Dense WDM-PON based on Wavelength Locked Fabry-Perot Lasers

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Abstract: We demonstrate 12-channel WDM-PON with 50 GHz channel spacing based on low cost wavelength locked Fabry-Perot laser diodes. The proposed WDM-PON can accommodate 80 channels with EDFA based broadband light source.

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1. Introduction

The passive optical network based on wavelength division multiple access (WDM-PON) has been considered as ultimate broadband access network. Each subscriber can communicate with the central office (CO) using an assigned wavelength that can carry a different data rate with a different protocol. However, it is required to use expensive wavelength specified sources in order to maintain assigned wavelength in WDM-PON. In addition, it increases management and installation costs considerably.

Several approaches have been proposed to reduce the management and installation costs using wavelength independent optical network termination (ONT). Spectrum-slicing using a broadband incoherent light source such as a light emitting diode (LED) may be used to realize the wavelength independent ONT [1-3]. The LED can be fabricated at a low cost and modulated directly. However, its output power and modulation speed are insufficient for high speed operation. Recently, a wavelength locked Fabry-Perot laser diode (F-P LD) with external spectrum-spliced amplified spontaneous emission (ASE) injection was proposed for a low cost WDM source for wavelength independent operation of the ONT [4]. By injecting spectrum-sliced broadband light source (BLS) into a F-P LD, the laser is forced to operate in a quasi single mode and the mode partition noise of the F-P LD is suppressed. Therefore, we can use the wavelength locked F-P LD as the WDM light source.

In this paper, we demonstrate WDM-PON with 50 GHz channel spacing using the wavelength locked F-P LDs. We transmit upstream and downstream data bidirectionally over 20 km of a single mode fiber (SMF). We also investigate the capacity of the proposed WDM-PON.

2. Experiment and results

The experimental setup to demonstrate WDM-PON based on wavelength locked F-P LDs is shown in Fig. 1. The CO consists of transmitters, receivers, an arrayed waveguide grating (AWG), two BLSs, and C/L band coarse wavelength division multiplexers (CWDM). The BLS is ASE light generated by the pumped Erbium-doped fiber (EDF). Two BLSs are located at the CO for injection of broadband light into lasers located at the CO and the ONTs. The CWDM filters are used to separate the different band signals (i.e., C-band and L-band). The remote node (RN) consists of an AWG. We may need athermal AWG for operation over wide temperature range. However, we used
thermal AWG for experimental propose. At ONT side, each subscriber has a transmitter that includes a F-P LD to send upstream data and a receiver to receive downstream data. The CWDM filters are also used to separate the two different bands.

The F-P LDs inside of the transmitters are TO-can packaged F-P LDs. Typical mode spacing and front facet reflectivity are 0.6 nm and 1 %, respectively. We used a heater to operate FP-LD at high temperature. The wavelength variation of the laser with the heater was about 0.05nm/10°C, when operating temperature is below the heater setting temperature. We used conventional C-band (1548.9 nm ~ 1553.3 nm) for the upstream data transmission and L-band (1581.3 nm ~ 1585.8 nm) for the downstream data transmission. The F-P LDs were directly modulated at 155 Mb/s with a 2^{31}-1 PRBS pattern. The AWGs used in our experiment have Gaussian type pass band with 50 GHz channel spacing. To use a single AWG at both transmission bands (multiplexing of a band and demultiplexing of the other band or vice versa), we take advantage of periodic property of the AWG. The transmission length between the CO and the ONT is 20 km. It may be noted that a laser, a CWDM filter, a photodiode, and a transimpedance amplifier can be packaged in a small form factor module (BiDi module) or hybrid integrated in a single platform.

The broadband light from C-band BLS was coupled into the transmission fiber and sent to the AWG2 located at the RN. Then, it was spectrally sliced by the AWG2 and injected into the F-P LD located at ONT of each subscriber. The injection power into the F-P LD was -14 dBm/0.2 nm at peak. The upstream transmission wavelength of the each subscriber is determined by the wavelength of the injected spectrally sliced BLS. The upstream signals were multiplexed by the AWG2. The multiplexed signals were transmitted through the transmission fiber. At the CO, the received signals were demultiplexed by the AWG1. Then, the receiver recovers the upstream data. For the downstream data transmission, L-band BLS output was coupled into the AWG1 located in the CO. It was spectrally sliced and injected into the F-P LDs. The lasers were directly modulated with the downstream data. The demultiplexed signals were multiplexed by the AWG1. The multiplexed signal was transmitted through the transmission fiber and demultiplexed by the AWG2. Then, the receiver located at the ONT recovers the downstream data.

The measured upstream and downstream spectra are shown in Fig. 2. The upstream spectrum (a) was measured at the input of the AWG1 with a tap coupler, while the downstream spectrum (b) was measured at the input of the AWG2 with a tap coupler. Each spectrum shows multiplexed 12-channel signals and the BLS output. We measured the bit error rates (BER) for single individual channel transmission and for 12-ch WDM transmission to investigate the crosstalk induced by WDM transmission. As shown in Fig. 3, the measured BER curves of 24 channels show error free transmission. It is observed that the crosstalk induced by WDM transmission is negligible.

We inserted an attenuator between the RN and an ONT that has the minimum output power to investigate the dependency of the distribution fiber loss that is the transmission fiber between the RN and the ONT as shown in Fig. 1. The measured BER curves according to the attenuation values are shown in Fig. 4. The power penalty is less than 1 dB within 2.4 dB attenuation. The power penalty is mainly caused by the reduction of the injection power to the F-P LD. The crosstalk induced by WDM transmission has a minor effect on the power penalty. It means that the proposed WDM-PON can support about 10 km distribution fiber length difference.

We also changed the temperature of the AWG2 to investigate the effect of detuning between the AWG and the F-P LD as shown in Fig. 5. The power penalty is less than 1 dB between 50°C and 59°C. The 9°C temperature variation corresponds to 0.1 nm wavelength variation. In other words, this system can support 0.1 nm wavelength variation of the F-P LD. Based on the previous tuning results of 0.05 nm/10°C, the operation temperature range of F-P LD with a heater is about 20°C.
We demonstrated 50 GHz spaced 12-channel WDM-PON based on the wavelength locked F-P LD with a heater. The crosstalk induced by WDM transmission is negligible. We also investigated the power penalties due to the distribution fiber loss difference and the detuning between the AWG and the F-P LD. We can accommodate maximum 80 channels with 50 GHz channel spacing. This gives 12.4 Gb/s total capacity.

We can use a single type of F-P LD for all ONTs. However, it does not mean the wavelength independent operation of the ONT, since we have a large penalty due to wavelength mismatch between the spectrum-sliced injection wavelength and the laser mode. It may be noted that the penalty is less than 1.5 dB, when we use 100 GHz spaced channel (In this case, we can achieve wavelength independent operation of ONTs). By increasing the cavity length of the F-P LD to have at least one mode within the injection bandwidth of the ASE light, we can achieve wavelength independent ONT. We also can achieve the wavelength independency by maximizing the output power from the F-P LD, since it is maximal when the injection wavelength matches with a lasing mode.

3. Conclusion

We demonstrated 50 GHz spaced 12-channel WDM-PON based on the wavelength locked F-P LD with a heater. The crosstalk induced by WDM transmission is negligible. We also investigated the power penalties due to the distribution fiber loss difference and the detuning between the AWG and the F-P LD. We can accommodate maximum 80 channels with conventional EDFA based BLSs. The transmission length can be achieved up to 30 km including about 10 km of distribution fiber.

4. References