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Comparison of the polarization dynamics of three different gain fibers in a continuous wave laser oscillator

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ABSTRACT

We experimentally investigate the polarization dynamics of three kinds of gain fiber, the single-polarizing photonic crystal fiber, double clad polarization-maintaining large mode area fiber and double clad large mode area nonpolarizing fiber, in a continuous wave fiber laser oscillator under different initial polarization directions and pumping powers. The comparison results demonstrate that there are some distinguishable differences for the polarization evolutions inside the three kinds of active fibers. The polarization operation status of the fiber oscillator strongly depends on not only the gain fiber's kinds, but also the length of the fiber, initial polarization directions and pumping power. The results suggest that polarization instability in a fiber laser should be an inherent reason for the higher operation noise.

1. Introduction

Polarization control in fiber has attracted wide interests for the novel fiber design, fabrication and application since the invention of fiber [1–4]. This kinds of fibers are classified into two categories by considering polarization characterizations: single polarization fiber (SPZ fiber) [5] and polarization maintaining fiber (PM fiber) [6]. SPZ fiber is like a polarizer by only transmitting one polarization state of light in a certain wavelength range. To this end, elliptical form of the core/cladding [3,7], stress-induced [8,9] or hole-assisted fibers [10,11] were achieved, to eliminate one of two polarization modes to preserve the wanted polarization mode evolution at certain wavelength in the fibers. Compared to the SPZ fiber, PM fiber is known as a polarization-maintaining fiber that can keep two perpendicularly polarized modes transmitted through its length by different propagation constants, resulting in the polarization plane of the light launched into it is maintained. PM fiber can be made by introducing the geometrical birefringence in its shape [12,13] or the stress-applying parts (SAPs) induced birefringence in its internal stresses [14,15]. With the advancement in fiber manufacturing process, especially the invention of photonic crystal fiber (PCF) [16], the SPZ and the PM PCFs have much renewed interest because the highly birefringence can be easily realized in PCFs due to its intrinsic characteristics and fabrication process, which can form the required asymmetric microstructure in core and cladding [17–20].

In practical applications such as light communication, fiber sensors, fiber gyroscopes, fiber devices and fiber lasers, the control of the polarization state is most important. Therefore, a number of experimental studies on the polarization prop-

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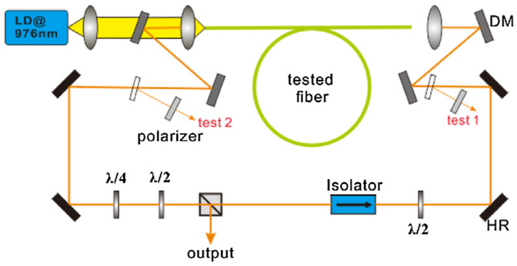

Fig. 1. Experimental: layout of CW testing system: DM, dichroic mirror; HR, highly reflective broadband dielectric mirror; λ/4, quarter-wave plate; λ/2, half-wave plate; PBS, polarization beam splitter.

erties of passive SPZ and PM fibers have been reported elsewhere in the literature [21–24]. In parallel, the polarization dynamics of continuous wave (CW) fiber lasers with active SPZ and PM fibers have also been investigated [25–28]. It has been proved that the devices and the lasers with SPZ or PM fibers are expected to be to a large extent insensitive against environmental fluctuations than that with the non-polarization single mode fiber. Furthermore, in mode-locked fiber lasers, the polarization-state locking is more important concerned with the stability of mode-locking operation [29,30]. Especially, for nonlinear polarization evolution (NPE) [31] mode-locking, the Kerr nonlinearity differential excitation of the two polarization modes of a fiber generates a nonlinear rotation of the polarization state that depends on the pulse intensity. It is believed that the nonlinear polarization effect must be stronger than the linear polarization effect in the fibers for NPE mode-locking so that the fibers are generally the non-polarization or weakly birefringence [32,33]. Although the polarization dynamics of vector solitons in active birefringent fibers have already been investigated theoretically and numerically [34,35], the experimental observations on the polarization dynamics of the pulses propagation in laser are always round-trip whole laser cavities rather than going through the single gain fiber [36,37]. However, the polarization states evolution of laser in the cavities is usually different from that of the propagation only in fibers, due to the interreaction with the cavity polarization components. It is important to understand how the polarization states evolution is in the active fiber in a laser, but it has not been addressed yet.

In this paper, we conducted a comparison experiment of the polarization states evolutions in three commercial types of Yb-doped fibers, i.e. large mode area (LMA) SPZ-PCF, double clad LMA-PM fiber and double clad non-polarization (NPZ) fiber, with a CW fiber laser oscillator under different pumping powers and initial polarization directions. The distinguished results demonstrate that polarization operation status in the active fibers is dominated not only by the fiber's structure and parameters but also by the length of fiber, the initial polarization and the pumping power. The output power of laser via the polarization states evolutions in these gain fibers are described in detail. It is shown that the linear birefringence of active fibers' impact on the operational status of laser, which suggest that polarization instability of fiber lasers should be an inherent reason for the higher operation noise than that of bulk solid laser. All the results would be helpful for the design and development of polarization stable fibers and fiber lasers.

2. Experimental setup

A schematic diagram of the experimental setup is given in Fig. 1. The laser is pumped by a laser diode (LD) with a central wavelength of 976 nm, which is coupled into the tested gain fiber with two aspherical optical lenses. An isolator in the laser cavity ensures the unidirectional operation of the laser. The quarter-wave plate (QWP) before the isolator modifies the output laser's polarization state. The half-wave plate (HWP), together with the polarization beam splitter (PBS), acts as an output component of the laser cavity, and adjusting it makes sure the largest output of the laser. The other HWP after the isolator enables us to change the polarization direction of laser entering the gain fiber. To investigate the polarization dynamics in the gain fibers, two thin wedges are inserted into both ends of gain fiber for drawing off the incident and transmitted laser beams (labelled as test 1 and 2) after two dichroic mirrors to filter the pump light, respectively. A polarizer (Thorlabs, LPNIR050), with a polarization extinction ratio >100000:1 at 1040 nm, is placed both in the output positions of test 1 and 2, as a polarization analyzer to examine the polarization states of the incident and emitted laser. In the experiment, the polarization direction of incident laser is changed by manually rotating the HWP after the isolator, and then the maximum output from PBS output port is obtained by adjusting the set of QWP and HWP before PBS. At the meantime, the polarization states at the positions of test 1 and 2 are checked and recorded.

Three kinds of tested active fibers used in the experiment are commercial types of Yb-doped fibers, and their information and cross-sections are showed in Table 1 and Fig. 2, respectively.

All the end surfaces of the test fibers are grinded to an angle of 7° to suppress the self-oscillation. All the fibers are coiled with a diameter as large as 35 cm, keeping a horizontal orientation of the plane of SAPs without any twist. During the comparison experiment, it must be paid attention that laser configuration and experimental parameters remain unchanged but the tested gain fiber is replaced.