Multicasting in WDM-PON Using Cross-Gain Modulation in Semiconductor Optical Amplifier

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Abstract Using cross gain modulation in a semiconductor optical amplifier (SOA), we experimentally demonstrate a novel scheme to provide broadcasting service in a colorless WDM-PON system. Due to simple structure, it offers intrinsic stability and cost-effective solution for multicasting in WDM-PON.

Introduction
Dense wavelength division multiplexed optical network (WDM-PON) is an attractive solution of the access network due to its large bandwidth, network security, protocol transparency, and easy upgradability. However, it is difficult to provide broadcasting service caused by virtual point-to-point connection between central office and subscribers. To overcome this problem, many approaches have been proposed. One method is to use N x N arrayed waveguide grating (AWG) and a power splitter. However this scheme has an additional insertion loss due to the power splitter and complexity of the remote node (RN). In another method, broadcasting data combined with baseband data directly modulates a DFB-LD at OLT for each ONU to overcome the drawback of the wavelength selectivity, but it is costly because of multiple DFB-LDs. Also, it has been proposed to use a low cost broadband light source based on mutually injected Fabry-Perot laser diodes (FP-LDs). However, the mutual injection locking is complicated and bandwidth is limited due to noise peaks based on the external cavity structure.

In this study, we present a more simple method for multicasting over colorless WDM-PON. Here, we use a spectrum sliced method to obtain the wavelength converted signal induced by cross gain modulation (XGM) in a semiconductor optical amplifier (SOA) when a high intensity pump signal comes into a SOA. In this scheme, single pump signal can be converted into multiple wavelength signals without any other probe light sources. Another advantage for this scheme is that it could be very practical and cost-effective because of its simplicity, stability, and polarization independence.

Principle
The proposed DWDM-PON with multicasting function, which uses XGM in SOA, is depicted in Fig. 1. The multicast signals are imposed on the DFB-LD by direct modulation of bias current. When a high intensity modulated pump light is coupled into a SOA, the whole spectrum of the amplified spontaneous emission (ASE) output is modulated due to XGM effect. So, if the pump signal is in high level, the ASE spectrum will be in low level, and vice versa. Such a modulated spectrum of ASE is combined with colorless WDM-PON system, which includes centralized A- and B-band broadband light sources (BLS).
which supply unmodulated optical carriers for colorless operation of multiple FP-LDs in central office (CO) and ONUs, respectively, using a WDM filter. The multicast signal, centralized seeding light for the colorless ONUs, and downstream data signals, are spectrum sliced or demultiplexed by the AWG2 located at the remote node (RN) after passing through a feeder fiber. Then the sliced or demultiplexed signals are transmitted to optical network units (ONUs). At each ONU, these optical signals are separated into three wavelength bands, one is fed into receiver1 to recover downstream data, another into receiver2 to recover multicast signal, and the other is injected in FP-LD as a seeding light source and modulated by FP-LD for upstream data. Here, we use the periodic property of the transmission wavelength spectrum of AWG for the simultaneous transmission of three bands using the single AWG. In Fig.1, the wavelength band of the SOA-ASE output is separated by the free spectral range (FSR) of the AWG from that of the upstream data. Also the wavelength band of the downstream data is separated by the integer multiples of the FSR. For example, we can use conventional C-band (1534.2~1559 nm) for the upstream data transmission, L-band (1574~1599.2 nm) for the downstream data transmission, and S-band (1460.6~1484.1 nm) for the multicast by using AWG with a free spectral range (FSR) of ~ 4.927 THz.

**Experiment and results**

The experimental setup is shown in Fig. 2. First, we generate the multicast signal by directly modulating a DFB laser ($\lambda_{opt}=1530$ nm) at 155 Mb/s using 2$^{31}$-1 pseudo-random bit sequence (PRBS) pattern. This modulated optical signal is injected into a SOA. The SOA has a polarization independent gain (PDG < 0.5dB) and the unsaturated gain peak of the SOA was about 1490 nm at the drive current of 200 mA. As shown in Fig.3, when the pump signal (DFB light) is in high level, the ASE spectrum of the SOA is in low level due to the XGM effect. Fig.3 shows the XGM effect in SOA for 3 dBm pump. Fig. 4 shows the extinction ratio (ER) of the ASE-XGM spectrum of SOA. From the figure, it could be seen that the ER is higher than 15 dB in a range of about 40 nm.

For the experiment, we used S-, L-, and C-band wavelengths for the multicast, downstream, and upstream channels, respectively. For the proof of concept, we composed two-channel WDM-PON with 4 FP-LDs wavelength-locked by spectrum-sliced ASE injection (for ch1: $\lambda_{u1}=1593$ nm, $\lambda_{d1}=1535$ nm, $\lambda_{multicast}=1481$ nm; for ch2: $\lambda_{u2}=1593.8$ nm, $\lambda_{d2}=1535.8$ nm, $\lambda_{multicast}=1481.7$ nm ). Here, the FP-LDs are directly modulated at 1.25 Gb/s with a 2$^{31}$-1 PRBS data. The AWG1 at the CO and the AWG2 at the RN have a 100-GHz channel spacing and a FSR of about 54 nm. The ASE-XGM converted signal was again combined with data signals after combined with C-band seeding light (C-BLS). The combined multicast signals were transmitted through a 20 km single mode fiber and demultiplexed by the AWG2 at RN. The demultiplexed signals were then transmitted through a 5 km fiber, and then multicast signal, downstream data, and sliced seeding light were separated by using two filters (C+S/L WDM and C/S WDM). We measured eye diagram and bit error rate (BER) at the end of fiber.
From the measured optical eye diagram of the multicast signal at the Rx', we can see a relatively high noise in the transmitted '1' level but still the transmitted multicast signal has a wide enough eye opening.

To evaluate the performance of the multicast signals, we measured the BER curves, as shown in Fig. 5. The results show that the multicast signal is successfully XGM-converted and transmitted with a power penalty of less than 1 dB compared with back-to-back (b2b) configuration.

We also measured the BER curves for the data stream. Fig. 6 shows BER performance measured with the downstream and upstream data transmission, respectively at room temperature. As can be seen, with respect to the signal in back-to-back configuration, upstream and downstream transmitted signal exhibit a limited power penalty (~ 2dB in the downstream case at BER=10^-9).

Conclusions
We have proposed novel multicasting colorless WDM-PON with optical wavelength conversion by cross gain modulation in a semiconductor optical amplifier and demonstrated simultaneous bidirectional 1.25 Gb/s data transmission and 155 Mb/s multicasting with 100GHz channel spacing by using a SOA and FP-LDs. This proposed system enables broadcasting service in the colorless WDM-PON with a simple and low cost structure.

References