A Diode-pumped Continuous-wave Nd:YAG Laser with an Average Output Power of 1 kW

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1. Introduction

A diode-pumped Nd:YAG laser with an average output power of 1 kW is developed for industrial applications, such as metal cutting, precision welding, etc. To develop such a diode-pumped high power solid-state laser, a series of laser modules have been used in general with and without thermal birefringence compensation. For example, Akiyama et al. used three laser modules to obtain a output power of 5.4 kW CW.[1] In the side-pumped Nd:YAG laser, which is a commonly used pump scheme to obtain high output power, the crystal rod has a short thermal focal length at a high input pump power, and the short thermal focal length in turn leads to beam distortion within a laser resonator. Therefore, to achieve a high output power with good stability, isotropic beam profile, and high optical efficiency, the detailed analysis of the resonator stability condition depending on both mirror distances and a crystal separation is essential.

2. Methods and Results

To develop a diode-pumped Nd:YAG laser with the output power of 1 kW we adopted two 600 W-class laser modules in a plane-parallel resonator. Using a ray-propagation matrix method, we analyze graphically the resonator stability condition. The characteristics of the laser output power are confirmed experimentally in association with the analyzed resonator stability condition.

2.1 Laser Module Design

Figure 1 shows one of Nd:YAG laser modules designed newly for the development of the 1 kW laser system. Two laser modules have the same geometry, and each module is constructed with a Nd:YAG rod having the diameter of 6 mm and doping concentration of 0.6 at. %, a cooling flow tube, a diffusive reflector, and three laser diode modules having a summed output power of 1,800 W. The diffusive reflector is made of spectralon material, and has an inner diameter of 16 mm. The inlet slit of the diffusive reflector has a width of 1.5 mm. The flow tube has an outer diameter of 16 mm, and its surface is contacted with the inner surface of the reflector. This removes heat condensation in the reflector and has a role to maintain the reflector shape under high input pump power conditions. Other detailed design parameters could be obtained from our early report.[2]

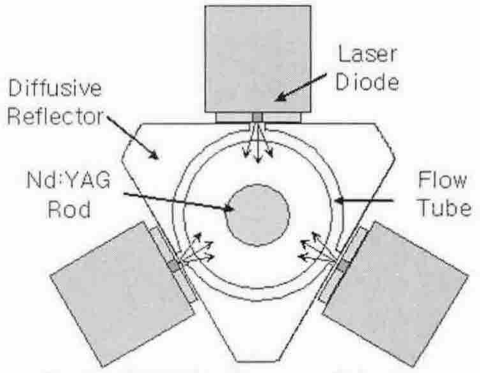

Figure 1. A schematic diagram of the laser module, which consisted of three laser diodes, a diffusive reflector, a flow tube, and a Nd:YAG rod.

2.2 Resonator Stability Analysis

The resonator stability of the plane-parallel resonator including two pump modules is analyzed using a ray-propagation matrix method described in our early report.[3] For this analysis, the ray matrix distance of the crystal rod separation is assumed to be 102 mm and the slope of the reciprocal thermal focal length to be 7.5 D/kW in laser operation condition. Figure 2 shows the resulting resonator stability calculated for r- and θ -polarizations. In the figure, the darkened areas correspond to the unstable resonator conditions, in which the laser can not be operated stably.

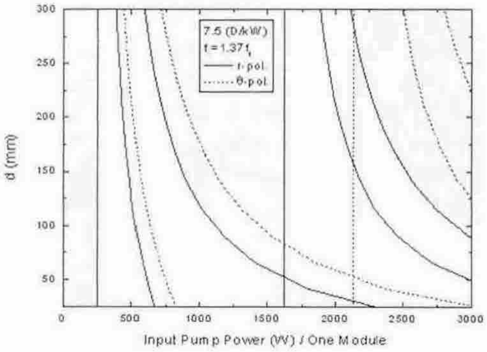

Figure 2. Stability condition of the resonator depicted as parameters of both the mirror distance and an input pump power for the crystal rod separation of 102 mm.

2.3 Experimental Results

Based on the analysis of the stability condition described in the section 2.2, we analyzed experimentally the resonator characteristics with two crystal rods. With the ray matrix distance d_m= 102 mm for two crystal separation and d=81 mm for the mirror distance from the pumped crystal rod end, as shown in Figure 3, the laser output power is measured for the various mirror reflectance of 40, 50, and 60%. The laser output power increases steadily in proportional to the input pump power. In the figure, the input pump power represents sum of input pump powers applied to two laser modules. The maximum laser output power of 1003 W is obtained at the reflectance of 50%, and this corresponds to the optical conversion efficiency of approximately 30%. However, at the input pump powers of approximately 1200 and 3100 W the unstable regions are observed and these regions are related to the unstable regions observed around 600 and 1550 W in Figure 2. We see that the unstable points measured experimentally are coincided well with that of the calculated stability condition.

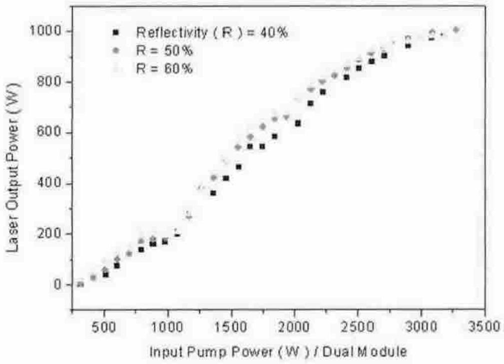

Figure 3. Dependence of the laser output power on the input pump power for the various reflectivity(R) of the laser output mirror.

Figure 4 shows the measured M^2 beam quality factor of 86.7 at an input pump power of 3086 W. For some applications such as metal cutting, a laser beam with smaller M^2 values could be desirable. To meet such a condition of laser beam quality, the laser beam could be improved by properly adjusting a mirror distance, the curvature of mirror surfaces and crystal rod ends, and/or discriminating high order modes by small aperture stop and crystal rod. By a thermal birefringence compensation scheme using a 90^0 rotator or a Faraday rotator, the M^2 value can be further improved.

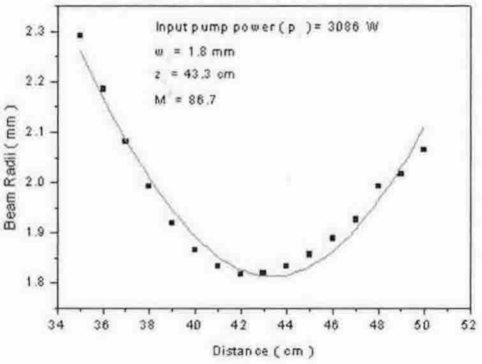

Figure 4. A M^2 beam quality factor measured at an input pump power of 3086 W.

3. Conclusion

By using two home-made 600-W class laser modules, a laser system with an output power of 1-kW was developed and the resonator stability condition of the system was analyzed for the stable laser operation. The calculated resonator stability condition explained well the resonator stability of 1-kW laser system. The developed laser system had an optical-to-optical efficiency of approximately 30%, and a M^2 beam quality factor of approximately 86. A multi-kW laser system can be constructed by adding more laser modules and properly designing the resonator.

REFERENCES

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