100 Gbps WDM OWC Link Performance Using IMOS Surface Grating Coupler and Commercial Fiber Receivers

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Abstract: We propose the use of an IMOS surface grating coupler for light collection and commercial pigtailed receivers for light detection in short-link OWC system. We demonstrate error-free OOK transmission of four 25 Gbps WDM channels.

1. Introduction

Optical Wireless Communication (OWC) becomes increasingly important in unloading the existing RF-based wireless technologies due to the availability of very wide spectrum. The transmission capacity per user is greatly increased in OWC due to no link dispersion, resulting in very high bandwidth. It is power efficient and secure as the narrow optical beam is pointed only when and where needed; unlike RF waves, optical beams are highly directive. Optical spectrum is also unlicensed which means no extra costs when deploying it. Although, one of the limitations is the transmitted power which must be below eye-safety limits [1].

Due to the limited transmitted power, one of the challenges for the OWC receiver is high sensitivity. Commonly used top illuminated photodiodes have their bandwidth inversely proportional to their size; the higher the achievable data-rates the less light it is possible to capture. However, by decoupling light collection from light detection, the bandwidth of the receiver is not limited by its aperture size [2]. A way to do that is to couple light from free space through a grating coupler into a waveguide receiver on a photonic integrated circuit (PIC). Such concept opens opportunity to create integrated PIC receivers for OWC where light is collected with a grating coupler and detected with high speed photodiode on chip. When light is coupled into a waveguide and/or fibre, many limitations of the top-illuminated photodiodes can be overcome. For example, link budget and spectral efficiency can considerably be improved by using coherent systems in combination with advanced signal processing including equalization, shaping, and modulation formats. The use of grating coupler also opens a way to use commercially pigtailed receivers which are relatively low cost and commonly available. Data throughput can also be increased with Wavelength Division Multiplexing (WDM); a method used in this paper. At the receiver an Arrayed Waveguide Grating Router (AWGR) is used to split different wavelengths into separate waveguides, thus making it possible to detect and process individual WDM signals. OWC WDM can be applied in applications which require very high capacity data transmission, e.g. outdoor OWC between buildings or dynamic capacity allocation by top-of-rack switches in data centers, see Figure 1.

Coupling WDM with grating couplers has been addressed before in Xu et al. [3] and Cheng et al. [4]. These works have integrated the wavelength decoupling function into the grating coupler itself. However, these couplers

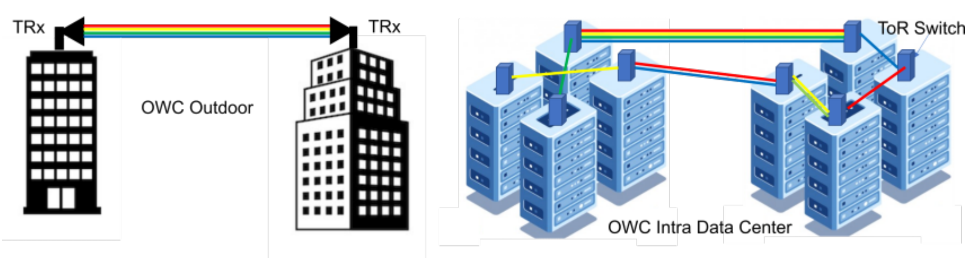

Fig. 1. OWC scenarios where WDM can be applied. Outdoor OWC for communication between the building, and between top-of-rack switches in data centers.

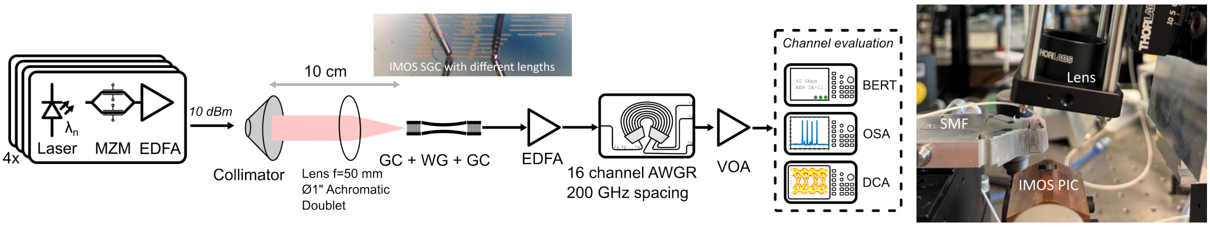

Fig. 2. *Left:* Diagram of the experimental setup used for optical wireless data transmission with surface grating coupler as light collection part of the receiver. *Right:* Photo of the part of the setup with the lens, IMOS SGC and SMF. Due to high losses in SGC, the wireless link is limited to 10 cm. Better light in-/outcoupling can increase the link significantly.

can only decouple two and three wavelengths, respectively. Such limitation hinders scalability in terms of number of wavelengths used in the WDM communication link, thus limiting data throughput.

In this paper we demonstrate a grating coupler together with a commercial fibre-pigtailed AWGR as a receiver for OWC WDM transmission. The grating coupler was fabricated using the Indium Phosphide Membrane on Silicon (IMOS) integration platform. In this work, we focus on the grating coupler as light collection device from free space, the rest of components and equipment in the experiment are off the shelf commercial devices.

2. IMOS Grating Coupler

IMOS is an attractive platform for fabrication of PICs due to its ability to feature smaller structures compared to generic InP platforms because of the high refractive index contrast that leads to high optical confinement of light [5]. IMOS can make passive waveguides with extremely small bending radius and can also make active elements such as light generation and amplification. Hence, IMOS is an excellent platform for fabrication of various optical devices, and among them are surface grating couplers (SGC).

The structure which was used in the experiment consisted of two linear SGCs, two tapers and a waveguide. SGCs were initially designed for fibre-to-chip coupling, so they have dimensions of 15×15 μm^2. The adiabatic tapers are necessary for efficient mode conversion between grating coupler and a waveguide. Photograph of the device is shown in the Fig. 2.

3. Experimental setup

In the Figure 2 the experimental setup used for WDM characterization is shown. Four tunable lasers emitted light in the C-band with a wavelength spacing of 200 GHz (or approximately 1.6 nm) on ITU grid, had polarizaton aligned to TE, then were modulated with a Mach-Zehnder Modulator (MZM) at 25 Gbps NRZ OOK with Pseudo Random Bit Sequence (PRBS) 15 and amplified with Erbium-Doped Fibre Amplifier (EDFA), and combined with two stages of 3 dB fibre couplers. It should be noted that the number of WDM channels are largely dependent on the optical bandwidth of SGC and AWGR. The AWGR has 16 WDM channels and the SGC -3dB spectral response is about 5THz or 40nm at C-band (see Fig. 3(a)), hence more WDM channels could be used in the existing setup. Light then was coupled into free space with a collimator. A lens with one inch diameter and focal length of 50 mm was used to focus the light on the surface grating coupler. The distance between the collimator and lens was 5 cm, and the distance between the lens and PIC was also 5 cm, so the total length of the wireless path was 10 cm. The collimator and lens were tilted 9° with respect to the surface of the PIC. The light was then coupled out of the chip by another grating coupler into a single mode fibre which was also tilted 9° with respect to the surface of the PIC. Another EDFA was used to compensate for the losses of the PIC. Then four wavelengths were decoupled with a commercial 200-GHz spacing AWGR. Channels were characterized with Optical Spectrum Analyzer (OSA) and Digital Communication Analyzer (DCA). Bit Error Rates (BER) were measured with BER tester.

4. Results

Firstly, the loss of the grating coupler was measured. When the light was coupled in and out of the grating coupler structure with single mode fibre on both sides. The loss dependence on wavelength and angle is shown in the Figure 3(a). Within the C-band the higher the frequency is, the higher the losses are of the grating coupler which was used. Here, 4 different discrete angles are tested, however the approximate field-of-view of the grating coupler is 10 degrees. Between the 8 degrees and 11 degrees angle the coupling loss can differ up to 3 dB. For the frequencies used in the WDM the loss was 8 dB per coupler. The addition of the 10 cm wireless path, collimator and lens increased losses by 3 dB. Figure 3(b) shows measured spectra of the modulated wavelengths at 25 Gbps with

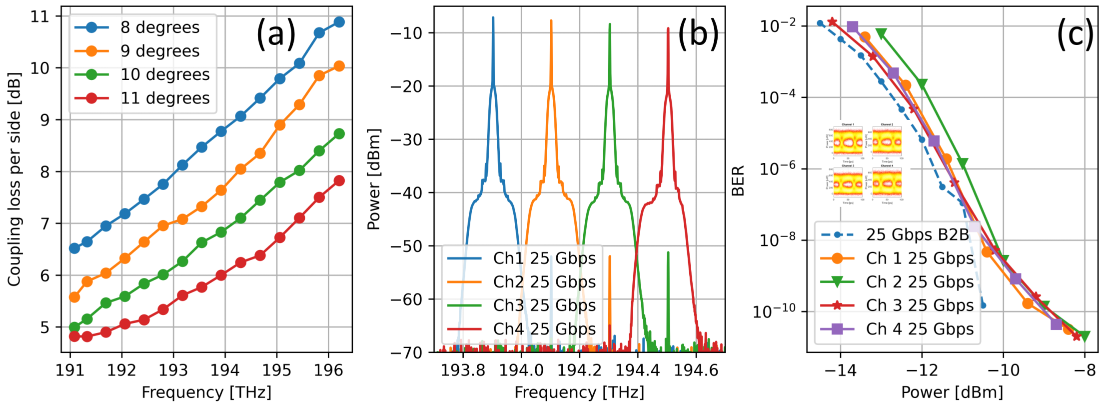

Fig. 3. **(a)** Measured relation between the wavelength, angle and coupling loss of the grating coupler. **(b)** Measured spectras of four WDM channels at 25 Gbps. **(c)** BER curves of four WDM channels vs. received power compared to back-to-back connection.

PRBS-15 after splitting by AWGR and amplification by EDFA. AWGR has adjacent channel isolation of $>$ 30 dB and between other channels $>$ 40 dB. The launch power for channels was set to be the same. However, channels experienced slightly different losses because of AWGR and the wavelength-angle dependent coupling efficiency of the grating couplers. The peak power levels of channels are within 2 dB margin. OSNR levels for all channels were 17 dB. Figure 3(c) shows the measured BER curves of the WDM channels through the wireless link and for comparison a back-to-back measurement. To achieve BER 10^{-9} the WDM channels needed to carry -9.5 dBm of power, which is 1 dB higher than the back-to-back connection. All BER curves stayed wihtin 1 dB margin from the back-to-back measurement for BERs lower than 10^{-9}. Eye diagrams of channels which resulted in error-free data transmission are shown in Figure 3(c).

5. Conclusion

OWC WDM data transmission of 100 Gbps through a 10 cm link and coupled into a waveguide on IMOS PIC through a surface grating coupler was demonstrated. Error-free performance was obtained for each WDM channel and BER curves, spectras and eyes were measured. Channels experienced different losses because of different channel characteristics of AWGR as well as because of wavelength dependent coupling efficiency.

This work demonstrates that grating coupler can be used as light collection devices to couple light from free space into a PIC. This concept indicates potential for future integrated receivers for OWC on PIC. For example, the grating couplers could be combined with AWGR and photodiodes on a PIC to make an integrated OWC WDM receiver. Another possibility would be to have a coherent receiver for OWC by using grating coupler for light collection and 90°hybrids togheter with local oscillator laser and photodiodes for coherent reception.

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