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Nd:YAG Lasers Operating at 1064 nm and 946 nm by Direct Pumping and Thermally Boosted Pumping *

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We demonstrate a 1064 nm Nd:YAG laser by directly pumping into the upper lasing level with a tunable Ti:sapphire laser. The valid wavelength is demonstrated at 868.3 nm, 875.2 nm, 883.8 nm, and 885.5 nm, respectively. To our knowledge, this is the first time that 1064 nm Nd:YAG laser pumped by 875.2 nm laser. In addition, laser wavelength at 946 nm is also generated by direct pumping together with traditional pumping.

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It is well-known that neodymium-doped materials possess several obvious absorption peaks in the spectral range from 800 nm to 900 nm. Take Nd:YAG for example, its several obvious absorption peaks are located around 808 nm, 869 nm and 885 nm etc. For the availability of the pump source at the early age of the laser development, researchers proposed and used the diode laser (LD) emitting radiation around 870 nm to pump different neodymium-doped laser crystals.[1−3] Actually, the 808 nm absorption band is much stronger and more suitable for LD pumping than the latter two wavelengths. For this reason, much attention has been focused on developing the 808 nm LDs and pumping the Nd-doped laser crystal with 808 nm LD. So far, such a pump scheme with 808 nm LD has been the dominating work in the field of LD pumped laser research, and is referred to as the traditional pump.[4] However, in the past few years, the well-established LD emitting 885 nm radiation has encouraged researchers to re-utilize the primal pump scheme to overcome the problems caused by heavy heat load and to increase conversion efficiency.[5−11] The pump schemes with 869 nm and 885 nm are regarded as direct pumping and direct thermally-boosted pumping,[5] respectively, for they pump the Nd^{3+} ions into the upper lasing level directly from the ground state or the thermally excited ground state levels (shown in Fig. 1). Compared with the traditional pumping, in principal, the latter two are able to decrease the quantum effect, so higher conversion efficiency, less heat-generation, and improved laser performance could be expected.

In this Letter, we report on a Nd:YAG laser operating at 1064 nm and 946 nm by directly pumping the Nd^{3+} ions into the upper lasing level with a tunable Ti:sapphire laser source. Several different pump wavelengths are demonstrated and the relevant slope efficiencies are obtained. Meanwhile, we analyse the feasibility of using LD pumps. It should be noted that the 946 nm laser is operating by direct pumping together with traditional pump of 808 nm LD.

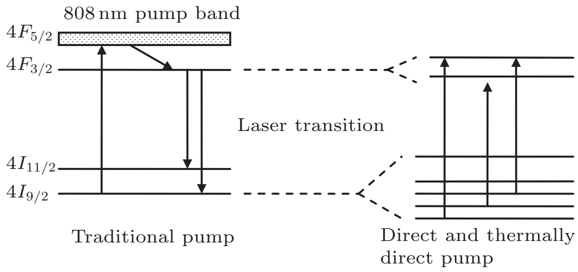

Fig. 1. Schematic of the Nd^{3+} ions levels related to laser emission and comparison between traditional and direct pump.

The experimental layout for 1064 nm laser operating is shown in Fig. 2. The Ti:sapphire source (Spectra- Physics, Model 3900 s) emits cw TEM00 laser and has a spectra width of less than 0.1 nm. A convex lens with a focal length of 300 mm focuses the pump laser into the crystal. The radius of the focus is about 50 μm. The crystal Nd:YAG used in the experiment has dimensions of $\Phi 8 \times 5\,\mathrm{mm}^3$, and Nd^{3+} concentration of 1 at.%. The two surfaces of the crystal are antireflection (AR) coated for 1064 nm. The crystals are wrapped with indium foil and mounted in a water-cooled copper block. The temperature of water flow is maintained at 10°C. The rear mirror is a planar one and high reflection (HR) coated for 1064 nm. The reflectivity for the wavelength ranging from 860 to 890 is less than 20%. OC1 has a radius of curvature of 1000 mm and a transmission of 6% at 1064 nm. The total cavity length is about 130 mm.

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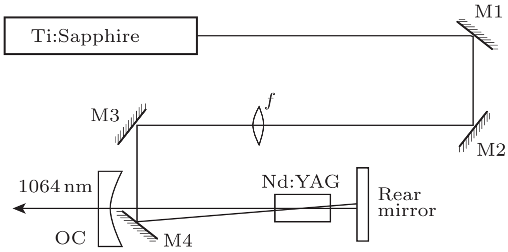

Fig. 2. Schematic of the experimental setup for 1064 nm operation. M1, M2, M3, M4 are all metallic mirrors. The focus lens has a focal length of 300 mm.

The 1064 nm laser was operating for both crystals when the pump laser was tuned at 868.3 nm, 875.2 nm, 883.8 nm, and 885.5 nm, respectively. To our knowledge, this is the first time that Nd:YAG laser is operating at 1064 nm pumped by 875.2 nm laser. The dependence of the output power on incident pump power is presented in Fig. 3. The slope efficiencies are 52.9%, 27.7%, 40.2%, 43.2%, respectively, and the corresponding pump threshold powers are 237, 420, 311, and 314 mW, respectively.

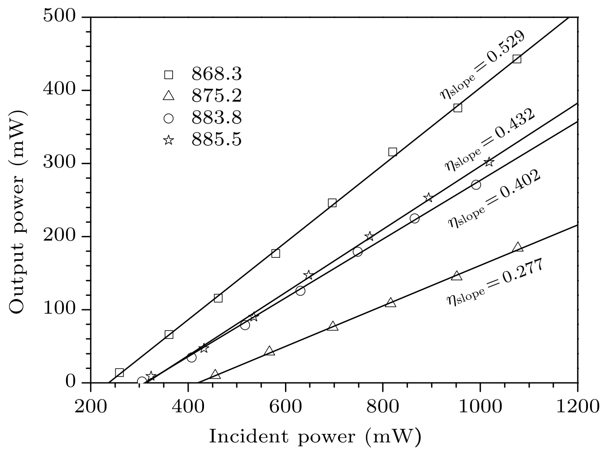

Fig. 3. Dependence of 1064 nm output power on incident power.

From the experimental results shown in Fig. 3, we find for the Nd:YAG laser crystal that the optical–optical conversion efficiency is maximal for 868.3 nm pump, secondly for the 885.5 nm and 883.8 nm pumps, and minimal for the 875.2 nm pump. On the other hand, the pump threshold powers for the four pump wavelengths are reversed. The efficiencies for the four pump wavelengths agree well with the corresponding absorption cross sections.[5] In addition, we found that even a tiny change of the wavelength of the pump laser could lead to a significant reduction of the output. This implies that the spectral width of the absorption peak is very narrow. It also coincides with the measured spectral width.[5] As the absorption peaks of 885.5 nm and 883.8 nm are separated closely, the laser keeps on operating when the wavelength of the pump is tuned from one absorption peak to the other. However, the output power would firstly decrease and then increase.

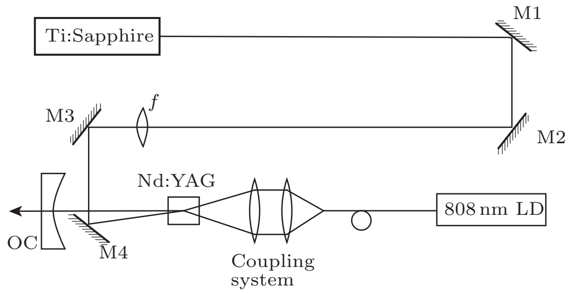

Fig. 4. Schematic of the experimental setup for 946 nm operation. M1, M2, M3, M4 are all metallic mirrors. The focus lens has a focal length of 300 mm.

Furthermore, another Nd:YAG crystal is used for the demonstration of 946 nm laser. Compared to the 1064 nm, the cross section of the emission peak around 946 nm is much smaller and 946 nm laser suffers from an added re-absorption loss. In order to make the 946 nm laser operate, a more robust pump source is desired or the total intra-cavity loss of round-trip should be reduced. Unfortunately, in this experiment the 946nm laser could not operate with direct pumping solely by Ti:sapphire laser for its limited power. In order to make the laser operate at 946 nm, an 808 nm LD laser was used to pump the laser together with Ti:sapphire source. The two sources pumped the crystal from the two ends simultaneously.

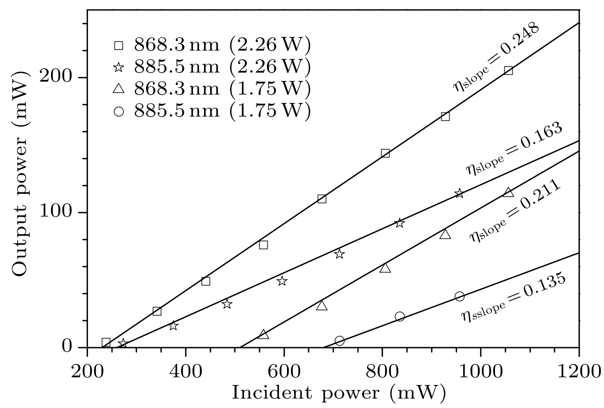

Fig. 5. Dependence of 946 nm laser output power on Ti:sapphire incident power. Squares and pentagons: Extra pump power of 2.26 W from 808 nm LD. Triangles and circles: Extra pump power of 1.75 W from 808 nm LD.

The experimental layout for laser 946nm operating is shown in Fig. 4. The Nd:YAG crystal is a composite one with dimensions of $\Phi3 \times 9\,mm^3$, consisting of a 3-mm-long 1 at.% Nd^{3+} doped Nd:YAG crystal and two diffusion bonded 3-mm-long un-doped YAG end caps. One of the two surfaces is AR coated for 946 nm and AR for 1064 nm, the other which acts as the rear mirror is HR coated for 946 nm, AR for 1064 nm and AR for 808 nm. OC_2 has a radius of curvature 1000 mm and a transmission of 2% at 946 nm. The total cavity length is about 130 mm.

Firstly, we set the pump power of the 808 nm LD below the pump threshold power of 2.7 W (which is the pump threshold power when pumping the 946 nm laser solely by 808 nm LD), and then we introduced the Ti:sapphire laser to pump. With such configuration, the 946 nm laser operated successfully. The dependence of the output power of the 946 nm laser on the incident power of the Ti:sapphire source is shown in Fig. 5. It should be noted that extra powers of 2.26 W and 1.75 W from 808 nm LD, which are both below the corresponding pump threshold power, have been used to pump Nd:YAG crystal simultaneously with Ti:sapphire laser wavelengths of 868.3 nm and 885.5 nm, respectively. The corresponding slope efficiencies are 24.8%, 21.1%, 16.3%, 13.5%, respectively. If a higher power laser source with emitting wavelengths around 869 nm, 875 nm, or 885 nm is available, or the coatings on the crystal could be optimized, it is sure that the 946 nm could operate under the direct-pumping or thermally boosted pump.

In conclusion, by pumping the Nd^{3+} ions into the upper lasing level directly with a tunable Ti:sapphire laser, Nd:YAG lasers operating at 1064 nm and 946 nm are realized, respectively. For the first time we demonstrate the 1064 nm lasing pumped by 875.2 nm wavelength. Although the 946 nm laser operates successfully only by the simultaneously pumping from two pump sources, the validity of the direct pumping has been shown. Moreover, we believe that the 946 nm laser operating could be realized by a direct pump scheme with high power LDs.

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