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Diode side-pumped Q-switched Nd:YLF laser for airborne and space lidar systems

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1.Introduction

High peak power diode pumped solid state lasers have been developed for airborne and space based laser remote sensing applications.[1,2] For these applications, high efficiency, good beam quality and stability under vibrations and shocks are the most important factors in designing the oscillators. Here,we describe the design and performance of 100mJ class laser with high efficiency, good beam quality and high stability for airborne and space lidar systems.

To obtain high efficiency with good beam quality, the laser material with high stored energy and low thermal distortions should be selected. We utilized c-axis Nd:YLF as the laser material because of its long upper laser level lifetime, low thermal lensing and natural birefringence. In particular, c-axis Nd:YLF laser rod is suitable for high power operation using diode-side pumping arrangement compared with a-axis rod. [3]

To obtain high stability under vibrations and shocks, the resonator must be insensitive to misalignment. There are two types of standing wave prism resonators whose misalignment sensitivities for both vertical and horizontal are much lower than those of conventional resonator with a pair of mirrors. One is crossed roof-prism resonator with polarization coupling optics and the other is cube corner prism resonator with output coupling mirror. Although the cube corner prism resonator is simple, three different polarization modes caused by three different bounces in the prism oscillate independently. The effective Fresnel number of the resonator is therefore much lower, resulting in high diffraction loss and large beam divergence.[4] Therefore, we selected the crossed roof-prism resonator. In this resonator, the resonant mode is equivalent to that of plane parallel resonator and this resonator acts as a stable resonator using an intracavity positive lens. Using conventional roof prism resonator, the output coupling ratio cannot be set continuously from 0 to 1 by retardation plate because double bounces inside the roof prism change the polarization state. Thus we devise polarization-state maintaining roof prisms to change the output coupling ratio continuously using retardation plate. The polarization state is maintained in this prism by means of making the number of bounces for both vertical and horizontal to be the same.

2.Configurations

A schematic diagram of the developed Q-switched laser is shown in Fig.1. The resonator consists of crossed polarization-state maintaining roof prisms (PMRP's) , a polarization-state maintaining folding prism (PMFP), a polarizer, an intracavity telescope[5] and a half-wave plate 1(HWP1). The polarizer is used as an output coupler with the HWP1 which gives a variable output coupling ratio. A magnification of the intracavity telescope is set to be 1.8 for the sake of using the laser rod itself as a mode selecting aperture and of maximizing extracted energy of TEM_{00} transverse mode. The telescope is slightly defocused to compensate the negative thermal lens power of the laser rod as well as to make this resonator stable. Designing the generalized G parameter of telescopic resonator ^{5} as $G1 \cdot G2 \sim 0.5$ by setting the effective focal length of the intracavity telescope to be about 7m , the spot size in the rod of 1.3mm is nearly constant in the range of the focal length of thermal lens from $-\infty$ to -10m. The $MgO:LiNbO_3$ Pockels cell, which is 6mm×6mm×35mm in size, is used as an Electrooptic Q-switching element. The polarizer and Pockels cell with a half-wave plate 2 (HWP2) and PMRP generate Q-switched pulse when quarter wave voltage is applied to the cell.

The pump module was assembled with a Nd:YLF laser rod and LDA's (Laser diode arrays). The rod is fabricated from a c-axis grown 1.5atm.% Nd:YLF crystal and is 4.1mmϕ × 65mm in size. The rod is pumped by 16 three-bar-stacked LDA's (SDL-3230-TZB) using close-coupled 16-fold symmetrical side-pumping arrangement. These LDA's provide a combined maximum pump power of 2.9kW with 48% electrical efficiency. The combined central emission wavelength of these LDA's is 796nm at heatsink temperature of 25℃ and the emission linewidth (FWHM) is approximately 5nm. Taking into account π-polarized absorption coefficient of the rod and combined linewidth of the LDA's, absorption efficiency is estimated to be from 75% to 80% in the range of the central pump wavelength from 792nm to 798nm. This indicates that the fluctuation of the laser output is less than 6% when the heatsink temperature of LDA's changes by about 20 ℃. Thus the LDA's do not need severe temperature control and are thermally conducted to the heatsink which is cooled by roughly temperature controlled liquid coolant.

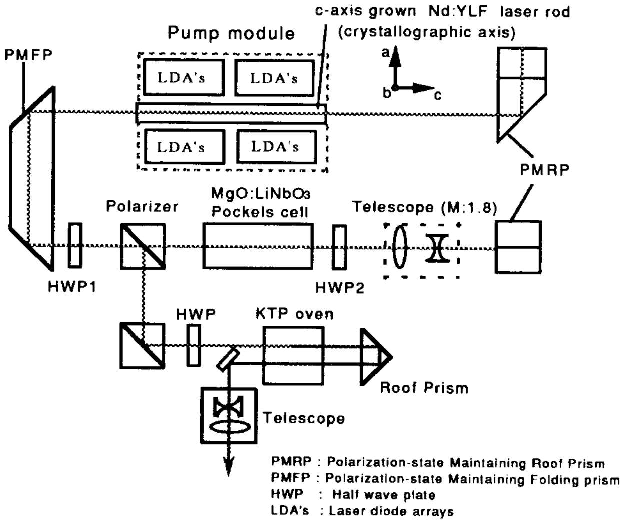

Fig.1 Schematic diagram

TypeⅡ KTP crystal, which is 5mm×5mm×10mm in size and controled at 60 ℃ in the oven, is used as a second harmonic generator. The beam reducer is not used because the beam divergence from the oscillator is narrow enough to obtain high conversion efficiency (>50%).

3.Results

By using the pump module and 120mm long conventional concave(2m) - concave(2m) resonator with 30% transmitting output coupler, the maximum output energy of 155mJ in multimode regime at the pulse repetition frequency (PRF) of 100Hz was obtained at 525mJ pump pulse energy with 200μs pulse duration. An optical slope efficiency was 36.5% and the maximum electrical efficiency was 14.2% . The thermal lensing of the laser rod was evaluated by means of the optical path difference measurement using a Mach-Zehnder interferometer at 633nm. The focal length f at 1053nm is $f = -520 / P_a$ (m) ,where P_a is the average absorbed pump power in Watt.

Figure 2 shows the Q-switched laser output characteristics of the fundamental beam. The output coupling was set to be the experimentally optimized value which was estimated to be about

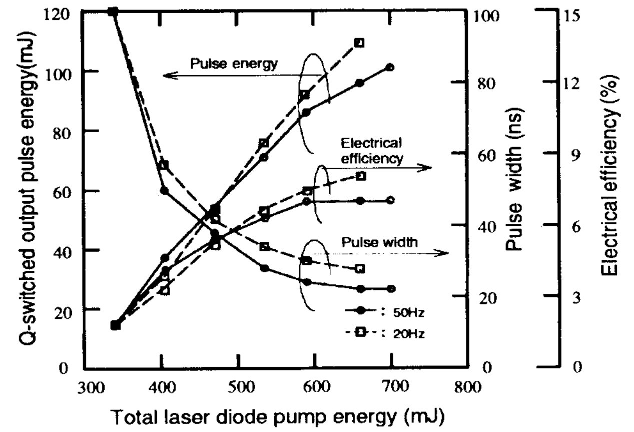

Fig.2 Q-switched output pulse energy, pulse width and electrical efficiency in TEM$_{00}$ transverse mode.

70%. The maximum output pulse energy of more than 100mJ in less than 25ns pulse width was obtained at the PRF of up to 50Hz. The corresponding peak power was more than 4.5MW and the electrical efficiency was more than 7%. The fluctuation of the output average power was measured to be ±0.5% or less for 50,000 shots operation when the coolant temperature was set to be constant and ±2.3% for the coolant temperature variation from 10 ℃ to 30 ℃.

The near field spatial energy distributions of the output beams are slightly modulated by the edge diffractions at the laser rod. But the spatial energy distributions become well fitted to Gaussian profiles as the Fresnel number becomes smaller than 1.0. Figure 3 shows a typical three dimensional spatial energy distribution of the output beam measured by a CCD camera at the point of Fresnel number 0.67. The Gaussian correlation factor is more than 0.96 in this case. The beam quality was also characterized by measuring its M^2 value. At the output energy of 90mJ, the M^2 factors have been measured to be 1.03 and 1.17 at the PRF of 20Hz and 50Hz respectively. The beam profile and the M^2 factor indicate that this laser oscillates in TEM$_{00}$ transverse mode.

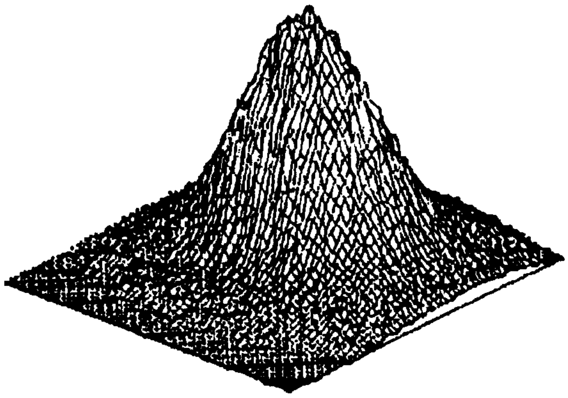

Fig.3 The spatial energy distribution of the output beam.

At the fundamental output energy of 100mJ, the conversion efficiencies of second harmonic generator were about 55% at the PRF of up to 50Hz. Taking into account the peak intensity of fundamental beams of 50MW/cm^2 and the experimental conversion efficiency, phase mismatch of the KTP crystal was estimated to be about 0.6cm^{-1}. If the peak intensity of fundamental beam becomes as high as 150MW/cm^2, the maximum conversion efficiency of 80% would be expected using this second harmonic generator.

4.Summary

We have developed a 100-mJ-class laser diode side-pumped Q-switched laser oscillator for airborne lidar systems using c-axis Nd:YLF rod and the crossed prism resonator with intracavity telescope. At the PRF of up to 50Hz, the electrical efficiency of more than 7% has been obtained in TEM$_{00}$ mode which has the M^2 factor of less than 1.17. The conversion efficiency of second harmonic generator using KTP has been 55%. Considering the relative low stimulated cross section of σ-polarized lasing at 1053nm (1.34×10^{-19} cm^2 was estimated), long lifetime (350μs at 5kw/cm^2 pump condition was measured) and low thermal lensing effect of c-axis Nd:YLF, the output energy of one Joule and the electrical efficiency of more than 10%, which are required in the space lidar systems, would be easily obtained using a master oscillator power amplifier configuration (MOPA).

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