Eyesafe microchip laser for laser range finder application

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Laser materials for eyesafe wavelength generation and Q-switching crystals for short pulse operation were studied. Er,Yb:phosphate glass as a laser crystal and Co^{2+}:$MgAl_2O_4$ as a saturable absorber were found to be an effective pair for a compact, light-weight passively Q-switched eyesafe laser operation. Laser diode (LD) pumped microchip laser was built and tested.

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There is a considerable interest in compact laser sources that generate radiation of the eyesafe wavelength region near 1.55 μm because such lasers have numerous applications in range measurement and telecommunications. In last few years much progress has been made in this area, and pulsed as well as continuous wave (CW) operation of erbium active material in different hosts, such as Er,Yb:phosphate glass, Er,Yb:YSO, Er,Yb:$SrY_4(SiO_4)_3O$, and Er,Yb:Ce:CAS, has been successfully demonstrated[1]. Among them, studies on Er,Yb:phosphate glass have been extended so far due to its outstanding characteristics and have brought substantial achievements to come into the market.

A microchip laser with eyesafe wavelength radiation is suitable for the current trend of requirements for the light weight, battery operated, long distance laser range finder (LRF)[2]. Research on the eyesafe laser employing micro or microchip regime has been actively done since mid 1990's. For pulsed operation of a microchip laser, passively Q-switched regime is typically used.

We started R&D activity on microchip laser aiming at dual use application. At first, feasibility study on laser materials and saturable absorbers was done since a variety of options with respect to choice of them were possible at the beginning of the current program. Er,Yb:phosphate glass and Co:spinel were chosen as the laser material and the saturable absorber respectively. With micro laser regime, preliminary experimental data were obtained and utilized for design of the microchip laser. The prototype of a microchip laser consisting of a laser diode, a micro lens and a monoblock was constructed and tested. Finally output performance with pulse energy of 0.15 mJ and pulse width of less than 4 ns was obtained. Pulsed operation was stabilized within 0.7%.

Time of flight optical ranging is one of the applications of the eyesafe microchip laser. The LRF is becoming more and more vital for high-precision targeting engagements of the individual soldiers. For the next generation of LRF of the individual soldiers, the goal is to produce a smaller, lighter, low-cost version that is easily weapon mountable and readily integrated into other systems.

Requirements from our customer for LRF application are usually described in the followings: light weight, small, low cost, operation over temperature, battery operated, singe shot up to 4 pulses/s, energy: $\sim$0.1 mJ, pulse width: $<$5 ns,

All lasers with eyesafe fundamental radiation are based on Er^{3+}-doped materials. Yb^{3+} ion is widely used as a sensitizer to improve quantum efficiency of the Er laser because absorption cross-section of Er^{3+} ion is small. Energy level structure of Yb^{3+} sensitizing Er^{3+} ion is represented in the Fig. 1. Laser transition occurs between ${}^4I_{15/2}$-${}^4I_{13/2}$ levels. Three-level lasing scheme of Er-ions needs relatively higher threshold than four-level systems.

There have been made a number of attempts to develop an Yb-Er doped crystalline medium for laser applications[3−5]. The main advantages of such materials are their high thermal conductivity and high thermal damage threshold. The attempts to grow this type of crystal for laser application encountered unexpected problems. Due to long decay time of the ${}^4I_{11/2}$ level comparable with that of the ${}^4I_{13/2}$ level, laser action for such laser materials with crystalline host was not practically effective.

Therefore, Er,Yb:phosphate glass for an eyesafe laser application has outstanding advantages for eyesafe laser radiation up to now in spectroscopic characteristics of Yb and Er ions and output performance with high efficiency as well as low production cost.

Use of electro-optical Q-switches in microchip laser application is impractical due to their large dimensions. Much more promising is the use of passive Q-switching with a crystalline saturable absorber. Such passive Q-switches for 1.5−1.6 μm range have already been demonstrated: Er:CaF_2, U:CaF_2, Co:ZnSe. Saturation intensity in these crystals is on the order of $10^{-2} - 10^{-1}$ MW/cm^2. Still, fluoride crystalline hosts are highly hygroscopic, while halcogenide crystalline hosts lack resistance to damage.

Therefore, searching for the efficient passive Q-switching materials for Er glass lasers is the other problem. It was suggested a new cobalt-doped material for passive Q-switching of erbium glass lasers[6,7]:

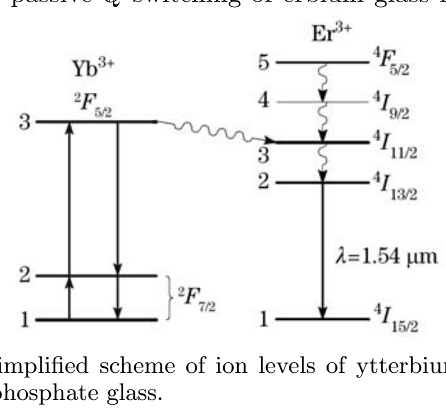

Fig. 1. Simplified scheme of ion levels of ytterbium and erbium in phosphate glass.

magnesium-aluminum spinel $Co:MgAl_2O_4$. The comparison of CaF_2:U and $Co:MgAl_2O_4$ passive Q-switches in diode array pumped Er-glass lasers showed quite obvious advantage of $Co:MgAl_2O_4$ material[8]. In this regard, $Co:MgAl_2O_4$ has shown best result as the saturable absorber.

The eyesafe microchip laser shown in Fig. 2 consists of a pump laser diode (LD), a beam delivery optics (B, C) and a monoblock (D, E) of an active material and an saturable absorber. The Er,Yb:phosphate glass plate is end-pumped at approximately 975 nm. The pump LD operates in a quasi continuous wave (QCW) mode with a peak power of 4 W. Pump energy is controlled by adjusting the pulse duration and the applied current. The LD has astigmatic aberration. Aberration in fast axis is corrected by the micro-lens directly attached LD in factory. In order to correct aberration in slow axis, the cylindrical micro-lens is designed and manufactured. The beam propagating through the monoblock is designed to keep the beam diameter as uniform as possible (Fig. 2). The monoblock is made with two optically bonded materials, Er,Yb:phosphate glass and Co:spinel. The pumped face was coated so as to be highly reflective at laser wavelength and anti-reflection coated at pump wavelength. The output coupling side was coated partially reflective at laser wavelength and highly reflective at pump wavelength.

The experimental test bed as shown in Fig. 3 was constructed for testing the output performance of the microchip laser.

By preliminary experiments using micro laser configuration, the cavity parameters such as output coupler reflectivity and initial transmission of saturable absorber were approximately determined. The locations of the cylindrical micro-lens and the monoblock were critical in this configuration. At vicinity of optimized position of the elements, the output of the microchip laser was highly stabilized better than 0.3 in standard deviation and transversely Gaussian profiled.

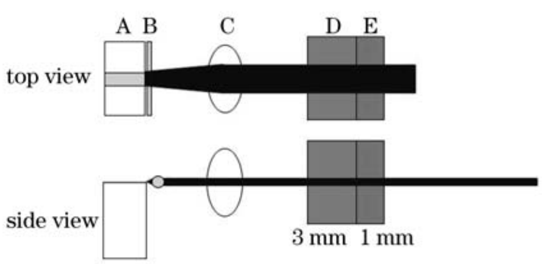

Fig. 2. Conceptual structure of the eyesafe microchip laser.

Fig. 3. Prototype for the eyesafe microchip laser.

Output performance of the eyesafe microchip laser was stated in the Table 1. At the fixed output coupler reflectivity of 85%, pulse energy, pulse width and stability were measured varying initial transmission of the saturable absorber.

50 shots of pulses were registered to check pulse energy stability. Energy distribution was plotted in Fig. 4. As shown in the figure, energy of output pulses was highly stable better than 0.7%.

The temporal pulse profile was captured using oscilloscope as shown in Fig. 5. It was measured with Co:spinel of 92% initial transmission. For LRF application, the

Table 1. Output Characteristics of the Eyesafe Microchip Laser

Saturable Absorber T_0 (%) (R85%@PR)	Pulse Energy (μJ)	Standard Deviation σ (μJ)	Pulse Width (ns)
90	187	0.7	3
92	143	0.7	<2

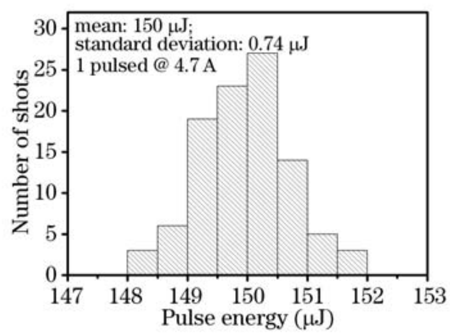

Fig. 4. Pulse energy distribution of the microchip laser.

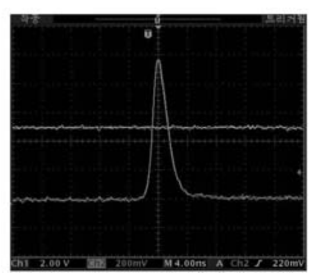

Fig. 5. Temporal pulse profile at single pulse mode.

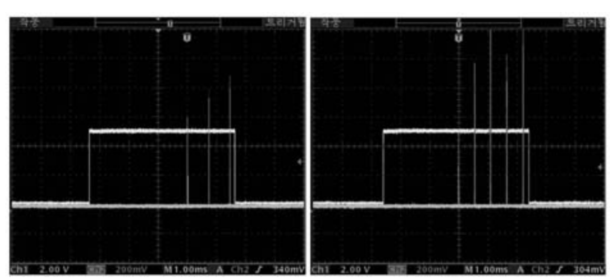

Fig. 6. Temporal pulse profiles at burst pulse mode.

eyesafe laser with single pulse output is preferable owing to advantage in signal processing. Pulse train at burst mode was also obtained with varying modulation depth of pump pulse or increasing pump energy, as shown in Fig. 6.

In conclusion, a prototype of the eyesafe microchip laser has been developed with intention to a compact LRF application. Passive Q-switching method with Co:spinel was used for pulse operation. To minimize weight and dimensions, the monoblock optically bonded with Er,Yb:phosphate glass and Co:spinel was prepared using special optical processing and coated appropriately. This monolithic approach brings another advantage in laser cavity alignment with elimination of the need for manual alignment. Output performance by the prototype which produces less than 4 ns pulse duration with an energy of 0.15 mJ at eyesafe wavelength was found to meet technical requirements.

Based on this result, engineering work of design and manufacturing for chip packaging was already started. After chip packaging, environmental test will be done following given military specification. In addition, another approach using side-pumping configuration will be tried to obtain higher pulse energy.

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