Objectives

High-efficiency Yb:YAG regenerative amplifier for industrial applications

- pulse energy > multi-mJ
- pulse duration < ps
- wall-plug efficiency > 10%
- repetition rate > multi-kHz
- beam quality ~ single mode
- To be a commercial product as an industrial laser for fine laser processing

  low cost, compact, simple, high stability, robust, room-temperature operation, easy to handle,,

Calculation

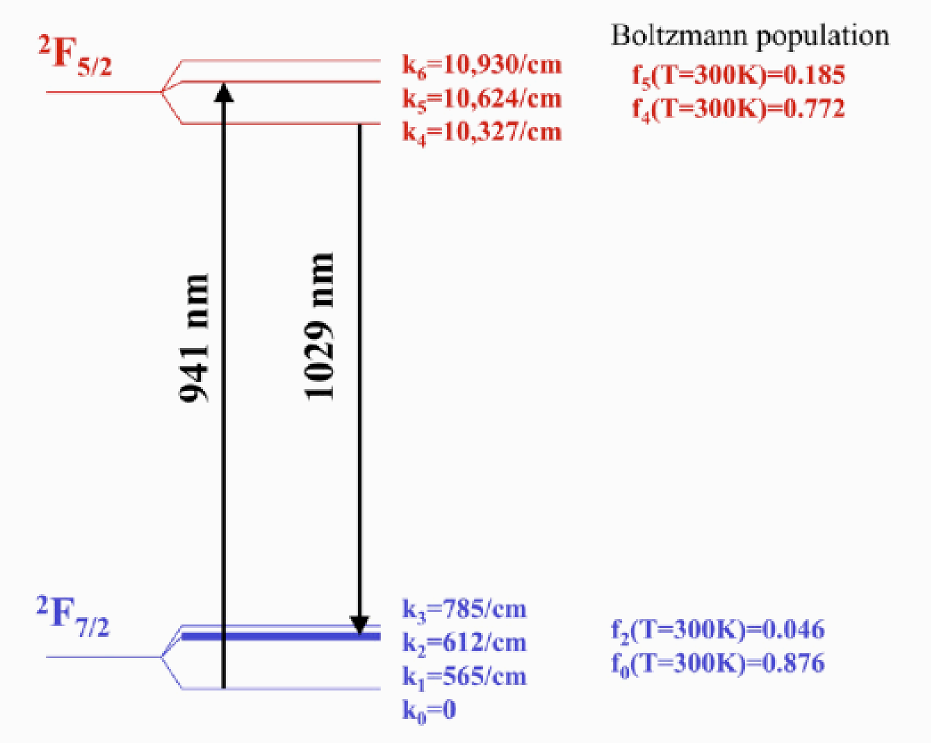


Fig. 1. Energy level scheme of Yb:YAG. f_i Are the relative thermal occupancies and the k_i's denote the wave number for the different levels with regard to the ground level.

Optics Communications 274 (2007) 422 –428

"Theoretical investigation of feasibility of Yb:YAG as laser material for nanosecond pulse emission with large energies in the Joule range"
Martin Ostermeyer, Alexander Straesser, University of Potsdam, Institute of Physics, Nonlinear Optics and Experimental Quantum Information, Am Neuen Palais 10, 14469 Potsdam, Germany

Rate Equation for pumping

Optics Communications 200 (2001) 331 - 342

“Comparison of pulse amplification performances in longitudinally pumped Ytterbium doped materials”
Gilbert L. Bourdet, LULI, Palaiseau, France

Absorbed power

$$P_{abs} = P_{pump}(1 - \exp[-\sigma_p\{N_d f_0 - (f_0 + f_5)N_u\}])$$

Upper level population

$$\frac{\mathrm{d}N_u}{\mathrm{d}t} = \frac{P_{abs}}{E_{PhotonPump}} - \frac{N_u}{\tau_u}$$

$$N_u(t=0) = \frac{E_{st0}}{E_{PhotonLaser}} + \frac{f_2}{f_2 + f_4} N_d$$

Stored fluecne and small signal gain

$$\Delta N = f_4 N_u - f_2(N_d - N_u)$$

$$E_{st} = E_{PhotonLaser}\Delta N$$

$$E_s = E_{PhotonLaser} / \sigma_l$$

$$g_0 l = \sigma_l \Delta N = E_{st} / E_s$$

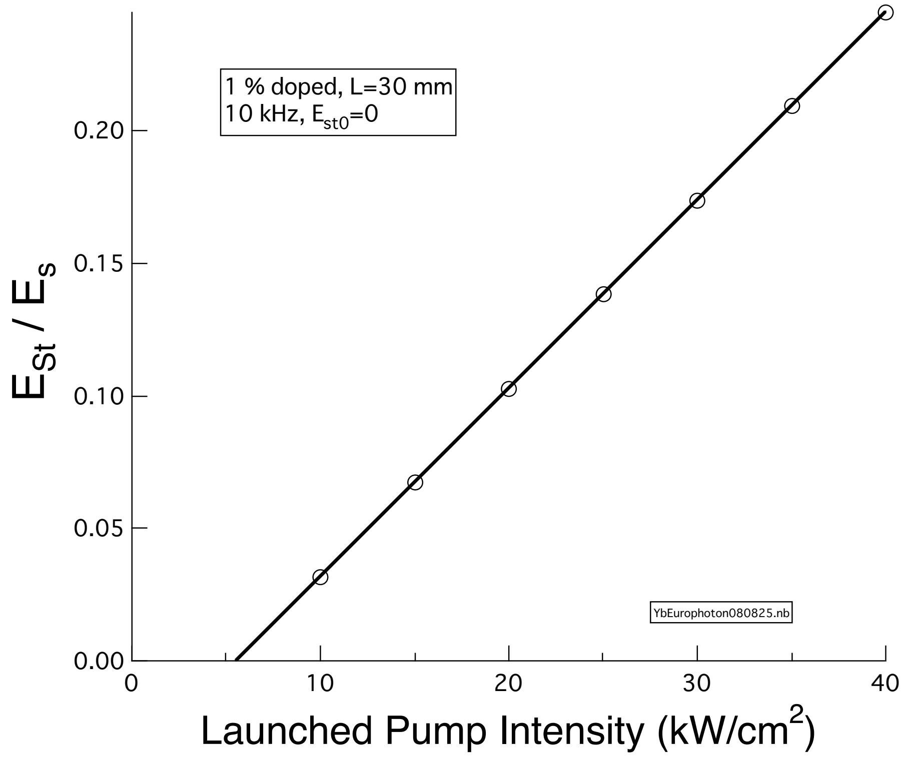


Fig.2 Calculated stored fluence

Pulse amplification

Frantz-Nodvik equation

$$E_{out}{}^{(n)} = E_s \ln\left\{1+\left[\exp\left(E_{in}{}^{(n)}/E_s\right)-1\right]\exp\left(E_{st}{}^{(n)}/E_s\right)\right\}$$

$$E_{st}{}^{(n+1)} = E_{st}{}^{(n)} - \left(E_{out}{}^{(n)} - E_{in}{}^{(n)}\right)$$

$$E_{in}{}^{(n+1)} = \left(1-L_{oss}\right)E_{out}{}^{(n)}$$

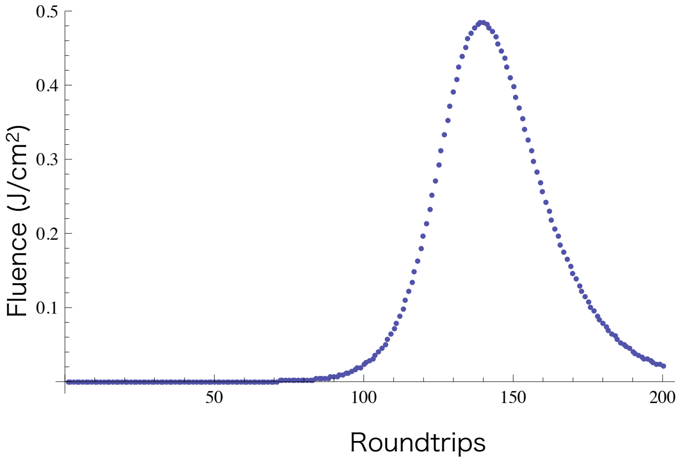


Fig.3(a) Calculated pulse growth in amplification for the resonator roundtrip loss of 10% with 25 kW/cm^2 pumping at 10 kHz repetition rate.

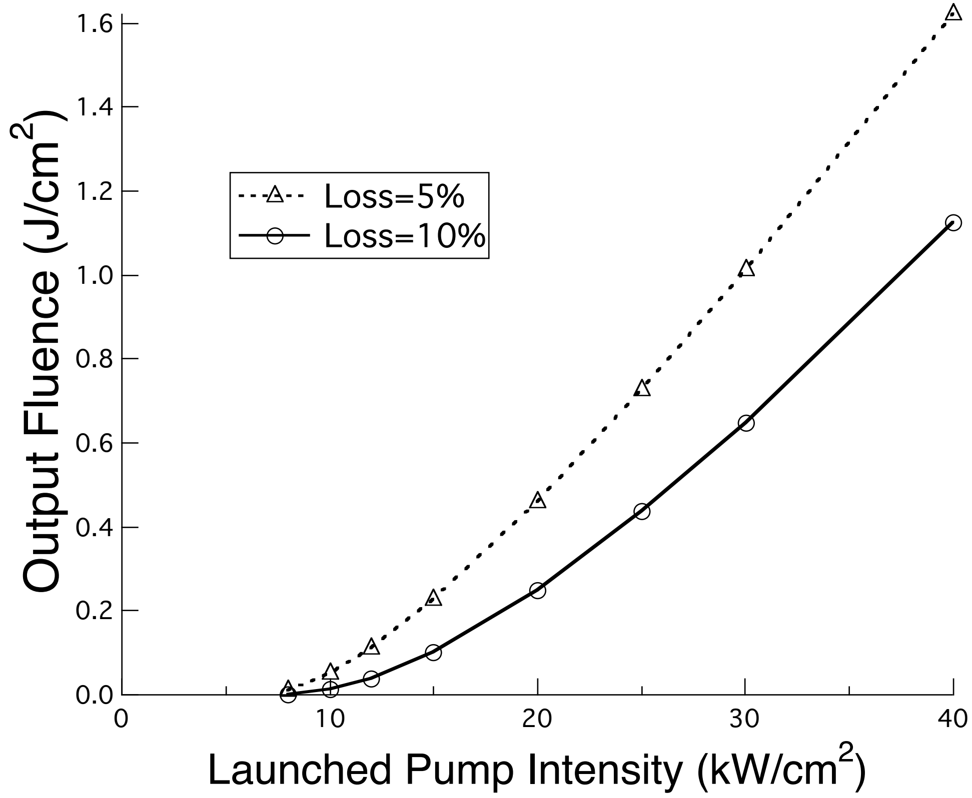
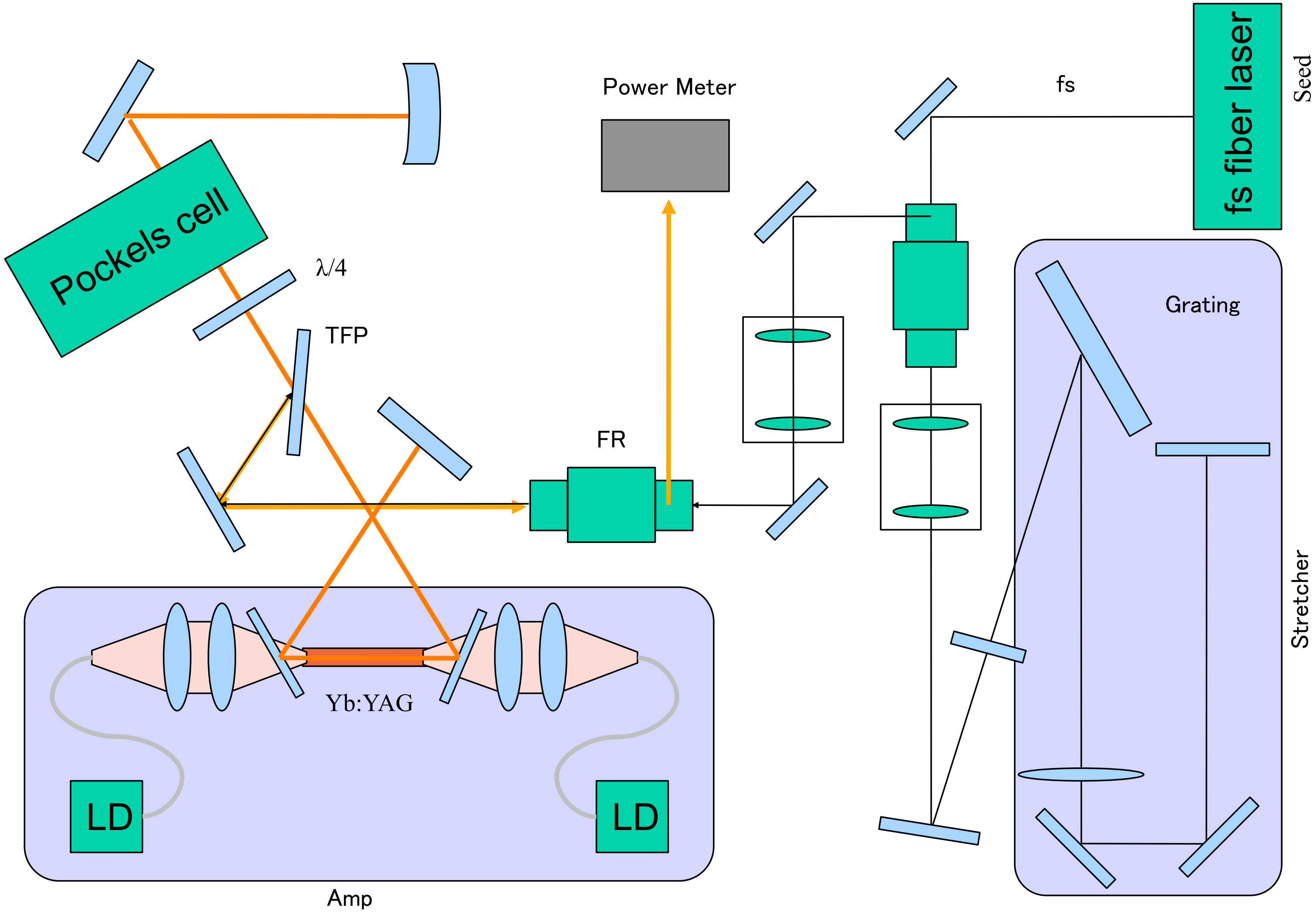


Fig.3(b) Calculated output fluence for 10 kHz repetition rate with pumping in Fig.2. The pulses were switched out at the peak intensities.

Experiment


Power Meter
fs
fs fiber laser
Seed
Pockels cell
λ/4
TFP
Grating
FR
Stretcher
Yb:YAG
LD
LD
Amp

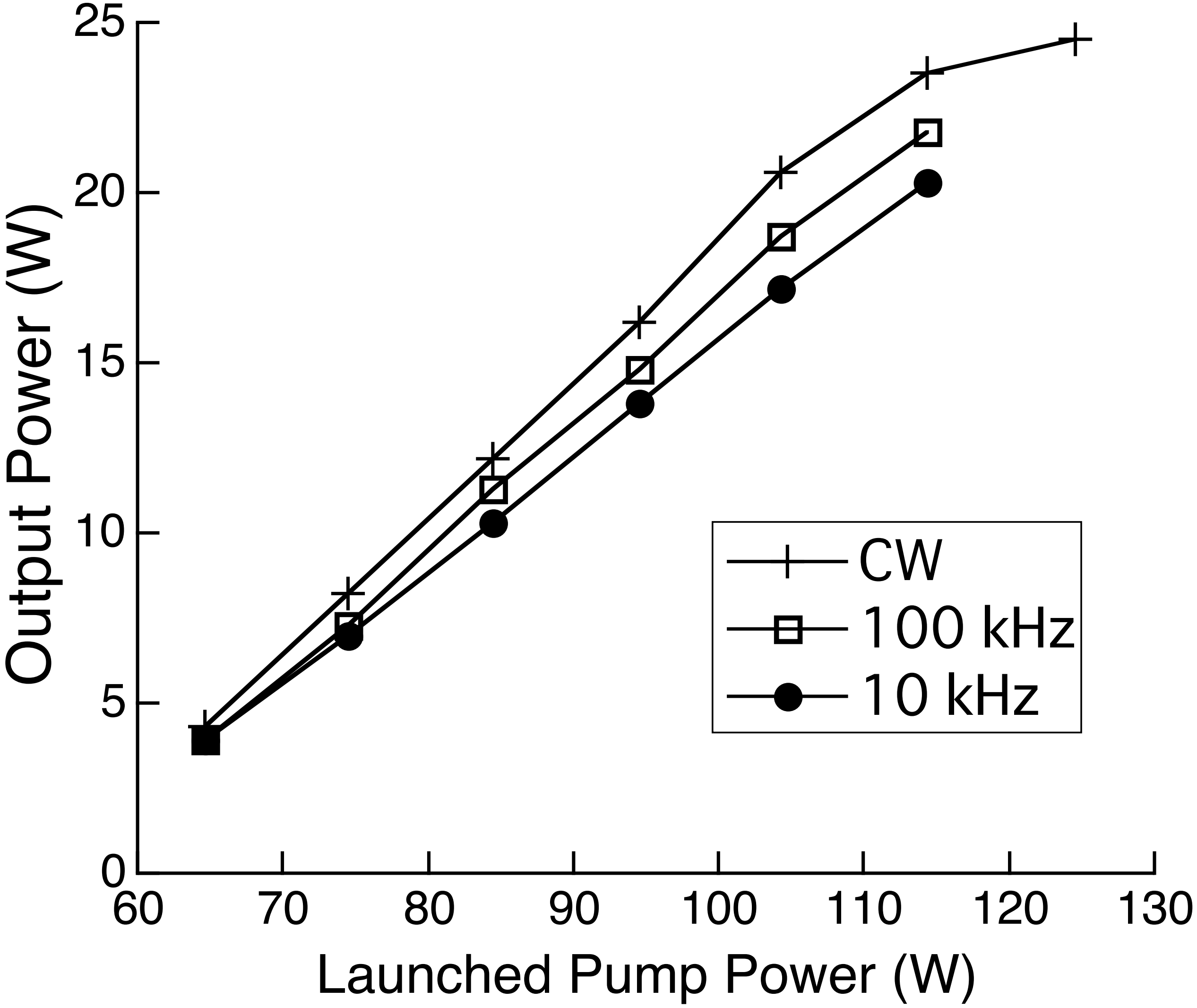
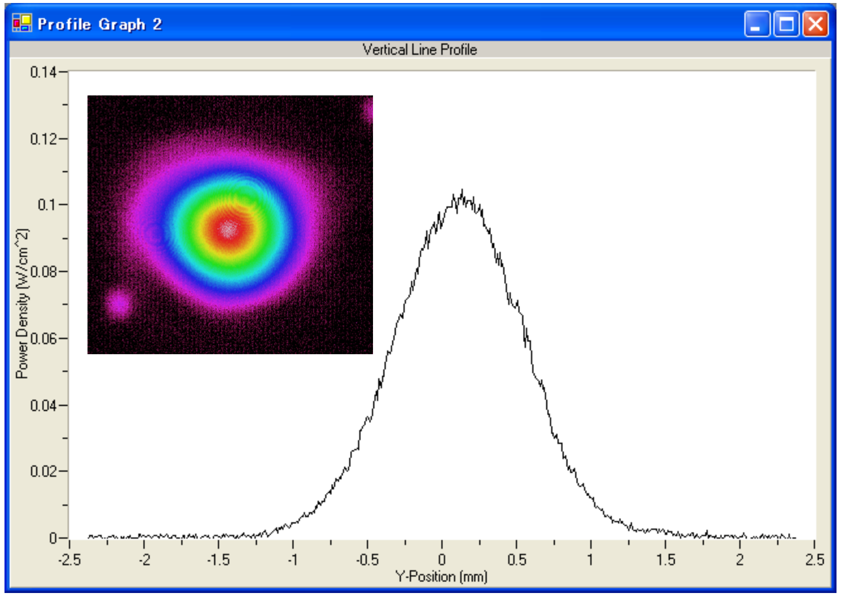
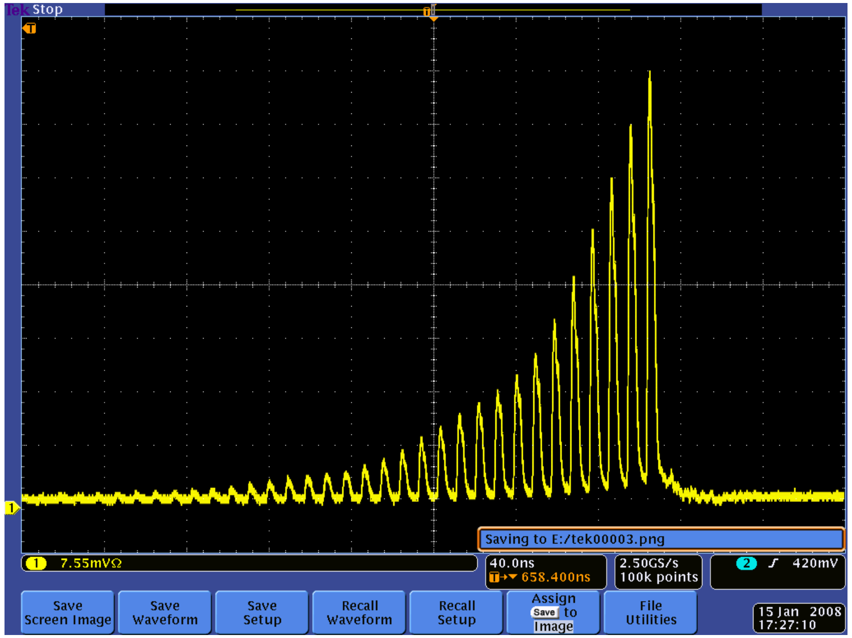
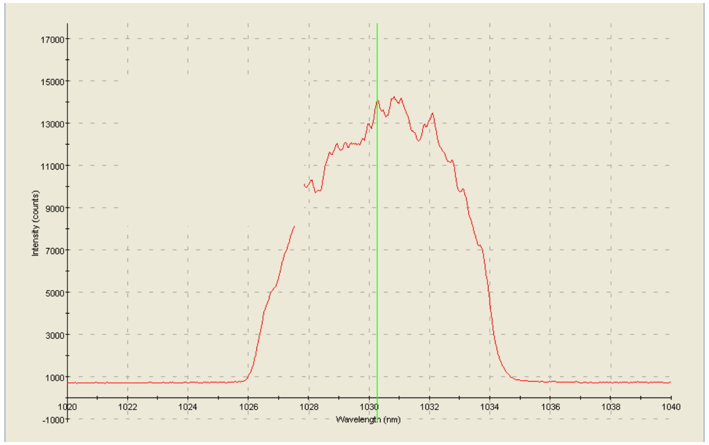


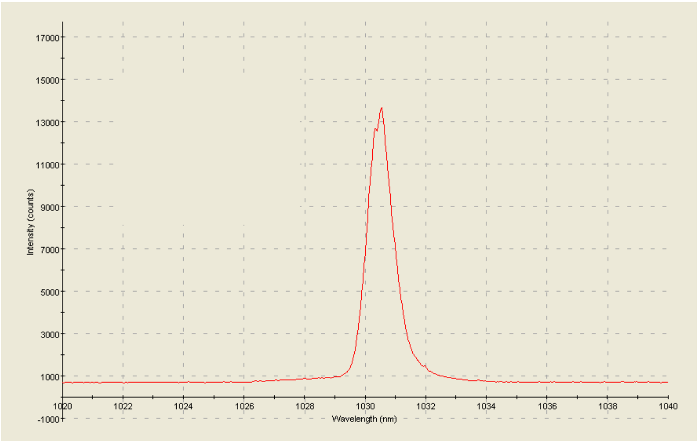
Fig. 4 Measured output power vs. launched pump power. An output pulse energy of 2.03 mJ before compression was obtained at a 10-kHz repetition rate. The optical conversion efficiency was 17.8%.







Seed FWHM=6.0 nm (186 fs)



Output FWHM=1.0 nm (1.1 ps)

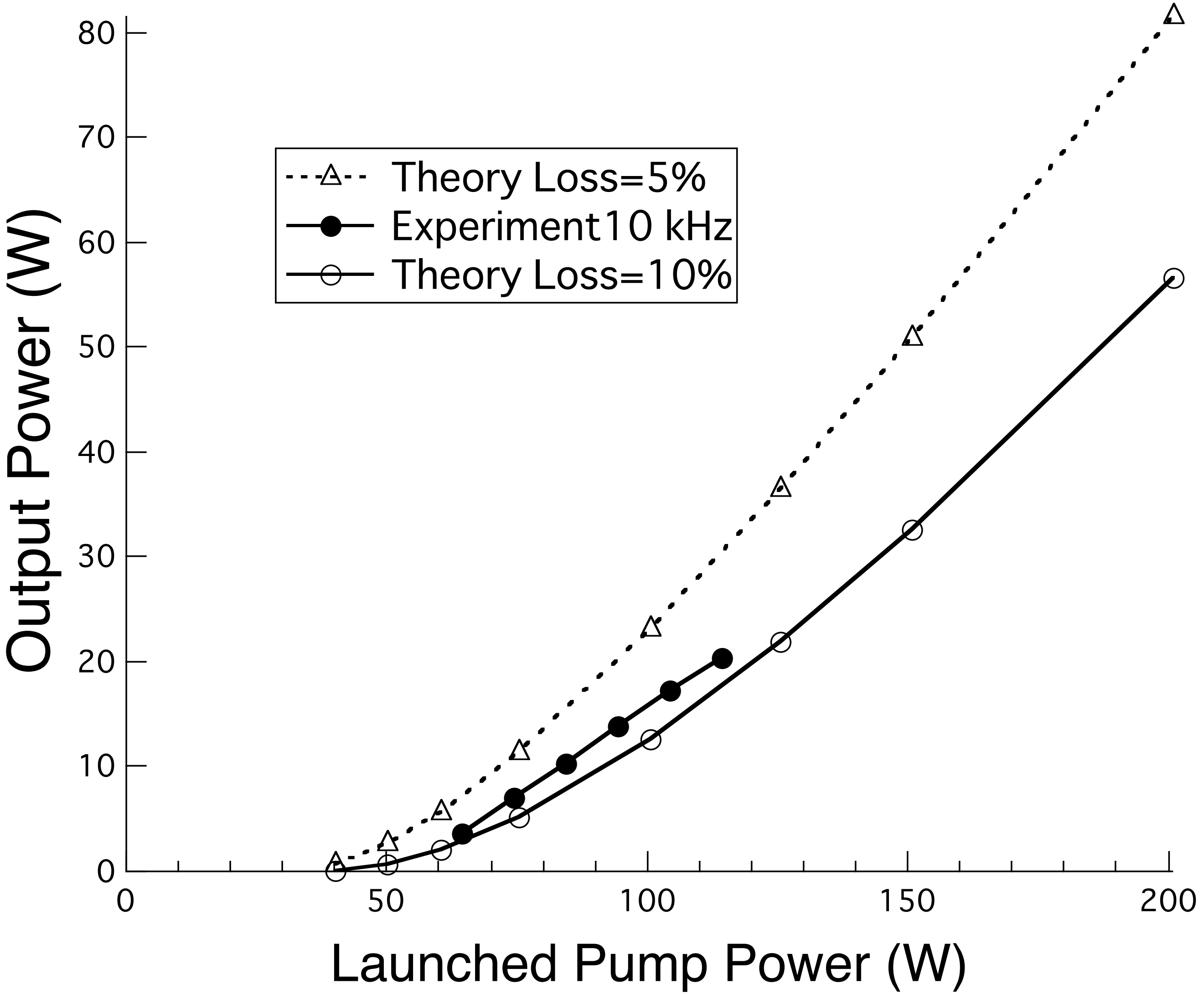


Fig.6 Comparison with the theory(Fig.3). The beam diameter of 800 μm is assumed.

Discussion for higher efficiency and pulse energy

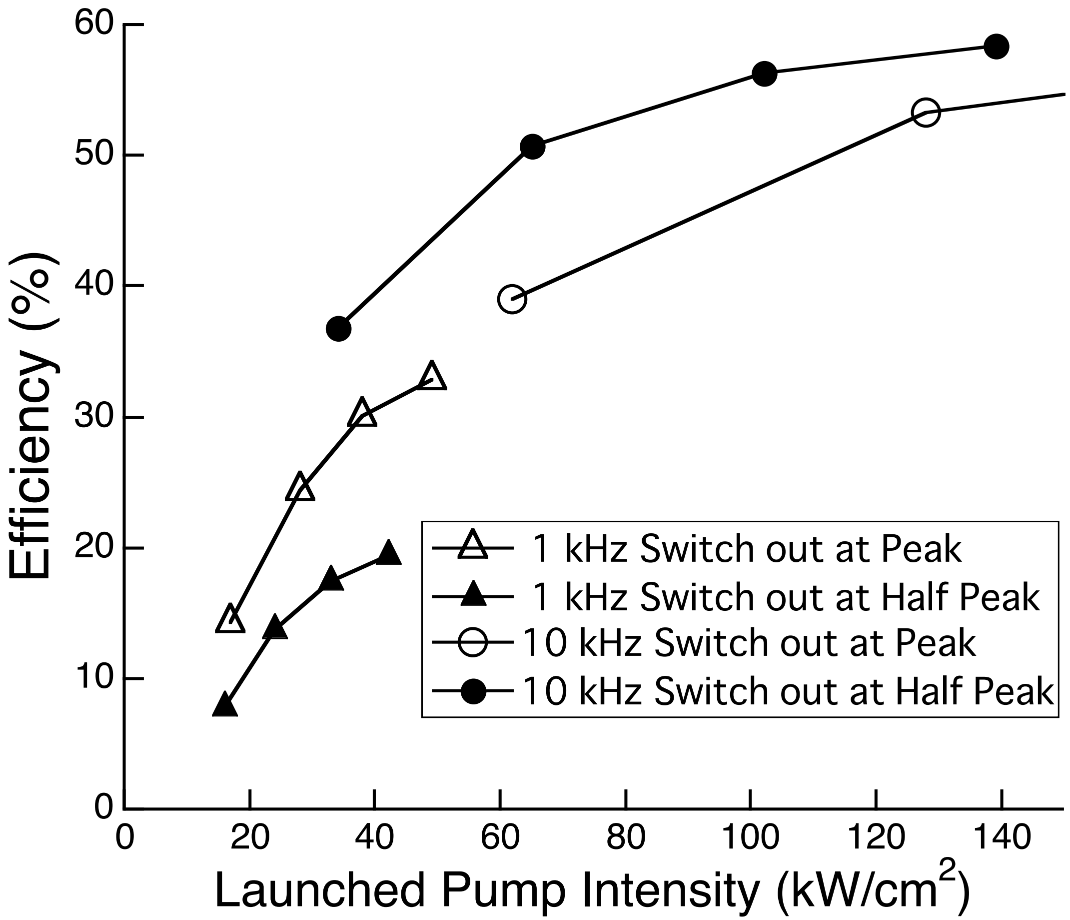
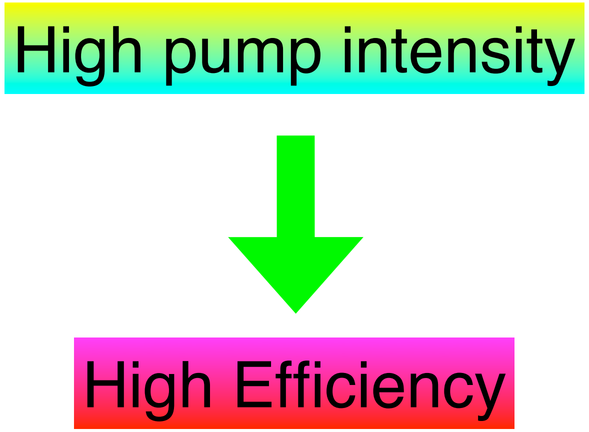


Fig. 7 Calculated optical-optical efficiency vs. launched pump intensity. 1% doped, L=40 mm, and resonator loss = 10%.


High pump intensity

High Efficiency

Limitation

Thermal problems,
Damage

Summary

- Developing a high-efficiency Yb:YAG regenerative amplifier
- 2.03 mJ (before compression) at 10-kHz
- Optical conversion efficiency of 17.8%.
- Agree with theoretical calculation
- Higher pumping intensity will achieve high efficiency and pulse energy.
- Switch out timing control is useful to reach higher efficiency.