Abstract: We propose a new broadband light source (BLS) based on the mutual injection between two AR-coated F-P LDs. We demonstrate colorless operation of WDM-PON by using the proposed BLS and Manchester coded data.

The passive optical network (PON) based on wavelength division multiplexing (WDM) has been investigated for fiber-to-the-home (FTTH). The WDM-PON is very attractive to provide almost unlimited bandwidth to the subscribers with the protocol and the bit rate transparency. However, implementation of WDM-PON requires a cost-effective WDM source. Recently, the wavelength locked Fabry-Perot laser diode (F-P LD) with external spectrum sliced broadband light injection was proposed [1]. It is very effective solution to reduce the installation and management costs using wavelength independent operation of the optical network termination (ONT). In implementing the wavelength locked F-P LD, we can use a light emitting diode (LED), a superluminescent diode (SLD), or an amplified spontaneous emission (ASE) source based on EDFA as a broadband light source (BLS). The LED doesn’t have enough output power and the others are expensive solution even though they can provide much higher output power compared with the LED.

In this paper, we propose and demonstrate a cost-effective BLS by using mutually injected AR-coated F-P LDs. We also demonstrate WDM-PON with the wavelength locked F-P LDs by injecting the proposed BLS as an injection source. We use Manchester coded data to have the wavelength independent operation of an ONT.

The proposed BLS is shown in dotted box of Fig. 1. It consists of two AR-coated F-P LDs, a 50:50 optical coupler, and two isolators. The reflectivity of the front facet and the mode spacing of the F-P LDs are 1% and 100 GHz, respectively. The fiber length between the two F-P LDs is 50 cm. We realized an unpolarized BLS by polarization multiplexing with two polarization controllers (PCs) and a polarization beam splitter (PBS). Fig. 2(a) shows the measured optical spectra of the F-P LD 1 and 2 without mutual injection. By mutual injection between the two F-P LDs, the 3 dB linewidth broadens up to 0.2 nm. The output spectrum of the mutually injected F-P LDs looks like the spectrum sliced broadband light as shown in Fig. 2(b). The center wavelength of gain envelope was shifted toward the long wavelength compared with individual F-P LD. It results from the decrease of threshold current because of mutual injection between two AR-coated F-P LDs.

To investigate feasibility of the proposed light source as a BLS, we measured the relative intensity noise (RIN) and compared it with a conventional BLS based on EDFA as shown in Fig. 2(c). A filtered single mode of the AR-coated F-P LD shows higher RIN than the spectrum sliced ASE because of mode partition noise. That was suppressed considerably by the mutual injection, although there exists 1/f noise component within a few MHz region. We measured the almost same RIN characteristic from all modes of mutually injected laser output whose power is within 10 dB from the peak intensity. The achieved RIN is considerably lower than RIN of the spectrum sliced ASE. Here, we match the 3-dB bandwidth of two BLSs, i.e., the spectrum sliced EDFA output and a single mode output from the proposed BLS.
Since the proposed BLS has 1/f noise within a few MHz range as shown in Fig. 2(c), it is better to use a modulation format that has no signal component within a few MHz range. The Manchester coded data has no signal component near at low frequency including dc as shown in Fig. 2(d). We also measured the electrical spectra of the NRZ signal and the proposed BLS for comparison.

The experimental setup to investigate wavelength-locking characteristics of the F-P LD with injecting the proposed BLS is shown in Fig. 1. The BLS output was amplified by an EDFA and it was filtered by an AWG. Then, it was injected into F-P LD at ONT. The F-P LD has 0.6 nm of mode spacing and 1% AR coating at the front facet. We use another AWG at central office (CO) to simulate optical demultiplexer. The channel spacing of the AWG is 100 GHz and the transmission distance is 20 km of a standard single mode fiber. The F-P LD was modulated with the NRZ data or the Manchester coded data. For the latter case, we used a band-pass filter (BPF) at the receiver to remove the 1/f noise part in the transmitted signal. The low frequency cut-off of BPF was optimized at 0.8 MHz for the best sensitivity of the optical receiver.

To investigate effects of the Manchester coding, we compared BER performance with the NRZ data. For both modulation formats we maintain the signal data rate at the same rate of 100 Mb/s, i.e., the transmitted bit rate of the Manchester coded data is 200 Mb/s. By sweeping the wavelength of LD mode with the temperature tuning, we can find the best BER and the worst BER under a fixed LD bias and a constant injection power. Here, we inject the BLS power that is 7 dB above the required injection power for the error-free transmission at the best BER case.

In the case of Manchester coded data, the measured spectra of the wavelength locked F-P LD at the best BER and the worst BER condition with the injection power of -13 dBm are shown in Fig. 3. Manchester coded data shows the error-free transmission even at the worst BER as shown in Fig. 4. The power penalty between the best case and the worst case is about 2 dB. Thus it is possible to have a wavelength independent operation with the proposed BLS provided by the Manchester coded data. However, 100-Mb/s and 200-Mb/s NRZ data shows error-floor at 10^{-6} BER level at the worst case with the injection power of -11 dBm and -4 dBm, respectively.

To demonstrate upstream transmission for WDM-PON, we use 3-channel (1560.6 nm ~ 1562.2 nm) with 100-GHz channel spacing. The F-P LDs at ONTs were modulated with the 100-Mb/s Manchester coded data. The injection power into F-P LDs is about -13 dBm. Then, the signal output power is -4 dBm, i.e., we obtain 9 dB fiber to fiber gain, when the injection wavelength is close to a lasers mode of the FP-LD. We measured the influence of crosstalk by adjacent channels in WDM transmission. As shown in Fig. 5(a) and (b), there is no crosstalk inducing the penalty.

When we consider 12 dB link loss (fiber loss of 6 dB (0.3 dB/km x 20), AWG loss of 5 dB and circulator loss of 1 dB), the required BLS power for 32-channel WDM-PON can be estimated to be about 14 dBm (-13 dBm (required injection power) + 12 dB (link loss) + 15 dB (for 32 channels)). The required bandwidth of the BLS will be 26 nm for 100 GHz channel spacing. It can be realized with the high power F-P LD with the broad gain spectrum.

In conclusion, we proposed and demonstrated a new BLS based on mutually injected AR-coated F-P LDs. We showed the wavelength independent operation of ONT with Manchester coded data. Therefore, the proposed BLS will be very useful to realize a cost effective WDM-PON. We demonstrated 3-channel WDM upstream transmission based on the wavelength locked F-P LDs with injection of the proposed BLS. Therefore, the proposed BLS will be very useful to realize a cost effective WDM-PON.

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References