Fiber-distributed feedback lasers for high-speed wavelength-division multiplexed networks

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Published in:
Optical Fiber Communications, 1996. OFC ’96

Link to article, DOI:
10.1109/OFC.1996.907633

Publication date:
1996

Document Version
Publisher's PDF, also known as Version of record

Link back to DTU Orbit

Citation (APA):
ber-coupled microchip laser. The polarization asymmetry was measured over a 16 h period and demonstrates excellent stability.

Operation of a miniature, monolithic Nd:YAG laser in two orthogonal polarization states has been previously observed and the frequency splitting between the two states was adjusted from ~300 MHz to 3 GHz by the application of stress. We use a similar technique in this work to adjust the frequency difference between the two polarization states of a microchip laser from 100 to 500 MHz. The microchip laser was isolated with a 60-dB polarization-independent isolator and coupled to a SMF. The power in each polarization state was >60 mW. Each polarization state lased in ~3 longitudinal modes, which minimizes the effects of SBS by dividing the launched power into several frequencies.

We have found that the polarization asymmetry could be optimized by adjusting the temperature of the microchip with a thermoelectric cooler. The polarization asymmetry is defined as \( \frac{I_{\text{min}} - I_{\text{avg}}}{I_{\text{max}} + I_{\text{avg}}} \) where \( I_{\text{max}} \) is the maximum and \( I_{\text{min}} \) is the minimum transmission of the output of the SMF through a polarizer while the SMF was subjected to a range of mechanical stresses. The mechanical stresses emulated the random phase variations that would occur over several kilometers of fiber (which we did not have available to us). The polarization asymmetry is shown in Fig. 1 as a function of the thermoelectric cooler temperature and can be seen to have a minimum value of very nearly zero. Figure 2 shows the polarization asymmetry measured over a 16 h period and demonstrates the excellent stability of the polarization ratio.

In conclusion, we have constructed a dual-polarization microchip laser, which provides greater than 60 mW in two orthogonal polarizations. The microchip laser was coupled to a SMF through a 60-dB polarization-independent isolator and a stable polarization asymmetry of ~0 was obtained using temperature tuning. Results of experiments using this laser to drive a remote Li:NB\(_2\)O\(_4\) modulator will be presented.


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**Fiber-distributed feedback lasers for high-speed wavelength-division multiplexed networks**

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Single-mode distributed feedback (DFM) erbium-doped fiber lasers, based on directly UV-written Bragg gratings in fibers were demonstrated recently.\(^1\) A \(\pi/2\) phase-shift, introduced in the central part of the structure, results in robust single-longitudinal-mode operation with high stability and low lasing threshold. These characteristics combined with optical fiber compatibility, compact size, and wavelength stability make fiber DFB lasers highly attractive sources for externally modulated high bit-rate\(^2\) and wavelength-division multiplexed (WDM) systems.

The fiber DFB lasers, used in this experiment, were fabricated by UV exposure of a highly photosensitive erbium-doped fiber through a phaseshadeck. The central part of the grating was illuminated by additional UV radiation, resulting in the permanent \(\pi/2\) phase shift required to achieve the single-frequency operation.\(^3\) The grating length was typically ~3.5 cm with a reflectivity of ~20 dB. The erbium-doped fiber, produced by Lycom A/S, has a dopant concentration of 1.5 \(\times 10^{20}\) m\(^{-3}\), a core diameter of 4 \(\mu\)m, and a numerical aperture of 0.27. We fabricated two lasers with operating wavelengths of 1533 nm and 1547 nm. They yield a stable single-mode output with linewidth of 15 kHz and signal power of ~20 \(\mu\)W at 50 mW of launched pump power at 1480 nm. A signal power of 5.4 mW can be achieved by absorbing the residual pump power in a subsequent length of erbium-doped fiber.\(^4\) Furthermore, for WDM systems and sensor applications, two or more lasers with different signal wavelengths can be connected in series.

We used bit-error-rate (BER) measurements to evaluate the performance of our fiber DFB lasers (Fig. 1). The measurements were performed at 2.488 Gbit/s using a NRZ 2\(^{21}\) - 1 pseudo-random bit sequence. First we measured BER curves for a single-fiber DFB laser (DFB 1) both back-to-back and through 30 km of standard fiber. After that, we spliced two fiber DFB lasers together (Fig. 1, with DFB 2 included) and measured a back-to-back BER curve. These measurements are shown in Fig. 2 and indicate no power penalty.

We improved the setup by inserting a polarization controller in front of the optical bandpass filter. This setup was used to compare our fiber laser with a commercial semiconductor DFB laser by measuring back-to-back BER curves (Fig. 3). Both lasers behaved similarly, demonstrating the fiber DFB lasers as very stable sources for high-speed WDM systems.
TuJ2 Fig. 1. Experimental setup for 2.488 Gbit/s BER measurements of DFB lasers.

TuJ2 Fig. 2. BER curve for single- and dual-fiber DFB lasers, including 30-km standard single-mode fiber experiment.

TuJ2 Fig. 3. BER curve and eye diagrams comparing the fiber DFB laser to conventional semiconductor DFB laser. Eye diagrams were obtained at -17 dBm of received signal power.

In conclusion, we have demonstrated that fiber DFB lasers constitute an excellent alternative to commercially available semiconductor DFB lasers. We have also shown that two fiber DFB lasers can be spliced together without any BER power penalty. Therefore, we suggest the possibility of using a single pump source for pumping a WDM laser array consisting of a number of fiber lasers spliced in series.


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