Conductively Cooled LDP Nd:YAG Laser for Spaceborne Lidar System

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Abstract

Reported here are results of design and experiment efforts on an entirely solid-state laser oscillator characterized by conductive cooling in consideration of use for a spaceborne lidar system.

The laser has achieved a Q-switched output energy of more than 100 mJ at a pulse frequency of up to 50 pps and a conversion efficiency in second harmonic generation of 48%.

1. Introduction

A lot of proposals have been made for over two decades on spaceborne lidar systems aimed at atmospheric observation. In September 1994, an experiment with a lidar (LITE) was conducted from the Space Shuttle and yielded useful observation results. [1]

A lot of research institutes in Japan are also making efforts for studying and test-fabricating spaceborne lidars. [2] Projects for spaceborne lidars are beginning to enter the stage of implementation.

A laser for spaceborne lidar systems must fulfill exacting requirements for restrictions on size and weight and must stand the vibration and shock when the space vehicle is launched. Especially heat dissipation system is one of the most important problems considering reliability and high effic iency.

With these born in mind, we made efforts for developing a conductively cooled laser diode pumping (LDP) Nd:YAG laser.

This paper outlines the laser oscillator we developed, discusses its heat dissipation system in detail, and reports results of its evaluation.

2. Design of Laser Oscillator for Spaceborne Lidar

2.1 Optical Configuration

A schematic diagram of the developed laser oscillator is shown in Fig 2.1-1. We adopted Nd:YAG as our medium considering that YAG is easily available in the form of high-quality large crystals and has track records about achievement of high efficiency and high power operation.

A total of 16 LDs are used to achieve good uniformity in Nd:YAG crystal pumping and accomplish pumping in 8 directions. Fig 2.1-2 shows the structure for LD pumping.

For the oscillator structure, we used a trapezoidal prism to minimize the size and weight in consideration of the vibration and shock that will be involved during the launch, giving the oscillator a two stage structure. Fig 2.1-3 shows the oscillator structure.

We adopted KTP(type II) as second harmonic generator. Considering the photochemical effect (gray tracking), KTP is placed in an 80℃ oven.

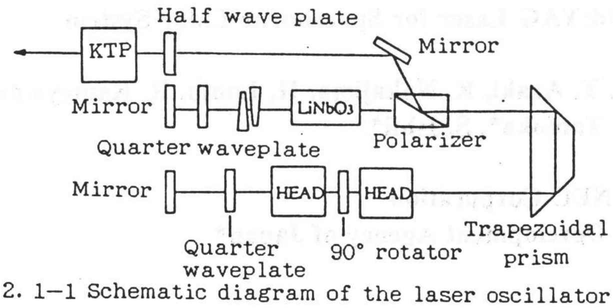


Fig 2. 1-1 Schematic diagram of the laser oscillator

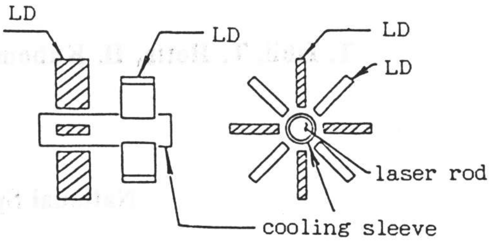


Fig 2. 1-2 Structure for LD pumping

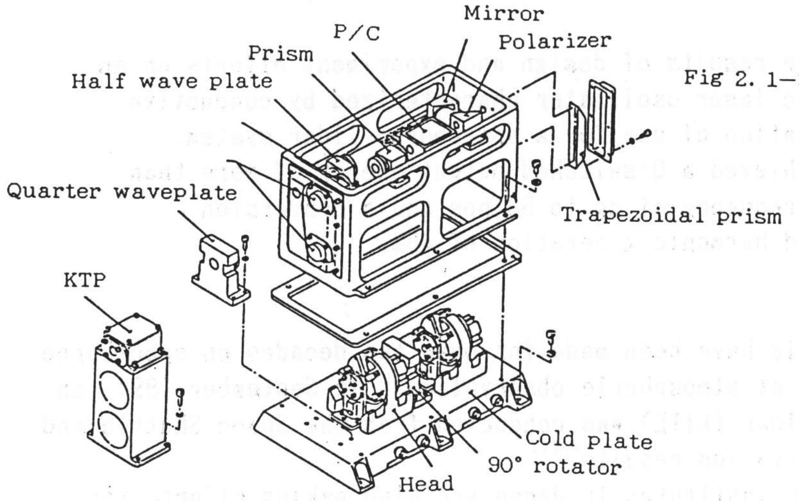


Fig 2. 1-3 The oscillator structure

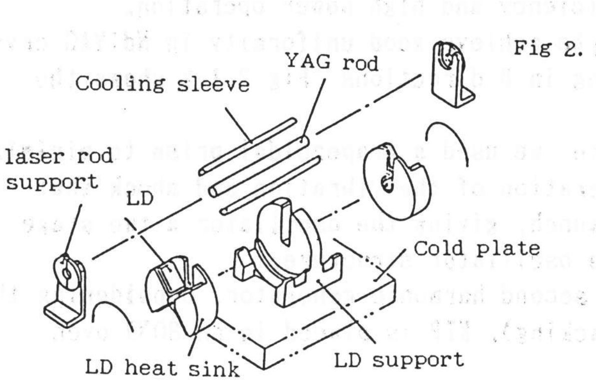
2.2 Heat Dissipation System

High-power lasers are often liquid-cooled. However, if liquid cooling is used in space environments, the pump and other moving components will be a dominant factor which influences the life and reliability of the entire system. In addition, this method causes the entire laser oscillator to be large and to consume more power. To avoid this difficulty, we adopted solely conductive cooling for the laser head rather than liquid cooling.

When designing a heat dissipation system based solely on conductive cooling, we performed thermal analysis using a mathematical model which simulates thermal conduction that will be actually involved. This thermal analysis will be discussed in Chapter 3.

Figure 2.2-1 shows the structure of the cooling unit for the laser head. Copper with good thermal conductivity is used for all of the LD heat sinks, LD supports, cooling sleeves, and laser rod supports.

Fig 2. 2-1 The structure of the cooling unit for the laser head



(1) LD cooling

Heat from the LD flows, by thermal conduction, to the LD support via the heat sink and into a cold plate.

A conductive sheet with a good thermal conductivity (0.23℃/W) is used for the contact between the LD and the heat sink.

(2) Laser rod cooling

The laser rod is cooled by the cooling sleeves placed around it. Therefore, the heat generated in the laser rod by the pumping light from the LD flows from the cooling sleeve to the laser rod support, then to the cold plate. The important point here is that good conduction cooling of the laser rod requires intimate thermal contact between the laser rod and the cooling sleeve. To fulfill this requirement, thin indium sheets are placed between the contact surfaces of the laser rod and cooling sleeve.

(3) Cold plate cooling

At present, a chiller with pure water as its coolant is used for cooling the cold plate. Heat piping will be used at the time of installation in the satellite.

3. Results

3.1 Evaluation of Heat Dissipation System

(1) Thermal analysis model

Figure 3.1-1 is a schematic illustration of our thermal analysis model. Table 3.1-1 gives the results of the thermal analysis. As indicated in the table, the projected temperature differences between the cold plate and the LD and between the cold plate and the laser rod are 7.1℃ and 37.7℃, respectively.

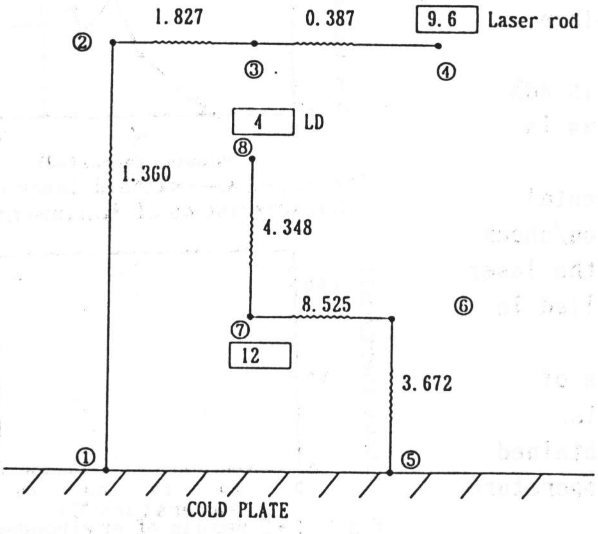


Fig. 3.1-1 Schematic diagram of thurmal analysis

Table 3.1-1 Result of thermal analysis

measurement points	temperature difference ΔT(℃)	
①	0.0	cold plate
②	5.3	
③	7.0	
④	37.7	cooling sleeve
⑤	0.0	cold plate
⑥	4.4	
⑦	6.2	
⑧	7.2	LD

(2) Temperature measurement

Temperatures at the necessary points were measured to study the heat flow characteristics of the LD and the laser rod cooling sleeve. While keeping the cold plate temperature at 15℃ using a thermistor, the temperature of the LD was measured with a thermistor embedded in the heat sink and the temperature of the cooling sleeve was measured at its center and end with a thermocouple.

Figure 3.1-2 shows the results of heat sink temperature measurement. The heat sink temperature is kept nearly constant independent of the LD oscillation frequency. In addition, the figure indicates that the temperature difference between the cold plate and the heat sink is smaller than the projected difference of 7.1℃.

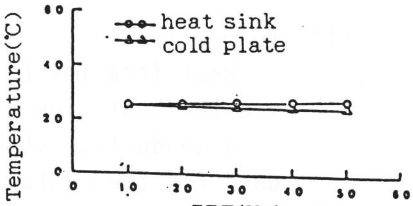


Fig3. 1-2 Results of heat sink temperature measurement

Figure 3.1-3 shows the results of cooling sleeve temperature measurement. As the LD oscillation frequency increases, the temper-ature of the cooling sleeve rises. At 50 Hz, the temperature in the state of thermal equilibrium is 52℃, nearly matching the results of analysis using the thermal analysis model.

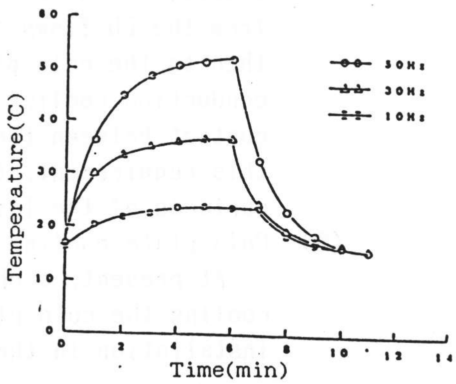


Fig3. 1-3 Results of cooling sleeve temperature measurement

3.2 Evaluation of Basic Performance of the Laser Oscillator

Figure 3.2-1 shows the Q-switched laser output characteristics of fundamental beam. A Q-switched laser output of 100 mJ or more is obtained when the input energy is 800 mJ under the condition that the oscillation threshold is 250 mJ and the slope efficiency is 26.7%.

The conversion efficiency is 48% when the input fundamental beam is 100mJ.

We also conducted environmental temperature tests and vibration/shock tests on the assumption that the laser oscillator will also be installed in an aircraft.

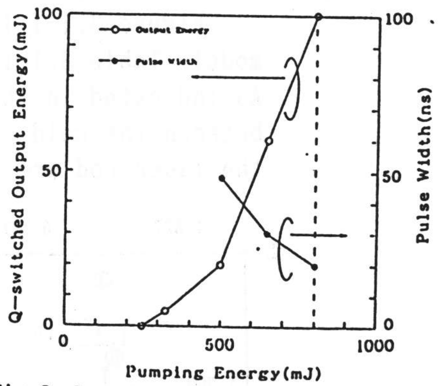


Fig 3. 2-1 Q-switched laser output characteristics of fundamental beam

Figure 3.2-2 shows the results of environmental temperature tests. A constant laser output was obtained independent of the ambient temperature (0 to 40℃).

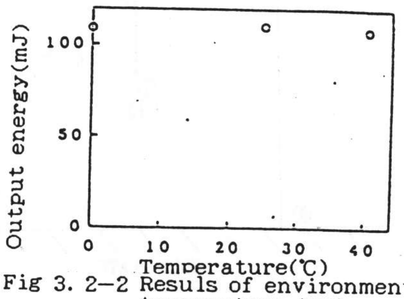


Fig 3. 2-2 Resuls of environmental temperature test

Table 3.2-1 indicates the conditions for the vibration/shock tests. The application of these conditions did not change the laser output.

Table 3.2-1 The Conditions for the vibration/shock tests

Tests	Conditions
Vibration	5～ 55Hz 0.254mmp-p 55～500Hz 1.5Gp-p
Shock	15G×11msec

4. Summary

We developed the LDP Nd:YAG laser with conductive cooling for spaceborne lidars .

More than 100mJ of Q-switched output energy is achieved at pulse repetition rate up to 50pps and the conversion efficiency of second harmonic generation is 48%. The laser oscillator is achieved to be compact on size using conductive cooling. The thermal analysis model which well agreed with the results of actual measurements is useful in the design stage.

Consequently, we conclude that the conductive cooling is a useful method for a LDP Nd:YAG laser for spaceborne lidars.

References

(1)M.Patrick McCORMICK:The Review of Laser Engineering,pp175-179 Vol.23 No.2 (1995)

(2)K.Asai:Abstract of Paper of 17th ILRC, Sendai, Japan, pp353-354 (1994)

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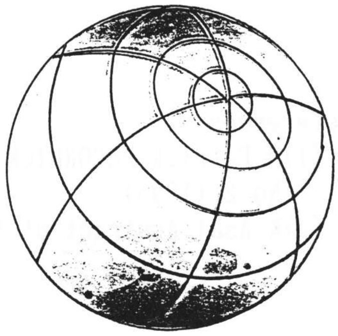


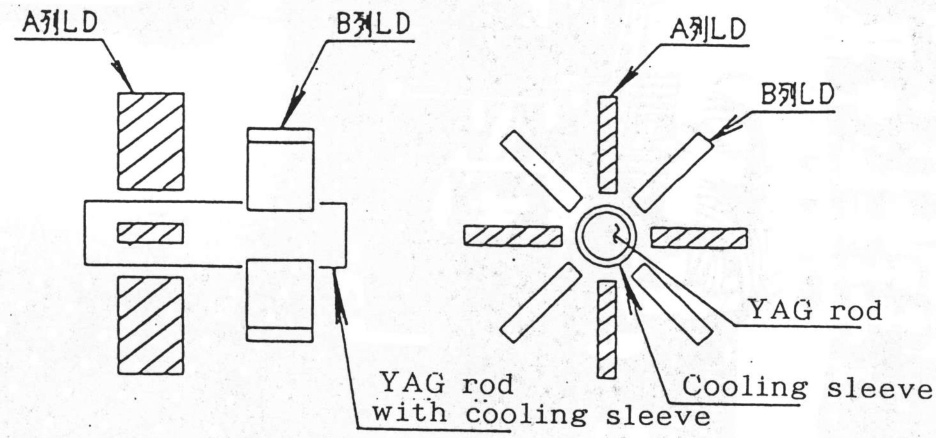
Design issues for Spaceborne lasers

- Efficiency
- Reliablity
- Size
- Resistance to vibration and shock

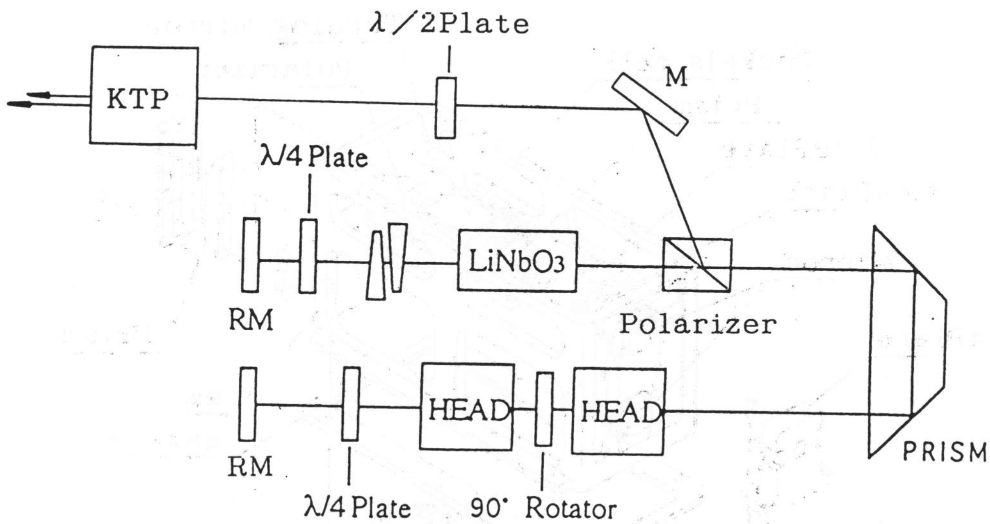
Nd:YAG VS Nd:YLF

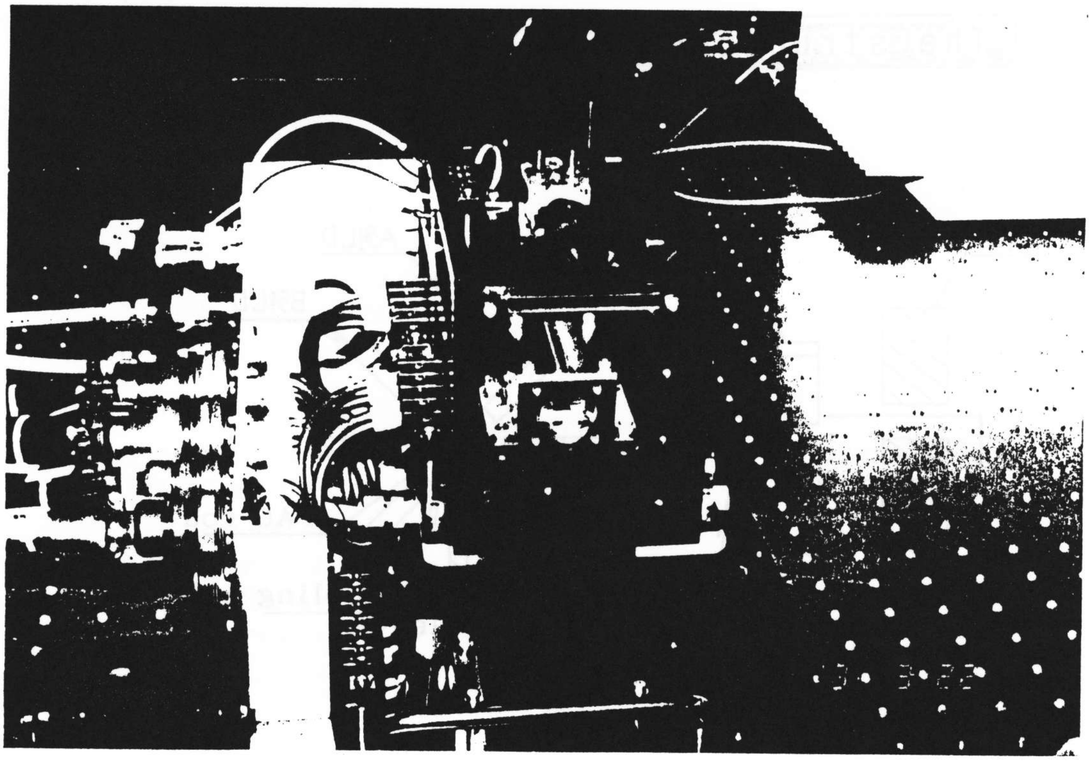
Items	YAG	YLF
Pumping eficiency	○	○
Thermal distortion	○ $\frac{dn}{dt} > 0$, no probrem for LD pumping	○ $\frac{dn}{dt} < 0$, athermal
Optical quality	○	△
Chemical stability	○	△

The structure for LD pumping

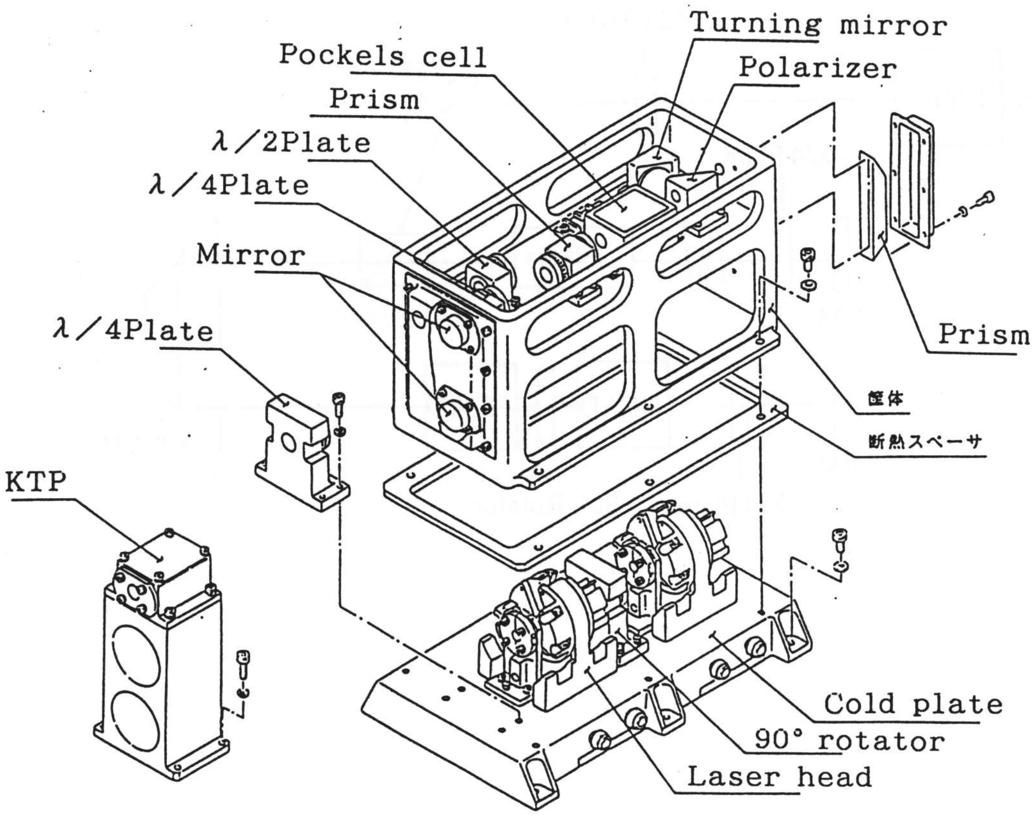


Schematic diagram of the laser oscillator





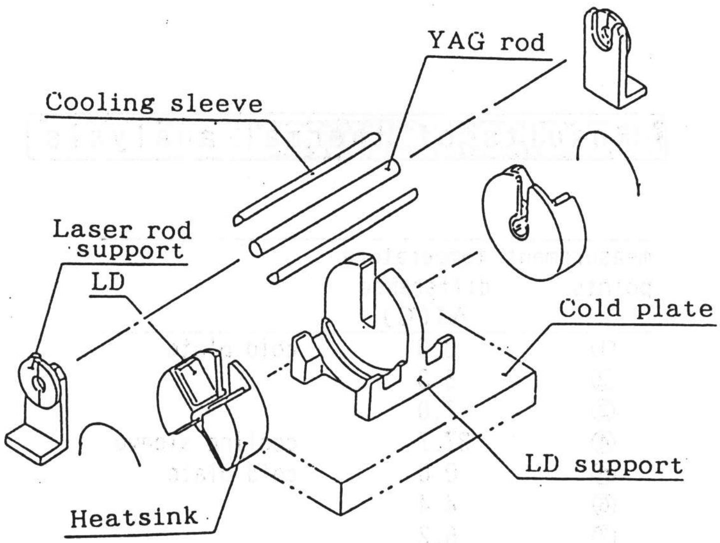
The oscillator structure



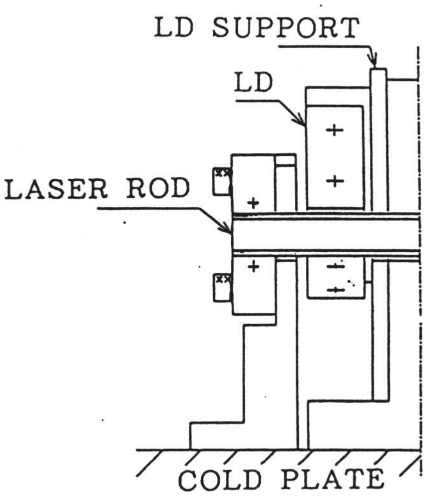
Liquid cooling VS. Conductive cooling

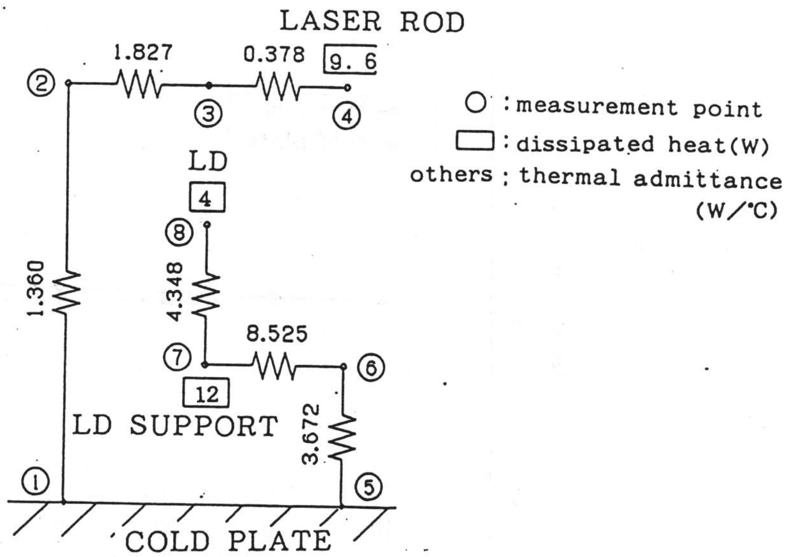
Items	Liquid cooling	Conductive cooling
Cooling capability	◎	○
Chemical stability for laser rod	△	◎
Lifetime	△	◎

The structure of the cooling unit for the laser head

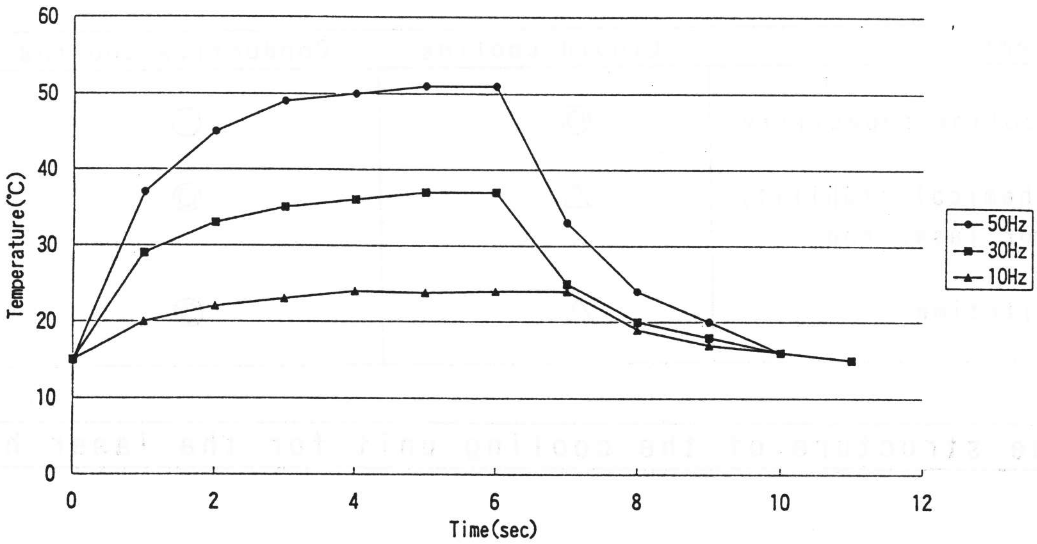


Thermal analysis model.





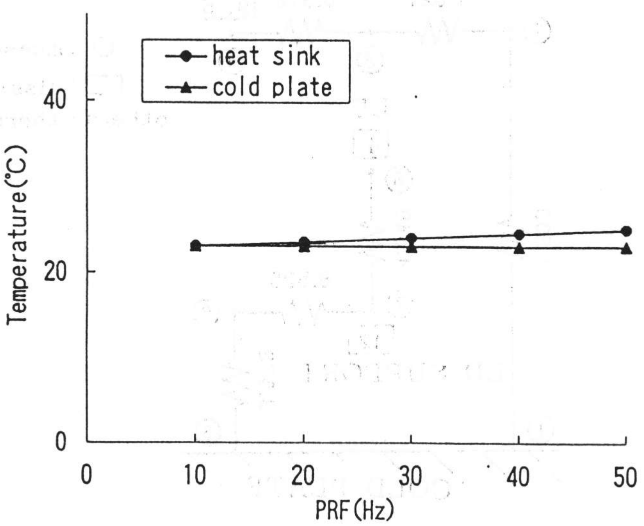
Temperature of cooling sleeve



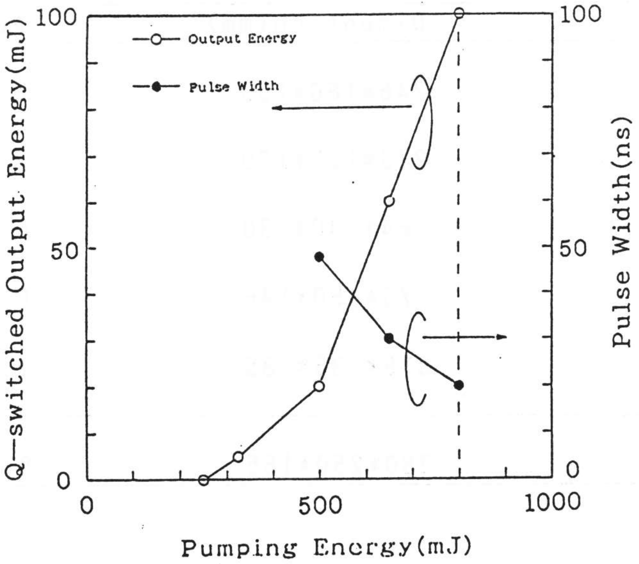
Results of thermal analysis

measurement points	temperature difference ΔT(℃)	
①	0.0	cold plate
②	5.3	
③	7.0	
④	37.7	cooling sleeve
⑤	0.0	cold plate
⑥	4.4	
⑦	6.2	
⑧	7.2	LD

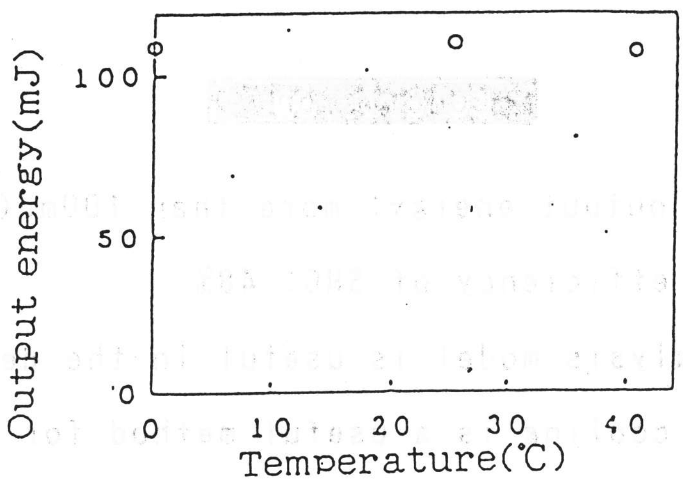
Temperature of heat sink



Q-switched laser output characteristics



Environmental temperature test



The conditions for the vibration/shock tests

Test	Condition
Vibration	5～55 Hz 0.254mmp-p 55～500Hz 1.5Gp-p
Shock	15G× 11msec

Principal demensions and weights

	Dimension(mm)	Weight(kg)
Laser Head	246*160*100	4.4
Optics	273*130*130	2.5
Pockels Cell	64* 30* 30	0.1
KTP	76* 50*146	0.9
Connector	316* 35* 85	1.3
TOTAL	380*250*155	9.2

Conclusion

- Q-switched output energy: more than 100mJ(50Hz)
- Conversion efficiency of SHG: 48%
- Thermal analysis model is useful in the design stage
- Conductive cooling is a useful method for a LDP Nd:YAG laser for spaceborne lidars.