Self-polarized ytterbium-doped fiber laser

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We demonstrate a linearly-polarized, ytterbium-doped fiber laser that uses an uncoated, undoped ceramic YAG plate as the output coupler, and the corresponding polarization extinction ratio of laser beam increases with incident pump power and then saturates at larger pump power. For comparison, the output coupler of the fiber laser is replaced by 10% reflectivity plane mirror, while the feature of the polarization of laser output is kept unchanged. The results show that the origin of the pump-dependent and self-started polarization is associated with the intensity-dependent nonlinear birefringence in the gain fiber.

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Fiber laser is known for its potential in providing high-brightness, high-power laser emission. For nonlinear frequency conversion[1−3] and coherent beam combining[3,4], the fiber lasers with single polarization are required. At present, the most widely used techniques to select linearly polarized oscillation of fiber laser include either the combination of polarization-maintaining (PM) fiber and a polarizer inside the laser cavity or the inscription of fiber Bragg grating (FBG) into the PM or birefringent fiber[5,6], but these involved methods bring several disadvantages, such as insertion loss, moderate-power durability, and increased cost.

In this letter, we reported the linearly polarized oscillation of ytterbium-doped (Yb-doped) double-clad fiber laser in the absence of the intracavity polarization-selective element. An undoped and uncoated ceramic YAG was used to provide the output coupling for the fiber laser, and the extinction ratio of the obtained laser beam increased with pump power and then saturated. To investigate the observed self-polarization phenomenon, a comparative experiment was also performed by replacing undoped YAG with 10% reflectivity plane mirror.

The experimental setup is shown schematically in Fig. 1, in which two single-mode-fiber-coupled 976-nm laser-diode (LD) sources were used to pump the 1.7-m-long gain fiber bidirectionally. The gain fiber was multi-mode, Yb-doped double-clad fiber manufactured by Institute National doptique (INO) of Canada with 12.5-μm core diameter, 125-μm hexagonal inner clad diameter, and 250-μm outer clad diameter. The numerical apertures (NAs) of the core and inner clad are 0.15 and 0.35, respectively. The fiber front end is flat and butt against the cavity mirror M1, while its rear end is angle-polished with an inclination angle of 10.7° M1 front surface was anti-reflection coated at 976 nm, while its rear surface was anti-reflection coated at 976 nm and high-reflection coated at signal wavelength for perpendicular incidence. M2 is a plane folding mirror which provides the 45° of deflection for signal light, and its front surface is anti-reflection coated at 976 nm and high-reflection coated within the wavelength range of 1 000–1 100 nm for both the p and s polarizations, and its rear surface was anti-reflection coated at 976 nm for 22.5° incidence. A 0.5-mm-thick uncoated and undoped yttrium aluminum garnet (YAG) ceramic plate was placed as the output coupler which had 8.46% Fresnel reflection at both surfaces. An aperture was applied to select the transverse lasing mode.

In the experiment, the intracavity aperture was adjusted to force only the single-transverse-mode laser oscillation. Figure 2 depicts the relationship between the power (P_{out}) of the obtained laser beam and the incident pump power (P_{in}). It shows that P_{out} is linearly

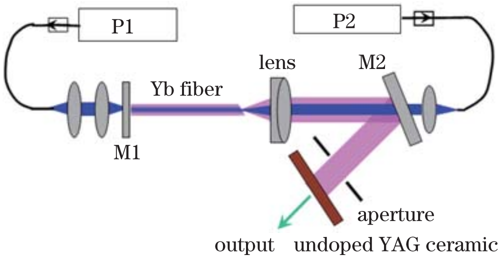

Fig. 1. Experimental setup of the Yb-doped fiber laser. P1 and P2 are 976-nm fiber-coupled LD sources.

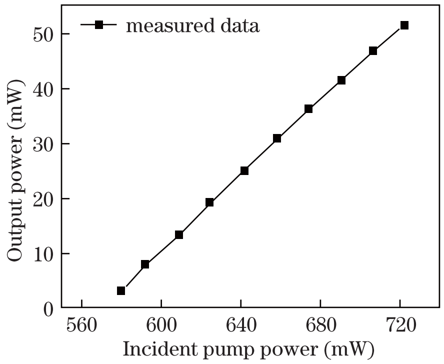

Fig. 2. Measured function relation between the incident pump power and output power of fiber.

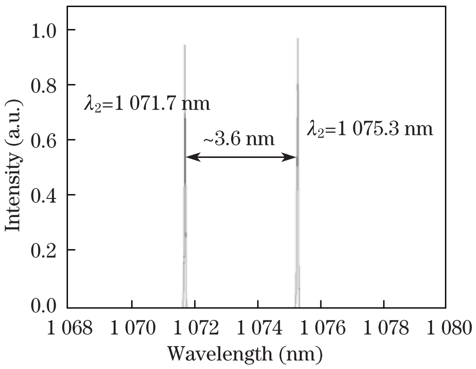

Fig. 3. Emission spectrum of Yb fiber laser at $P_{\rm in}$=625 mW.

proportional to $P_{\rm in}$ with a slope efficiency of 34%. At $P_{\rm in}$=722 mW, 51.4-mW output power is obtained. Figure 3 illustrates the typical output spectrum of the fiber laser at $P_{\rm in}$=625 mW, which revealed that the fiber laser oscillated at 1 071.7-and 1 075.3-nm wavelengths, where the 3.6-nm interval of them was corresponding to free spectrum range of a 159-μm-thick air gap, which originated possibly from the gap between the mirror M1 and the front end of gain fiber.

Before further investigation, it was emphasized that there was not any polarization-selective component inside the fiber laser cavity. Nevertheless one interesting phenomena is the self polarization observed in the obtained laser beam. Figure 4 plots the variation of the laser beam intensity passed through a polarizer analyzer with 625-mW pump power, in which the intensity signal minimized or maximized at every 90° when the angle of polarization analyzer was rotated. This means that the laser output was linearly polarized. Further the polarization direction of obtained laser beam was quite stable. Figure 5 depicts the variations of the polarization extinction ratio (PER) of obtained laser beam as a function of the incident pump power, and it can be seen that the PER of laser beam increased with pump power and saturated at the pump power larger than 660 mW where the maximum value of PER reached 6.1.

To discriminate the origin of this self-polarized laser oscillation, we applied the external disturbance, like extrusion and airflow, to gain fiber. It was observed that the laser beam was still linearly polarized while the polarization direction was sensitive to the surrounding variation of the gain fiber. This test could be initiate evidence that the gain fiber was responsible for the self-polarized oscillation of the laser.

Another particular feature of this fiber laser is the utilization of YAG ceramic plate as the output coupler of fiber laser. This polycrystalline ceramic consists of single-crystalline grains separated by thin boundaries, and the crystallographic axes in each grain are oriented randomly. And thus the ceramic is also isotropic and free from depolarization in the absence of thermal effects. Although the photoelastic effect associated with a temperature gradient can lead to birefringence in both ceramic and single-crystalline YAG, the undoped YAG ceramics applied in our scheme is almost transparent at both the signal wavelength and pumping wavelength.

To exclude the possibility of other mechanism associated with ceramic YAG output coupler in dominating the origin of linearly polarized output of fiber laser, the following investigation was performed. Firstly we replaced ceramic YAG plate by a plane mirror which has 10% reflectivity within the range of 1 030–1 070 nm, while other cavity conditions were kept unchanged. After the fiber laser was adjusted to oscillate, and the function relation ship between the incident pump power and output power was measured as shown in Fig. 6, where $P_{\rm out}$ was linearly proportional to $P_{\rm in}$ with a slope efficiency of 34% and reached 67 mW at $P_{\rm in}$=717 mW.

Further, we applied a linear polarizer to analyze the polarization state of emitted laser beam. Figure 7 plotted the variation of the laser beam intensity passed through

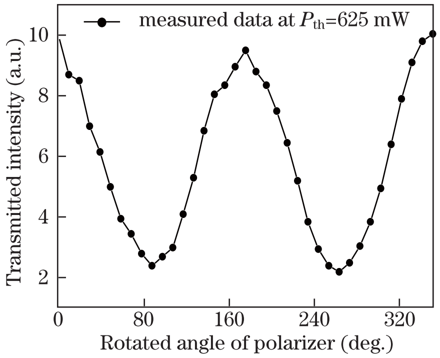

Fig. 4. Intensity of the laser beam transmitted through the polarizer at different rotation angles of the polarizer.

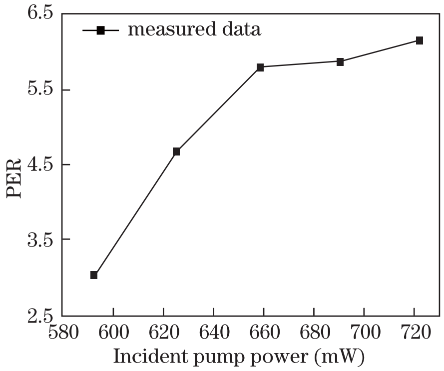

Fig. 5. PER of laser output as a function of pump power when applying an undoped YAG as output coupler.

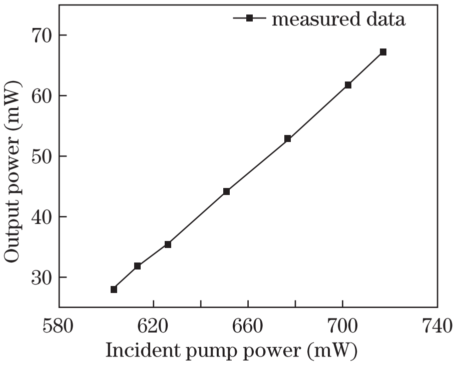

Fig. 6. Measured output power of fiber laser as a function of incident pump power when applying R=10% output coupler.

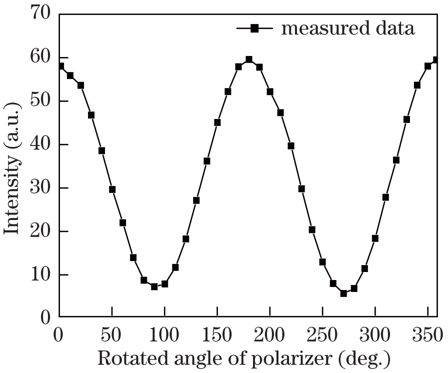

Fig. 7. Transmitted intensity of the laser output through the polarization analyzer when analyzer is rotated.

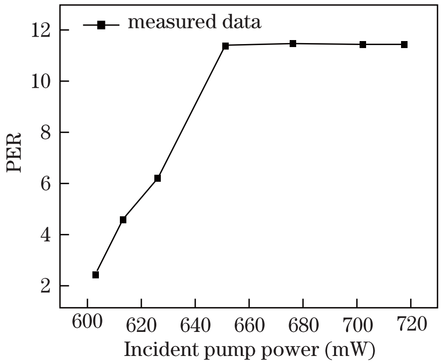

Fig. 8. PER value of fiber laser output as a function of the pump power when applying R=10% output coupler.

a polarizer analyzer at P_{in}=651 mW when the analyzer was rotated. It verified that the fiber laser was linearly polarized when applying a 10% reflectivity plane mirror as output coupler, and the undoped YAG ceramic plate was not the origin of linearly polarized output of the fiber laser. Simultaneously, the function relation between the PER of obtained laser beam and the incident pump power are depicted in Fig. 8, it is clearly seen that the PER of laser beam increased with pump power and reach a constant value of 11.5 at P_{in} >651 mW.

And now, we can see the behaviors of the polarization state as well as the PER of obtain laser beams when applying undoped YAG or 10% reflectivity plane mirror were quite identical to each other, thus it can be concluded that the Yb-doped gain fiber used here is the only factor responsible for the linearly polarized laser output. The pump-dependent PER of the laser beam, as shown in Figs. 5 and 8, revealed that the gain fiber possessed an intrinsic, pump-intensity-dependent nonlinear birefringence which had broken the circular symmetry of gain fiber into a unique axis of symmetry, and this property enabled the gain fiber to act as an intracavity polarizer.

In conclusion, we demonstrate an Yb-doped fiber laser with utilizing an uncoated, undoped and ceramic YAG as output coupler. This fiber laser is in the absence of intracavity polarization-selective component, the laser output was linearly polarized. The PER of laser beam increases with incident pump power and then saturates at large pump power. The origin of the pump-dependent polarized output in this Yb-doped fiber laser is associated with the self-induced and pump-dependent nonlinear birefringence in the gain fiber.

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