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Low quantum-defect laser oscillation by high intensity pumping at room temperature

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Abstract: Ytterbium laser oscillations at 980.6 nm and 983.0 nm are observed by high intensity 978.1 nm pumping of around 1 MW/cm^2 at room temperature. Corresponding quantum defects are 0.26 % and 0.50 %, respectively.

OCIS codes: (140.3510) Lasers, fiber, (140.3580) Lasers, solid-state, (140.3480) Lasers, diode pumped, (140.5680) Rare earth and transition metal solid-state lasers

Heat production control is a significant research to realize highly-efficient, compact and reliable lasers. The most of the thermal power comes from the quantum defects of laser ions, defined as $\eta = 1 - h\nu_l / h\nu_p$ where $h\nu_l$ and $h\nu_p$ are the lasing and pumping photon energy, respectively. The quantum defect reduction is a key issue of the research. Ytterbium is one of the most promising laser ions for highly efficient laser oscillation by laser diode pumping [1-13]. The simple two-level electronic structure inhibits undesired loss processes and it arrows high pumping intensity much larger than 100 kW/cm^2. Nearly quantum limited, highly efficient laser oscillation of Yb:YAG was also realized by high intensity pumping at room temperature [10]. Although the quantum defect reduction with lasing can be possible in the two-level electronic structure like Ytterbium ions, the threshold is extremely high due to its large population in the lower laser level. High intensity pumping is useful technique to overcome the induced loss by the population in the lower laser level. For example, an extremely low quantum defect of 0.8 % was observed for Yb:$CaGdAlO_4$ laser [14].

In this paper, Ytterbium laser emissions centered at 980.6 nm and 983.0 nm are demonstrated at room temperature by laser diode pumping centered at 978.1 nm with high pump intensity of around 1 MW/cm^2. The laser emission wavelengths closer to the pump wavelength, leading to extremely low quantum defects of 0.26 % and 0.50 %, respectively. The smallest values have been observed for the first time to our knowledge, and the smallest values have been observed also by laser diode pumping for the first time to our knowledge.

A unidirectional ring fiber laser was configured as shown in Fig. 1. A 6.2 µm core diameter, single-core, single-mode Ytterbium silicate fiber (Yb214, made by INO) is used as a gain medium to arrow high pumping intensity. The Ytterbium fiber length is 90 mm and the unsaturated absorption efficiency at 978 nm is measured to be almost 100 % while the absorption coefficient of around 978 nm is 730 dB/m. The maximum fiber-coupled power of the diode laser (LU0977M330-1001F10D, made by Lumics) is 290 mW with 978 nm center wavelength.

Figure 2 (a) and (b) shows the output spectra of the Ytterbium fiber ring laser at a fiber-coupled pump power of 290 mW. The resolution of the spectrometer is 0.6 nm. The dotted curve in Fig. 2 (a) indicates the output with blocking the ring laser path. The spectrum centered at 978.1 nm is corresponding to a leakage of the pump laser diode from the fiber laser. The pump absorption efficiency is estimated to be 79 % at 290 mW fiber-coupled pump power. Because of high pumping intensity, saturation of the pump absorption is measured. The solid curve indicates the output without blocking the ring laser path. When the 983.0 nm output is increased, the 978.1 nm power is reduced. The reason for the power reduction can be attributed by saturation decrease of the pump absorption by lasing. Unidirectional ring laser operation is also confirmed; For example, when the isolator position is changed to between the left-hand-side collimator and the Ytterbium fiber, the 983.0 nm output is also observed. The pump absorption efficiency with lasing at 983.0 nm is estimated to be 91 % which also smaller than the unsaturated pump absorption efficiency of almost 100 %. The rather low value of saturated pump absorption may enable the laser oscillation near pumped wavelength. If the pump intensity is much larger, the appropriate value of the pump absorption efficiency can be increased. Consequently, the output centered at 983.0 nm is considered to be an Ytterbium laser oscillation. The output centered at 980.6 nm is also observed in same condition by slightly changing the stress to the fiber. The output spectrum is shown in Fig 2 (b). The oscillation spectrum change can be caused by the stress induced birefringence of the fiber. The laser emission wavelengths centered at 980.6 nm and 983.0 nm closer to the pump wavelength of 978.1 nm, leading to extremely low quantum defects of 0.26 % and 0.50 %, respectively.

From the ratio between 978.1 nm power and 983.0 nm power with lasing, the laser output power is estimated as a function of fiber-coupled pump power. The slope efficiency of 983.0 nm output is estimated to be 15 % and the lasing threshold is estimated to be 140 mW for the fiber-coupled pump power. The pump intensity at the lasing threshold is a high value of 460 kW/cm^2. The high pump threshold intensity is attributed to large loss caused by WDM coupler and isolator, both which center wavelengths are 1030 nm. The maximum output power of 983.0 nm lasing is 18 mW at a fiber-coupled pump power of 290 mW.

In conclusion, Ytterbium laser emissions at 980.6 nm and 983.0 nm are demonstrated by laser diode pumping at 978.1 nm with high pumping intensity of around 1 MW/cm^2 at room temperature. The laser emission wavelengths closer to the pump wavelength, leading to extremely low quantum defects of 0.26 % and 0.50 %, respectively. The slope efficiency at 983.0 nm is 15 % and the maximum output power at 983.0 nm is 18 mW. The results may help increasing of the optical efficiency of the radiation balanced lasers [15].

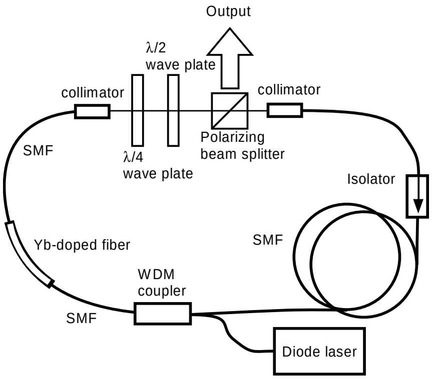

Fig. 1 Ytterbium fiber ring laser.

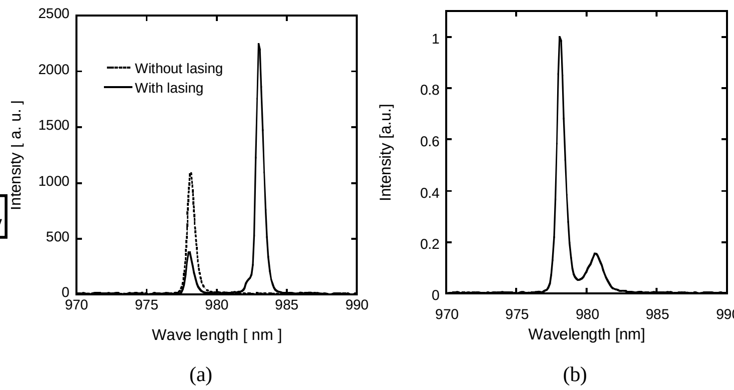

Fig. 2 Emission spectrum of the Ytterbium fiber ring laser. The laser emission center is 983.0 nm (a) and is 980.6 nm (b).

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