Accepted for OECC 2002, Japan 2396

Paper 11A1-1

No. 233

# 8-channel Bi-directional Spectrally Interleaved OCDMA/DWDM experiment employing 16-chip, four-level phase coding gratings

Peh Chiong Teh, Morten Ibsen* and David J. Richardson*
Optoelectronics Research Centre, University of Southampton, Southampton, United Kingdom.
*Also with Southampton Photonics Inc, Chilworth, Southampton, United Kingdom.
Tel: +44 2380 592483 Fax: +44 2380 593142 Email: pct@orc.soton.ac.uk

### *Abstract*

*We demonstrate a full-duplex bi-directional OCDMA/DWDM experiment comprising 8-coded channels in each direction incorporating 16-chip, 20 Gchip/s quaternary phase coding gratings. Error free performance was obtained over a transmission distance of 44km without requiring dispersion compensation.*

## Introduction

There is a growing need for access networks capable of supporting the broadband and bursty nature of packet-based data services. Optical Code Division Multiple Access (OCDMA) is one such technology that has the potential to support a large number of asynchronous users with simple network topologies.

Superstructure fiber Bragg gratings (SSFBGs) used to perform code generation/recognition as required within an OCDMA system offer advantages in terms of compactness, cost and ready integration within fiber systems. In this paper, we present a practical 8-channel full-duplex bi-directional spectrally interleaved OCDMA/DWDM access network based on four level phase encoded SSFBGs. Most importantly, we demonstrate the application of the inherent wavelength selectivity of SSFBGs to perform DWDM filtering at both OCDMA encoders and decoders without requiring additional filters.

## Experimental Results

Fig. 1 shows the experimental set up used to demonstrate the bi-directional OCDMA/DWDM network. Eight lasers, separated in frequency by 50 GHz are used to generate eight DWDM channels (denoted by $\lambda_1$- $\lambda_8$). The DWDM channels are combined together using fiber couplers before entering an Electro-Absorption (EA) modulator that was driven with a 10 GHz sinusoidal signal in order to produce 10 GHz, 20ps DWDM pulse trains. The pulse trains were then split using a fiber coupler to generate the up and down links. The downlink DWDM pulse trains were gated and modulated with a $2^7$-1 pseudorandom data sequence at a data rate of 622 Mbit/s using an intensity modulator (EOM). These modulated pulse streams were reflected from an array of eight coding gratings: two different OCDM codes (Q1 and Q2) centered on odd wavelengths, denoted by $\lambda_1$, $\lambda_3$, $\lambda_5$, $\lambda_7$ so as to generate eight separate coded data channels (2 OCDM x 4 DWDM on a 100 GHz grid). Note that no additional wavelength filtering is required to separate the individual 50 GHz DWDM before encoding since each SSFBG simultaneously performs both code generation and DWDM wavelength selection with ~18 dB of extinction between adjacent 50 GHz DWDM wavelengths (see Figure 1). These coded channels were then transmitted over a distance of 44km in non-zero dispersion shifted fiber (NZDSF) having a total dispersion of 118.8 ps/nm before being split using another fiber coupler and fed onto two decode gratings matched to the particular codes and wavelengths.

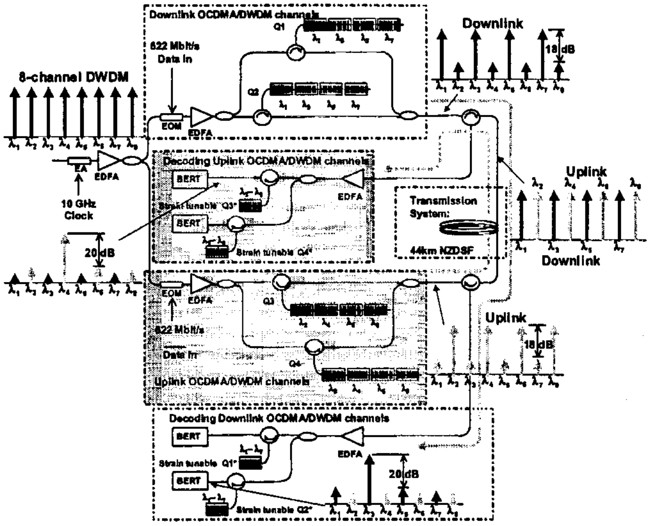

*Fig. 1: Bi-directional spectrally interleaved OCDMA/DWDM experimental set-up. Q1-Q4: SSFBGs matched to the DWDM wavelengths. Schematics showing the DWDM channel filtering using SSFBGs at various points along the system.*

Similarly the other output (uplink) was gated and modulated with the complementary data of the same data rate before being reflected from another array of eight coding gratings comprising two OCDM codes (Q3 and Q4) centered on even wavelengths, denoted by $\lambda_2$, $\lambda_4$, $\lambda_6$, $\lambda_8$ for upstream link. Again, two decode gratings were included at the receiving end, matched to the particular code and wavelength of interest. Hence we can simultaneously analyse the performance of both upstream and downstream pairs of OCDM code channels. Optical circulators are used at both ends of the transmission line to ensure a full duplex bi-directional link.

The 16-chip, 20 Gchip/s four-level phase encoded SSFBGs are fabricated using the continuous grating writing technique. This technique allows for the production of complex grating profiles incorporating discrete amplitude and phase responses [1]. All the four-level phase codes are obtained from Family A sequences that provide excellent auto/cross correlation features [2]. In Fig. 2 we show the phase modulation profiles imposed upon gratings Q1 and Q2 during writing process together with the corresponding measured and calculated plots of the reflectivity spectrum. Good agreement between the theory and experiment is observed.

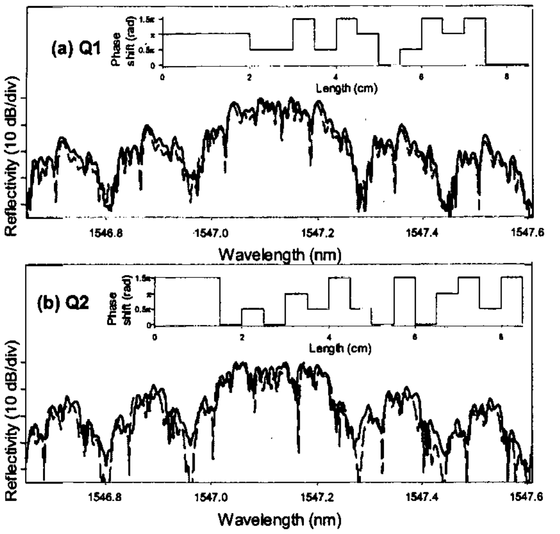

*Fig. 2(a): Optical spectral reflectivity profiles (experimental – solid line and theory – dashed line) for 16-chip, 20 Gchip/s SSFBG Q1. Inset: Phase modulation profile for SSFBG Q1. (b) Similar profiles for grating Q2. These gratings have their peak reflectivity at ~25 % and are 8.22cm long.*

The optical spectrum in Fig. 3(a) shows the downstream decoded response after matched filtering using grating Q2*. Extinction of ~20 dB between adjacent 100 GHz OCDMA wavelength channels is obtained. Similar extinction ratios are observed for the upstream decoded response after matched filtering using grating Q3* as shown in Fig. 3(b).

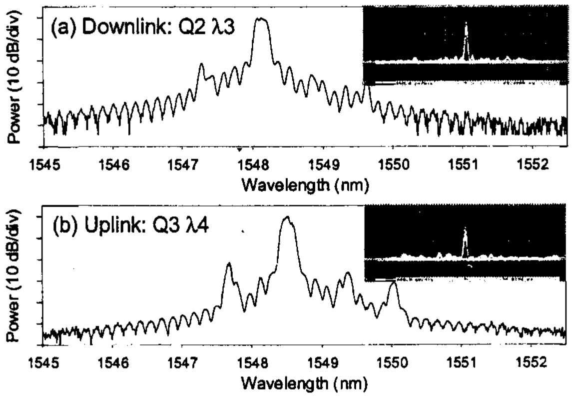

*Fig. 3 (a): Downlink optical spectra obtained after matched filtering with decode grating Q2*. Inset shows the corresponding eye diagrams at 622 Mbit/s. (b) Similar uplink results after matched filtering with grating Q3*.*

Again, the inherent wavelength selectivity of the SSFBG can be used both to provide the wavelength 'drop' function as well as the OCDMA decoding function for 'in-band' signals, eliminating the requirement for additional wavelength channel filtering elements at the receiver [3]. The clean eye diagrams obtained at the data rate of 622 Mbit/s are shown inset in both figures. The low level pedestal observed on both sides of the decode pulseforms after simple matched filtering alone can be eliminated by incorporating nonlinear thresholding device after the decode grating [4].

The performance of the full duplex OCDMA/DWDM bi-directional system was characterized by measuring the bit error rate (BER) of both upstream and downstream channels versus the total received optical power. These results are plotted in Fig. 4. Error free performance is obtained for all the measured channels with ~ 3 dB power penalty when compared to the laser back-to-back for both cases. Most importantly, no power penalty is observed when comparing both uplink and downlink performances.

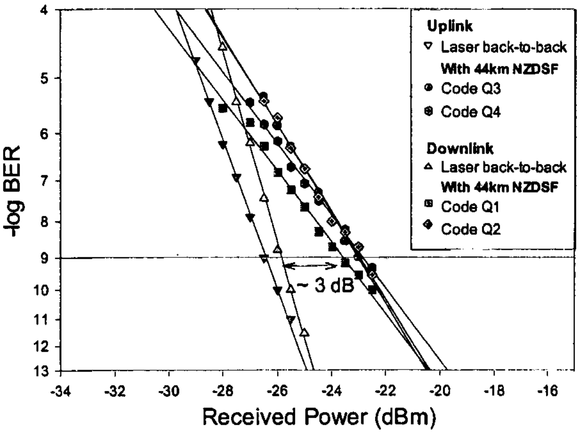

*Fig. 4: BER measurements for bi-directional OCDMA/DWDM experiment.*

## Conclusions

We have experimentally demonstrated a simple SSFBG coding/decoding and wavelength selection approach in a bi-directional spectrally interleaved OCDMA/DWDM system. These results further demonstrate that the SSFBG approach provides an extremely powerful and flexible way to perform many of the elementary optical processing functions required within both OCDMA and packet switched networks.

## References

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