Upstream signal transmission using a self-injection locked Fabry-Perot laser diode for WDM-PON

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Abstract. We present an upstream transmission method independent of temperature characteristics of the remote node (RN) in a WDM-PON. This method employs a self-injection locked Fabry-Perot laser diode (F-P LD) for upstream transmission in the optical network unit (ONU). Using this method, the sidemodes of the F-P LD are suppressed, and the F-P LD is matched to the center wavelength of the wavelength distributor/combiner placed at the RN. The experimental results confirm that bidirectional error-free transmission at 1.25/10 Gbit/s could be achieved. [DOI: 10.1117/1.1920069]

Subject terms: optical communications; injection locked optical source; optical subscriber loop; passive optical networks.

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1 Introduction

A wavelength-division-multiplexing passive optical network (WDM-PON) is attractive for the near-future optical access networks because it provides low-cost maintenance, large bandwidth, and high security.[1,2] There have been many efforts to reduce the installation cost either at the unpowered remote node (RN) or by the optical source.[2–6] A wavelength distributor/combiner in the RN, such as a waveguide grating router (WGR) is a prerequisite in a WDM-PON for distribution of downstream information carried on discrete wavelengths. The dependence of such devices on temperature is harmful to the stable operation of a low-cost bidirectional WDM-PON because it results in misalignment in the optical path of downstream and upstream directions.[1–4] Various approaches to reduce this undesirable effect have been tried, including wavelength tracking, spectrum slicing of a broadband light source,[2,3] loop-back method,[4] and remodulation technique.[5] However, these techniques mostly control the upstream wavelengths with the information from the downstream wavelengths and therefore are likely to lose the control in the case of downstream signal failure. Furthermore, a lot of research work for athermal technology of the WGR has been done.[6] However, the fabrication problems yet remain to be solved.

This paper proposes and experimentally demonstrates a self-injection locking method for upstream transmission on a WDM-PON with unpowered RN for urban areas.

2 Self-Injection Locking

Fiber Bragg gratings (FBGs) are added to the fan-out ports of the WGR in the RN as shown in Fig. 1. The resonance wavelength of each FBG is selected for matching to the corresponding upstream port of the WGR (i.e., the wavelength of the upstream signal). Then, the light generated by the unisolated F-P LD is reflected at the FBG, re-enters the F-P LD, and becomes self-injection locked. Because the temperature sensitivity of FBGs is almost the same as that of a WGR or silica-based planar-Bragg grating,[4] the upstream wavelength of the F-P LD can be self-tuned to the peak wavelength in the upstream passband of the WGR even in the presence of temperature fluctuation. Furthermore, a single F-P LD can be used for several ONUs since a F-P LD has a broadband spectral gain.

3 Experimental Results and Discussions

The proposed WDM-PON architecture is shown in Fig. 1. The RN, 20-km fiber away from the OLT, is implemented with a 1×32 WGR (1529.42–1554.22 nm with 100-GHz channel spacing, 3-dB bandwidth of 0.4 nm) without any active control functions (i.e., not temperature-controlled). The upper 15 ports (λ_{17} to λ_{31}) are used for downstream channels, while the other 15 ports (λ_1 to λ_{15}) are used for upstream channels. For downstream signal detection, a wavelength selective coupler (WSC) is used and has an isolation of more than 30 dB, enough to separate upstream channels. The sixteenth port (λ_{16}) is reserved for the monitoring channel (λ_M).

For self-injection locking, the FBG with resonance peak depth of -19.07 dB (98.76% reflectivity), together with the 0.32 nm FWHM, is added to the WGR. The dominant peak wavelength of the F-P LD is 1529.5 nm. The active region of the F-P LD used has the typical dimensions, 300 μm length, 1 μm thickness, and 3 μm width. Therefore the mode spacing is about 1.05 nm (the mode index of the gain medium is 3.54 at 1550 nm). The coating ratios of the front and rear facets of the F-P LD are 1% antireflection (AR) and 90% high-reflection (HR), respectively. The threshold current I_{th} is 25 mA with fiber-coupling efficiency of 43%.

To confirm the single-mode operation, the side-mode suppression ratios (SMSRs) for ONU1 were measured as a function of the detuning wavelength (i.e., the wavelength

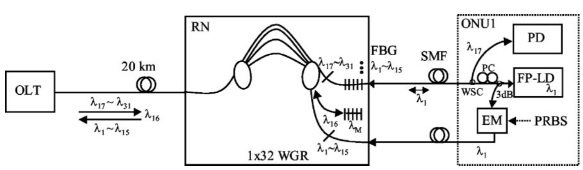

Fig. 1 Proposed WDM-PON using a self-injection locked F-P LD.

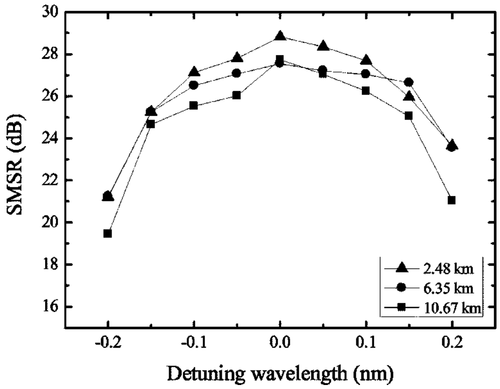

Fig. 2 SMSR with several lengths between the ONU and the RN. SMSR at each bias setting: 1.28 I_{th} (▲), 1.29 I_{th} (●), and 1.33 I_{th} (■).

difference between the FBG and the F-P LD) with various fiber lengths as shown in Fig. 2. After polarization adjustment with the polarization controller (PC), the optimized SMSRs at zero detuning wavelength appeared maximum 28.83 dB. We increase the bias current to compensate for the optical loss related to the distance as shown in Fig. 2. As a result of self-injection locking, SMSR of over 25 dB was achieved over the detuning wavelength range of about 0.3 nm, corresponding to the temperature variation of about 30 °C. The temperature fluctuation in urban areas is generally known to be 50 °C for underground installation.[7] However, the detuning range is limited by the mode-hopping and this can be improved by selecting a F-P LD with wider mode spacing. To demonstrate the wavelength tracking of the WGR, the center wavelengths of the WGR, FBG, and F-P LD were measured while varying the temperature [Fig. 3(a)]. Figure 3(a) shows the wavelength shift of the F-P LD (inverted triangle), same as that of the WGR (blank circle). Also, the range of the self-injection locking for a single F-P LD was confirmed over 10 longitudinal modes by changing the FBG wavelength as shown in Fig. 3(b). This was plotted by superposing each self-injection locked mode, and indicates the possibility of using the same F-P LD for more than 10 subscribers.

At the zero detuning wavelength and 1.33 I_{th} bias condition, the cw light from the F-P LD (λ_1) was modulated with pseudo random bit sequence (PRBS) of 2^7-1 by using an external modulator (EM), transmitted through port 1 of the WGR, and detected at the OLT.

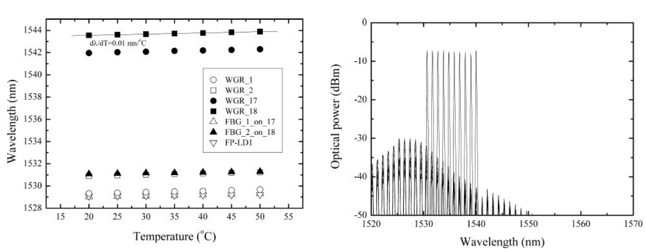

Fig. 3 Dependence of wavelength on temperature and tuning range of the F-P LD. (a) WGR (○, □, ●, ■), FBG (△, ▲), and the self-tuned F-P LD (▽). (b) Tuning range of single F-P LD for multiple ONUs.

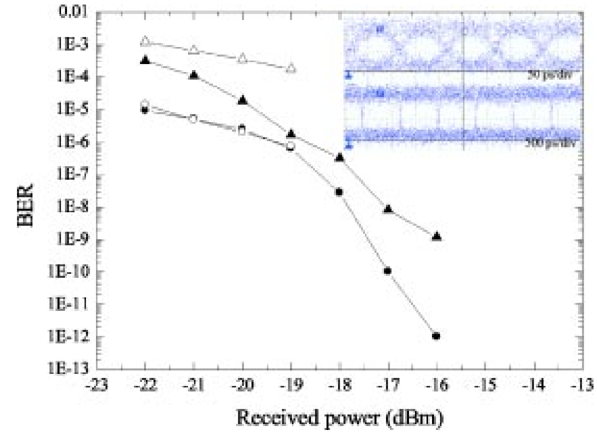

Fig. 4 Measured BER curves for the upstream signal at 1.25/10 Gbit/s with PRBS of 2^7-1. Self-locked F-P LD: at 1.25-Gbit/s (●), at 10-Gbit/s (▲). F-P LD: at 1.25-Gbit/s (○), at 10-Gbit/s (△). Inset: self-locked eye diagrams at 1.25 (lower: 500 ps/div), 10 Gbit/s (upper: 50 ps/div).

The measured BER curves, less than 10^{-9} after 30-km transmission at 1.25 and 10 Gbit/s, are shown in Fig. 4 with self-injection locking. The error-free transmission was observed at a BER of 10^{-12} for 1.25 Gbit/s.

4 Conclusion

As a result of the self-injection locking, the center wavelength of the F-P LD is self-tuned to the peak wavelength in the passband of the WGR. With the side-mode suppression exceeding 25 dB over a 0.3-nm detuning wavelength range, bidirectional error-free transmission over 30 km SMF at 1.25 Gbit/s was achieved at a BER of 10^{-12}. Incorporationof the FBGs in the WGR through one mask-etching processing and the electro-absorption type modulator in the F-P LD would provide a low-cost solution for implementing a high-speed WDM-PON.

Acknowledgments

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