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2.5-kHz Linewidth, Single-Frequency and Polarization-Stable Fiber Fabry-Perot Laser using a Non-Polarization-Maintaining Fiber and an Intracavity Etalon

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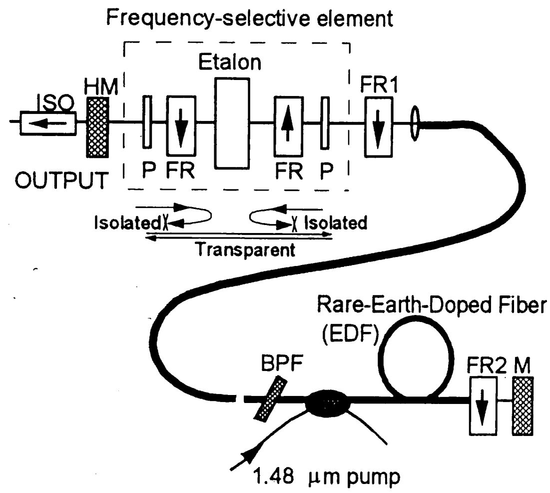
Abstract: We investigate CW oscillation characteristics of an Erbium-doped fiber laser having a newly designed cavity structure. Polarization-stable single-mode operation with a linewidth less than 2.5kHz was achieved by using a non-polarization-maintaining fiber.

Introduction: Rare earth-doped fibers provide us with compact and efficient lasers in the wide spectral range from visible to near infrared regions. However, the narrow longitudinal-mode spacing and the polarization-mode competition inherent in fiber lasers prevent the realization of stable CW operation.

To overcome these difficulties, we proposed a novel configuration for the single-mode, polarization-stable fiber laser using a non-polarization-maintaining active fiber and confirmed the principle of operation by using an Erbium-doped fiber [4]. In this paper, we report the fundamental CW oscillation characteristics of the proposed laser. Stable single-mode operation is maintained even in the free running state. In such stable state, the spectral linewidth less than 2.5kHz is achieved.

Cavity Design: Figure 1 shows the newly designed cavity structure of the laser. The Fabry-Perot(FP) cavity is constructed between two Faraday-Rotator mirrors. The state of polarization of the light reflected from a Faraday mirror is orthogonal to that of the incoming light at any position on the return pass. Therefore, the eigenstate of polarization is determined uniquely by the frequency-selective element acting as a polarizer even if any birefringence exists in the active fiber[1][2]. In addition, such orthogonality in polarization between counter-propagating lights eliminates the standing wave inside the cavity, resulting in the suppression of spatial-hole burning, which is helpful to improve the longitudinal mode stability.



M:	Mirror (100%)	HM:	Half Mirror
FR:	45deg Faraday Rotator	P:	Polarizer
BPF:	Tunable filter (0.7nm)		

Figure 1: Configuration of the proposed laser

The frequency-selective element indicated by the broken line in Fig.1 is designed so as to suppress the reflection from the etalon. In conventional FP lasers, the intracavity etalon should be tilted from the optical axis; otherwise the reflection from etalon causes spurious oscillation. However, the tilt of the etalon degrades the finess, resulting in poor mode selectivity.

In the present system, the light returned from the etalon experiences Faraday rotation by 90° while traveling between the polarizer and the etalon facet, and is blocked by the polarizer. On the other hand, the light within the passband of the etalon can go through in both directions. Therefore, the etalon can be used in the Fabry-Perot cavity without tilting, and its mode selectivity is maximized.

Experiment: We constructed an Erbium-doped fiber(EDF) laser as shown in Fig.1. The EDF is about 2m long. The etalon has free spectral range (FSR) of

10GHz (0.08nm) and finess of >95. The tunable bandpass filter with 0.7nm passband is inserted in front of the etalon for coarse tuning of the wavelength. The total cavity length is about 6m and the corresponding mode spacing is 16MHz.

First, we measured the optical spectrum both by a double-monochromator (resolution: 0.05nm) and an optical heterodyne receiver (resolution: 1MHz). The measured single-peak spectra assure the single longitudinal mode oscillation of the laser. The linewidth was measured by the delayed self-heterodyne setup, where the delay-line length was 40 km and the frequency resolution was 2.5kHz. Figure 2 shows the measured spectrum. The fullwidth of the spectrum is 5kHz, and the laser linewidth is estimated to be less than 2.5kHz. In Fig.2, we can also observe the small peaks near the main peak, which may be attributed to the relaxation resonance of the laser.

Next, we evaluate the frequency stability of the laser by heterodyne detection. The local oscillator, which is regarded as a frequency reference, is an external ring-cavity semiconductor laser. The linewidth is 50kHz, and its frequency drift is maintained within 1GHz/hour. Figure 3 shows the beat frequency between the laser under test and the local laser measured as a function of time. Circles show the main peak frequency of the beat signal, while crosses the second peak frequency when two-mode oscillation occurs. As shown in Fig.3, the single-mode operation is maintained for 3 to 8 minutes without active control of the optical path length.

Note that the laser frequency jumps by 62MHz on each occasion of mode hopping. This frequency step corresponds to four mode spacing, and is roughly equal to the full width of the passband of the etalon. The mode hopping is caused by either the drift of the longitudinal mode frequency of the cavity or the drift of the center frequency of the etalon; however, the reason why the oscillation mode does not hop to its adjacent mode is still unknown.

Conclusion: We demonstrated the single-mode and polarization-stable fiber FP laser composed of non-polarization-maintaining Erbium-doped fiber. Stable single-mode oscillation was achieved without active control of the optical path length. In such a stable state, the linewidth was less than 2.5kHz. We believe that the single mode operation without mode hopping can be realize by adding a feedback circuit to control the optical path length.

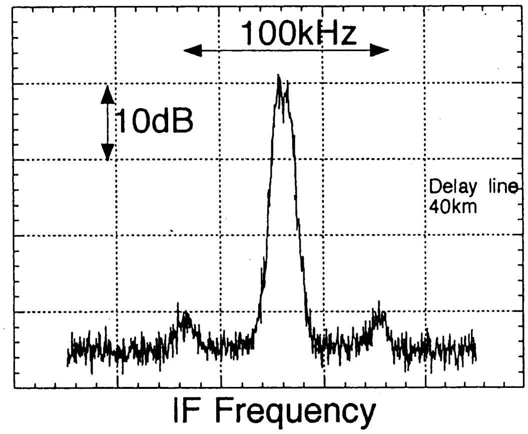


Figure 2: Delayed Self-Heterodyne spectrum

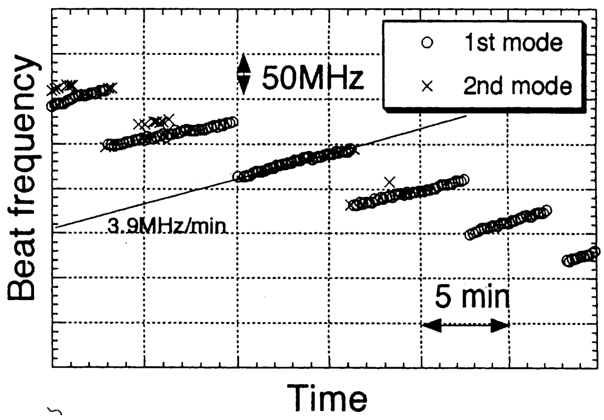


Figure 3: Frequency drift of the laser under test measured by heterodyne detection.

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