

# Highly efficient Q-switched Ho:YLF laser pumped by Tm: fiber laser

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**Abstract:** A highly efficient Q-switched Ho:YLF laser pumped by a Tm: fiber laser has been designed and demonstrated. When the pump power is 30 W, the pulse energy is 30mJ at the repetition rate of 100Hz.

**OCIS codes:** (140.3580) Lasers, solid-state; (140.3510) Lasers, fiber.

## 1. Introduction

There are many specific applications for 2  $\mu\text{m}$  lasers in atmospheric surveillance and medical therapy such as wind/CO<sub>2</sub> measurement and hard and soft tissue ablation. The salient features of 2  $\mu\text{m}$  lasers are eye-safety, high water absorption, and strong aerosol scattering [1]. Currently a diode pumped Tm:Ho:LuLiF system, which consists of a master Q-switched oscillator and three power amplifiers, has been developed at NASA Langley Research Center (LaRC). The output pulse energy is more than 1 J [2]. The dipole-dipole conversion in a Tm:Ho:co-doped laser crystal can convert the pump energy of diodes to the population inversion of Ho. The drawback of Tm:Ho co-doped laser is low efficiency because of the upper state absorption, Tm and Ho energy sharing, concentration quenching, and large heat loading. For the air and space borne lidar applications, it is very important to enhance efficiency of 2 $\mu\text{m}$  lasers. Theoretically, doping Ho and Tm in two separate crystals is helpful to eliminate or alleviate the mentioned-above effects. Experimentally, higher efficiency has been obtained from a diode pumped Tm:YAG laser pumped Ho:YLF laser [3]. With the advancement of Tm fiber lasers, continuous-wave output power of more than 100W is commercially available. This Tm fiber laser can be used to pump Ho lasers. Ho doped lasers have a larger effective stimulated-emission cross-section and lower saturation fluence [4]. Both large effective stimulated-emission cross-section and low saturation fluence are good for energy extraction of Q-switched oscillator or pulsed amplifier. Previously, we have reported the high efficiency operation of a Tm: fiber laser pumped Ho:YLF laser in continuous-wave mode [5]. In this paper we report the highly efficient operation of a Tm fiber laser pumped Ho:YLF laser in Q-switching mode.

## 2. The optimal design of Q-switched Ho:YLF laser

In continuous-wave operation, a small pump beam size without damaging the crystal is more efficient; however, Q-switch operation of a Tm: fiber pumped Ho:YLF laser requires a large energy storage. The storage of pump energy depends on the pump intensity, pump beam size, crystal length, and repetition rate. Fig.1 shows the analytical result based on a developed model at LaRC. With limited power, if the pump volume in the laser crystal is too large, the average pump intensity will be lower leaving most of pump power depleted to make population inversion. When the pump volume is too small, it is possible to damage the crystal. Even though the crystal is not damaged at small pump volume, the strong pump density results in the saturation of pump absorption and affects the laser efficiency. The expected pulse repetition rate for the system is 100 Hz and the calculated optimal pump intensity is around 2 kW/cm<sup>2</sup>.

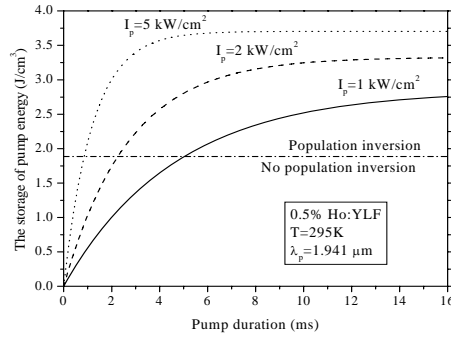


Fig.1 The storage of pump energy versus pump duration

### 3. The operation of Q-switched Ho:YLF laser

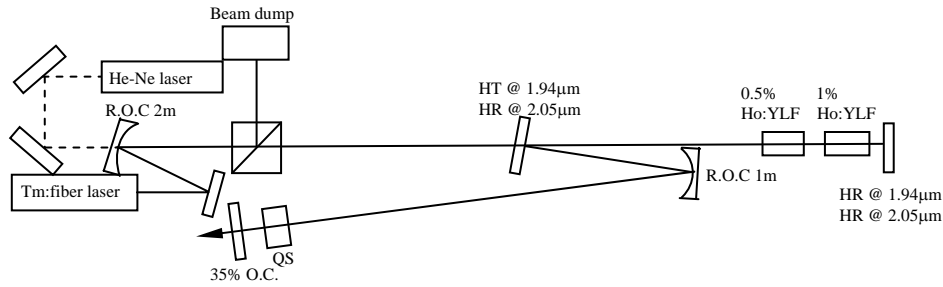


Fig.2 The Q-switched Ho:YLF laser pumped by a Tm: fiber laser.

Fig.2 shows the configuration of the designed Q-switched Ho:YLF laser which is pumped by a Tm: fiber laser. For the mode matching, a folded configuration is used where both pump and laser beams have the same confocal parameters. The maximum output power of Tm: fiber pump laser is 40W in random polarization. The center wavelength of Tm: fiber laser is 1.941μm, a difference of 2 nm from the absorption peak of Ho:YLF crystal. The output of the Tm: fiber laser beam is 5mm in diameter. In order to make the pump intensity in the crystal above 2 kW/cm<sup>2</sup>, This pump beam is focused on the Ho:YLF crystal by a concave mirror with 2m radius of curvature. The radius of the focused beam is 0.55mm at waist and the full divergence angle of the focused beam is 2.17mrad. By appropriate feedback from the back mirror of the laser, the polarization of Tm: fiber laser is changed from random to linear polarization. This results in >75% pump power (30W) incident on the Ho:YLF crystal along  $\pi$  polarization. The first pumped laser crystal is 0.5% Ho:YLF and its dimension is 5mmx5mmx25mm. The second pumped laser crystal is 1% Ho:YLF crystal and its dimension is 5mmx5mmx30mm. Both crystals are cooled by water at 10°C. The laser cavity consists of two flat highly reflective mirrors, one 1m radius concave and one flat output coupler with 35% reflectivity. The total laser cavity length is 1.65m.

30mJ of output pulse energy from this Q-switched Ho:YLF laser pumped by a Tm: fiber laser is obtained at a repetition rate of 100 Hz. The corresponding optical to optical efficiency is 10 % which is double than that of Ho:Tm co-doped lasers. Further improvement and be realized by pumping the Ho:YLF crystals from both sides to fully utilize the pump power.

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