All fiber, low threshold, widely tunable single-frequency, erbium-doped fiber ring laser with a tandem fiber Fabry–Perot filter

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An all fiber, widely tunable, single-frequency, erbium-doped fiber ring laser was constructed with a threshold pump power as low as 10 mW. Tuning over more than 30 nm was obtained by applying 0 to 17 dc V to an intracavity fiber Fabry–Perot filter. Threshold pump power versus wavelength data showed low variation over the tuning range. Mode hopping suppression with a tandem fiber Fabry–Perot filter is proposed and demonstrated. Stable single-frequency operation was demonstrated with side mode suppression higher than 35 dB.

Single-frequency, widely tunable laser operation at the 1.5 μm window has potential applications in optical coherent communication systems. Due to its narrow linewidth and inherent compatibility with optical fiber, the erbium fiber laser is a promising candidate for use in these communication systems and has received considerable attention recently. Most efforts on the fiber laser, to date, have employed discrete optical components as part of the system. These systems suffered from either large cavity loss (thus large threshold pump power),[1,2] small tuning range,[3,4] or severe mode hopping. Recently, a temperature compensated, electronically tunable fiber Fabry–Perot (FFP) filter was reported with low insertion loss and high finesse.[5] Here we demonstrate an all fiber, electronically tunable (1530–1560 nm with 0–17 dc V), single-frequency erbium-doped fiber ring laser with a fiber Fabry–Perot wavelength selective element. Use of the fiber Fabry–Perot filter leads to improved threshold performance (<10 mW, 980 nm pumping) as compared to other wavelength tuning approaches demonstrated to date.

Figure 1 shows the experimental setup. For the first part of our experiment, we investigated the behavior of our laser with a single broadband FFP (without the inset in Fig. 1). The 980 nm output of a titanium:sapphire (or diode) laser was coupled through a wavelength division multiplexer for the pumping source. The coupling efficiency was 50% and more than 60% of the pump power was absorbed after the 4.5-m-long piece of aluminum-codoped erbium fiber (BT&D, 50 ppm, 5 μm core diameter). A pig-tailed polarization-dependent isolator (isolation 35 dB) was used to prevent spatial hole burning caused by bidirectional operation for more stable single-frequency operation. The isolator also served to block feedback from the output port of the system. A polarization controller (PC) was used to match the polarization state to the input polarization of the isolator. The polarization-dependent isolator and polarization controller can be replaced by a polarization-independent isolator. The wavelength selective element was a broadband fiber Fabry–Perot (FFP) filter with a 26.1 GHz (0.196 nm at 1.5 μm) bandwidth (FWHM) and a 4020 GHz free-spectral range (FSR). The total cavity loss was estimated to be less than 6.5 dB from a small-signal gain measurement and threshold data. The specific sources of loss were 2.5 dB from the FFP, 1 dB from the isolator, 1 dB from the wavelength division multiplexer and coupler, and 2 dB from mode mismatch and splice losses between the erbium fiber and other devices. To provide some amount of isolation from acoustic noise, the entire system was placed inside a styrofoam box. The threshold was ~10 mW. The cavity length was 15 m corresponding to a free-spectral range (FSR) of 14 MHz for the laser.

The laser output was coupled to a 50/50 coupler at 1550 nm to enable simultaneous monitoring of the lasing spectrum using both a high-resolution scanning Fabry–Perot interferometer and a grating monochromator to determine the lasing wavelength. Figure 2 shows a lasing spectrum taken using the scanning Fabry–Perot Interferometer (Newport Research Super-Cavity SR-170 FSR 6 GHz). This device has a resolution of 1 MHz, which is sufficient to resolve the 14 MHz FSR of the ring laser longitudinal modes. The smaller peaks in the picture are caused by the weakly excited transverse Fabry–Perot modes of the supercavity device. Tuning was possible by changing the voltage on the FFP thus scanning the center

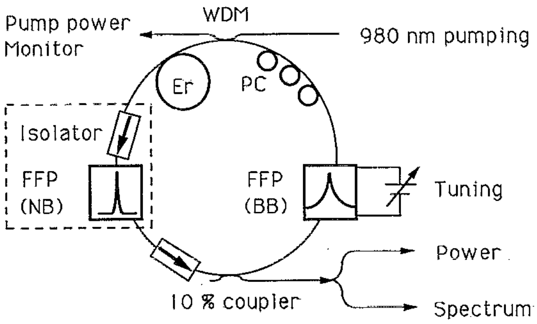

FIG. 1. Ring laser configuration (WDM: wavelength division multiplexer, NB: narrow band, BB: broadband, FFP: fiber Fabry–Perot filter, PC: polarization controller).

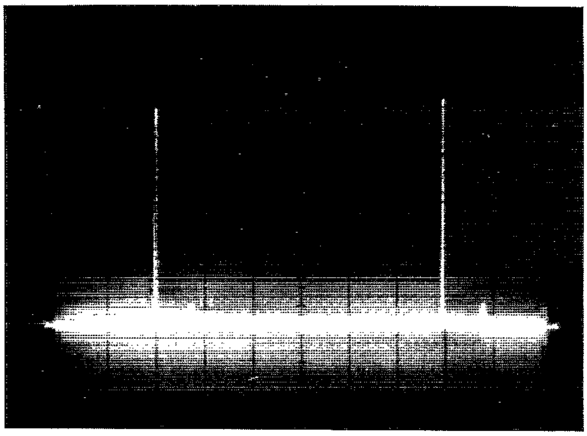

FIG. 2. Lasing spectrum obtained from scanning the supercavity Fabry–Perot interferometer (1 GHz/Div, FSR = 6 GHz, resolution 1 MHz). The smaller peaks (800 MHz away from the main peaks) are transverse modes from the supercavity Fabry–Perot interferometer.

frequency of FFP over a different longitudinal cavity mode of the ring laser. The PC was adjusted for polarization compensation to prevent frequency pulling and hopping.[1,2] Figure 3 shows the tuning curve as a function of the PZT applied voltage. Tuning over 30 nm (corresponding to the FFP filter FSR) between 1530–1560 nm was possible by applying 0–17 dc V. The tuning range is believed to be limited only by the FSR of the FFP filter. After 17 V, it retraced the wavelength at zero applied voltage. Single-frequency operation was observed for periods as long as several seconds although there existed mode hopping under an envelope on the order of 1 GHz, presumably due to cavity instabilities from thermal drift and acoustic noise.[6] Frequency stability was better when using the diode laser pump. We attribute this to gain fluctuation in the erbium fiber due to the pumping source frequency fluctuation,[7] which was more evident in our titanium:sapphire laser.

Figure 4 shows threshold pump power versus wavelength. Threshold pump power was between 8.8 and 10.4 mW, and the slope efficiency was between 2.3% and 2.6%. The data exhibit low variation (< 1 dB) over the entire tuning range. Gain shaping with an additional filter could be applied to further reduce the variation.[8] We attribute the weak periodic modulation of 0.2 dB which appears in the data to the fiber birefringence induced loss which originates from the fiber birefringence combined with the polarizer in the optical isolator.

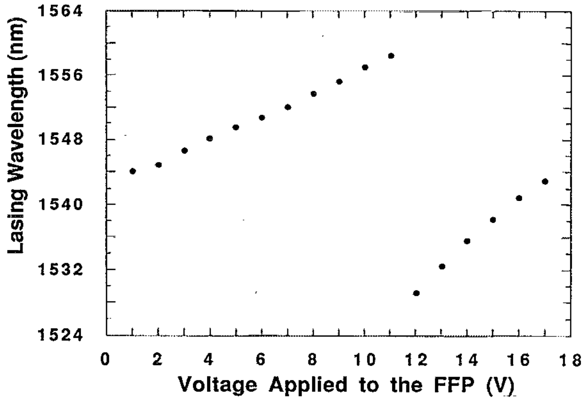

FIG. 3. Lasing wavelength as a function of the voltage applied to the FFP.

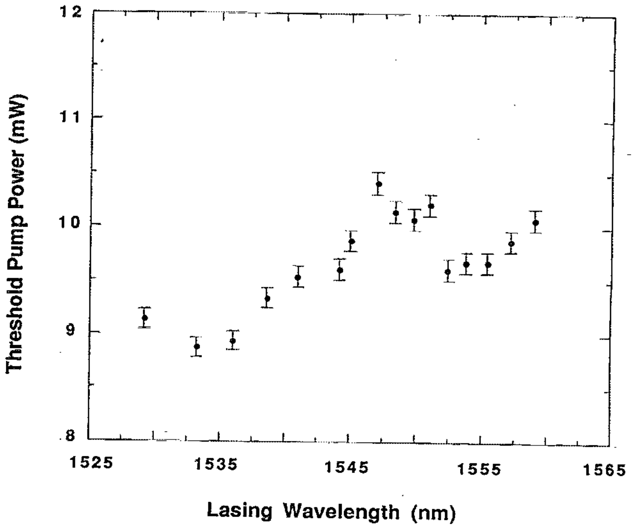

FIG. 4. Threshold pump power at various lasing wavelengths.

To investigate the mode hopping behavior, another FFP with a smaller bandwidth (1.39 GHz, 0.01 nm at 1550 nm, insertion loss 2.5 dB max) was placed in the cavity (see inset in Fig. 1). The measured threshold pumping power was around 14 mW with the tandem FFP. To prevent interétalon interactions, a polarization-independent isolator was introduced between the two FFP filters. These interactions were observed to produce additional mode hopping. With the isolator in place, the resulting transmission function from this tandem FFP filter can be considered as the product of two independent transmission functions of FFP filters. Tuning was possible over the gain spectrum with 1 nm intervals corresponding to the FSR of the smaller bandwidth FFP. Mode hopping was completely suppressed. Instead, the lasing mode was observed to slowly drift until, after several minutes, oscillation would jump to an adjacent longitudinal mode. The sidemode suppression ratio was measured by detecting the output using a high-frequency photodiode and then analyzing the photocurrent using a microwave spectrum analyzer. The measured sidemode suppression was higher than 35 dB.

We have demonstrated an all fiber, widely tunable, single-frequency, erbium-doped fiber ring laser using commercially available components. The laser was electronically tunable between 1530–1560 nm with a dc voltage source of 0–17 V. The laser has a low threshold pump power (< 10 mW) as well as low variation (< 1 dB) in its threshold pump power and output power over the tuning range. Complete suppression of mode hopping was achieved using a tandem FFP filter. Single-frequency operation stable for a period of several minutes was observed using this approach. This level of stability is, to our knowledge, the best reported to date. The measured sidemode suppression was higher than 35 dB. Further system improvement should be possible with optimization of cavity lengths and FFP design.

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