Highly Efficient Optical Beam Steering Using an In-Fiber Diffraction Grating for Full Duplex Indoor Optical Wireless Communication

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***Abstract*—Diffraction gratings have been widely used in wavelength-controlled nonmechanical laser beam steering for high data-rate indoor optical wireless communications. Existing free-space diffraction gratings suffer from inherent difficulties of limited diffraction efficiency, bulky configuration, high cost, and significant coupling loss with optical fiber links. In this paper, a new optical approach for highly efficient, compact, and fiber compatible laser beam steering using an in-fiber diffraction grating is proposed and experimentally demonstrated for the first time to our best knowledge. In-fiber diffraction is made possible based on a 45° tilted fiber grating (TFG), where wavelength-dependent lateral scattering is obtained due to the strongly tilted grating structure. Improved diffraction efficiency of 93.5% has been achieved. In addition, the 45° TFG works perfectly for both light emission and reception, enabling full-duplex optical wireless transmission. Utility of the 45° TFG in all-fiber laser beam steering for multiuser full duplex optical wireless communications has been verified in experiments. About 1.4 m free-space full-duplex wireless transmission has been demonstrated with data rate up to 12 Gb/s per beam using 2.4 GHz bandwidth OFDM signals.**

***Index Terms*—Beam steering, microwave photonics, optical diffraction, optical wireless communication, tilted fiber gratings.**

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I. Introduction

With significantly increased number of wireless personal devices and smart sensors connected in home area networks, there is ever increasing demand for higher data rate in indoor wireless communications in order to offer users better experience for fast internet access with unobstructed services. Conventional radio wireless communication suffers from limited transmission speed and ever-worse spectrum congestion [1]. Despite that the approaching 5G wireless techniques offer much higher data rate up to gigabits per second, the available radio frequency bandwidth has nearly hit its limit and cannot fulfil the increasing demand of even higher data rate for indoor wireless transmission applications.

On the other hand, optical wireless communication (OWC) has recently attracted increasing interests as it provides a promising solution for speed and bandwidth challenges in conventional radio wireless communications [2]–[4]. OWC takes advantages of the huge bandwidth of optical carriers and mature transmission technology developed in long-haul optical fiber communication systems. Additional advantages of OWC include unlicensed spectrum, immunity to electromagnetic interference, spatial diversity and physically ensured security as light waves do not penetrate walls.

Visible light communication (VLC) has been successfully developed for OWC [5]. Despite being a low-cost solution, VLC falls short in high data-rate wireless transmission (usually below Gbps) due to the fundamental speed limitation of direct current modulation in the light emitting diodes (LEDs) used [5, 6]. Another difficulty in VLC is significant attenuation due to beam divergence and single-pixel light reception. On the other hand, infrared OWC using lasers has shown great potential for high-speed indoor optical wireless transmission [6]–[11] thanks to its unique advantages of wide bandwidth, high speed, easy access and low cost benefited from readily available devices in optical fiber communications, such as lasers, low-loss optical fibers, and high-speed modulators and photodetectors. In addition, infrared OWC also offers higher link power budget compared to VLC due to the relaxed eye-safety regulations in the infrared band.

As opposed to VLC where omnidirectional LEDs illuminate large areas using largely divergent beam, infrared OWC uses narrow laser beams. Therefore, a beam steering device is usually required to scan the directional laser beam for multi-user and large area coverage [12]. Great research efforts have been made to meet the need of fast and precise beam steering in infrared OWC. Conventionally, mechanical beam steering solutions have been extensively studied since 1980's owing to their simple configuration, high resolution and relatively large scanning angles [13]. However, they have inherent disadvantages of relatively low steering speed and bulky size. Various mechanical-free beam steering methods have been reported recently, such as the use of diffraction gratings based on wavelength tuning [12], [14]–[16], optical phased arrays [17], and a slow-light waveguide amplifier [18]. Key challenges in these free-space or waveguide-based beam steering devices are their high coupling loss with the existing fiber links, and the complicated and expensive setup. Therefore, to facilitate practical deployment of indoor infrared OWC systems, a highly-efficient and low-cost all-fiber beam steering device is of high demand.

In this work, we investigate and demonstrate the first use of an in-fiber diffraction grating as a wavelength-controlled all-fiber beam steering device for high-speed indoor OWC. Highly efficient in-fiber diffraction is made possible using a 45° tilted fiber grating (TFG) [19], where wavelength-dependent lateral diffraction is obtained due to the strongly tilted grating structure inside the fiber core. We demonstrate that the 45° TFG offers greatly improved diffraction efficiency (>93.5%) compared to normal ruled or holographic diffraction gratings that fall short in diffraction efficiency (usually up to 75%) due to the inherent zeroth-order reflection and non-Littrow configuration. The proposed TFG-based beam steering solution offers inherent compatibility with existing fiber links, which is particularly attractive in achieving seamless interface with fiber-to-the-home (FTTH) access networks. The significant coupling loss between fibers and free-space or waveguide devices is completely eliminated. In addition, the tilted grating structure in the TFG allows it to function as a light receiver as well enabling beam steering for full-duplex wireless transmission due to reversibility of light path. These features help to improve signal-to-noise-ratio in indoor OWC and make the 45° TFG an excellent candidate for infrared laser beam steering in high-speed full-duplex OWC systems.

Some preliminary experimental observations have been recently reported by us [20], [21]. To provide a better understanding of the proposed approach, a comprehensive analysis and further simulation and experimental verifications are presented in this paper. A 45° TFG has been designed and fabricated. Its utility in laser beam steering for multi-user indoor duplex OWC has been verified in experiments. We first demonstrated TFG-based optical beam steering in a 2.6 m free-space link. Wireless data transmission over 1.4 m serving three remote users with data rate of 9.6 Gbps per beam has also been demonstrated using 2.4 GHz bandwidth signals.

The remainder of this paper is structured as follows. In Section II, we first describe the principle and characteristics of the 45° TFG as a highly efficient in-fiber diffraction device. In Section III, TFG's utility in all-fiber beam steering based on wavelength tuning for indoor full duplex OWC is verified with proof-of-concept experimental demonstrations. A highly efficient, low-cost, and fiber-compatible OWC system is achieved. Discussions on system performance and optimization of TFG design are provided in Section IV. Finally, we summarize the main findings and conclude our work in Section V.

II. Principle

Wavelength-controlled passive optical beam steering can be achieved using a fixed diffraction optical device [12, [14]–[16]. Optical beams with different wavelengths are diffracted into different spatial positions by the diffraction device. Therefore mechanical-free beam steering is achieved via wavelength tuning. The goal of this work is to develop a low-cost and compact in-fiber diffraction grating device based on a 45° TFG, which tackles the real challenges in conventional diffraction gratings, such as bulky size, low diffraction efficiency, high cost and significant coupling loss with existing optical fiber links in OWC systems.

TFGs are a special type of optical fiber grating where grating structure has a tilted angle with respect to the fiber axis [22], which endows it with unique optical properties compared to normal fiber Bragg gratings (FBGs) [23]. A small tilted angle (less than 9°) could couple the transmitted light inside the fiber core into backward propagating cladding modes, resulting in multiple resonances at the transmission spectrum. This feature makes small-angle TFGs an excellent candidate for sensing applications [24]. On the other hand, in excessively tilted fiber gratings (Ex-TFGs) [25], the fiber core mode can be coupled into forward propagating cladding modes. Due to birefringent mode coupling, Ex-TFGs have been applied in refractive index sensing with extremely low thermal cross sensitivity [26].

Different from small-angle and excessive-angle TFGs, a 45° TFG enables light coupling from core mode into radiation modes owing to its largely tilted facet angle, leading to direct first order lateral light diffraction into free space. Without cylindrically symmetric grating structures in a 45° TFG, lateral diffraction is highly polarization dependent [27], making it a perfect in-line fiber polarizer [19]. 45° TFGs have also found rich applications in optical spectrum analysis [28], mode-locked lasers [29], Fourier-domain optical coherence tomography [30], wavelength-encoded imaging [31], and ultrafast photonic time-stretch imaging [32]–[33]. Here, we present the first comprehensive study and experimental demonstration of using a 45° TFG as a highly efficient in-fiber diffraction device for wavelength-controlled passive optical beam steering.

The structure of a 45° TFG and the principle of wavelength-tuning-based laser beam steering using the TFG are illustrated in Fig. 1. Broadband lateral diffraction from the fiber core is produced when the incident light is propagating through the TFG due to the 45° tilted reflection. To fulfil the phase matching condition, lateral diffraction is strongly wavelength dependent, making the 45° TFG a good in-fiber diffraction device. The off-core angular dispersion of the 45° TFG, which enables one-to-one mapping between wavelength and diffraction angle for wavelength-controlled beam steering, is given by [28]

$$D = \frac{d\theta\left(\lambda\right)}{d\lambda} = \sin\left(2\theta\right)\frac{1}{\lambda} \tag{1}$$

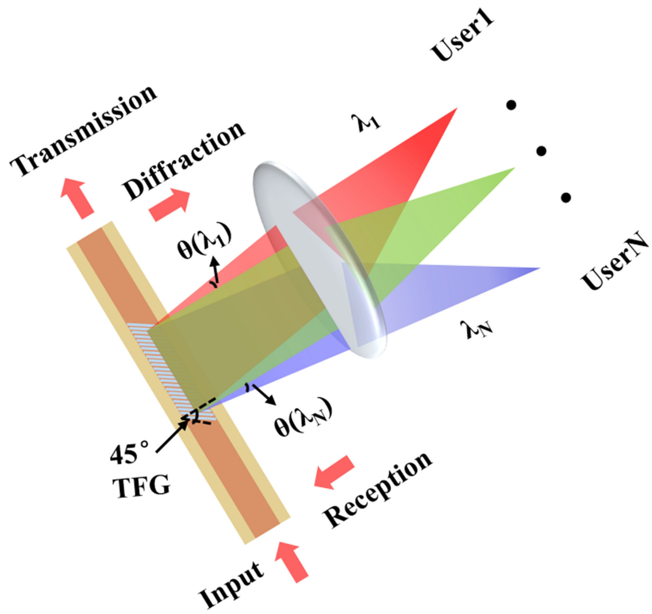

Fig. 1. The structure of a 45° TFG and the principle of wavelength-tunning-based laser beam steering using the TFG for full duplex optical wireless communicaiton. The incident light in the fiber core is scattered into free space from the side of the fiber due to strongly tilted reflection from the 45° tilted grating structure. Receiption of light is achieved due to reversibility of light path.

where λ is the wavelength of incident light and θ is the angle of lateral diffraction off the fiber. It can be seen from (1) that for a given incident optical wavelength, the tilted angle of 45° achieves the maximum angular dispersion. This confirms the utility of 45° TFGs as a good in-fiber diffraction device.

III. Experiment

A. Performance of the 45° TFG

A 45° TFG was fabricated using the standard UV-light imprinting and phase mask technique. The phase mask is tilted at an angle of 33.7° with respect to the fiber axis to form the required 45° slanted grating fringes in fiber core. The fabricated 45° TFG is 24 mm long and has a grating period of 748 nm. The equivalent groove density of the in-fiber diffraction grating is much higher than a conventional free-space diffraction grating. Its off-fiber beam diffraction angles with respect to the fiber axis across a wide wavelength range from 1530 to 1570 nm is measured with results shown in Fig. 2. The angular dispersion is estimated to be 0.053°/nm according to a linear fitting. Note that for an incident wavelength of 1550 nm, the theoretical off-core angular dispersion value is estimated as 0.037°/nm according to (1). Considering a further refraction at the interface between the fiber cladding and air, the theoretical angular dispersion value is modified as 0.054°/nm. An excellent agreement between the experimental and theoretical values are obtained. Considering an operating bandwidth of 40 nm (1530-1570 nm), the coverage of TFG-enabled beam steering is 2.12° without magnification. Our recent theoretical study [34] has shown that a longer grating period or shorter optical wavelength can lead to greatly improved angular dispersion of 45° TFG for larger coverage area.

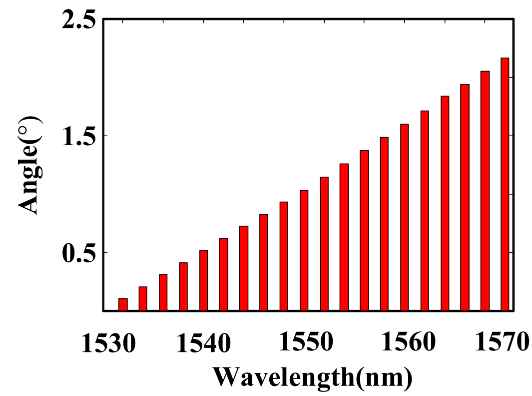

Fig. 2. Measured off-fiber diffraction angles of a 45° TFG across a wavelength range between 1530 and 1570 nm, indicating an angular dispersion of 0.053°/nm.

Lateral light diffraction from the 45° TFG is strongly polarization dependent [19]. Only the s-polarized light beam can be diffracted out of the fiber core. Therefore, by properly adjusting the polarization state of the incident light, a greatly improved diffraction efficiency (>93.5%) has been achieved [31]. In addition, as the TFG can be made long (several cm), the interaction length for lateral diffraction is greatly enhanced and independent on the incident beam size. These unique features make 45° TFGs a promising solution for highly-efficient, low-cost and compact in-fiber diffraction devices.

A 2.6 m free-space optical link is first implemented, which is a typical propagation distance for indoor optical wireless communications. The fabricated 45° TFG is employed as a light emitter. Light beam diffracted out of the TFG is first collimated by a cylindrical lens in vertical dimension with focal length of 20 mm. Due to limited space on the optical table, several mirrors are used to extend propagation distance. Light reception at the receiver end is achieved using a plane-convex lens with a focal length of 100 mm and a multimode fiber (MMF) with a core diameter of 105 μm and numerical aperture (NA) of 0.22, which are followed by a telescope setup to shrink the optical beam size to match the sensitive area of a free-space photodetector (PD). Point-to-point optical propagation loss, which is defined in our system as power difference between the incident light to the TFG and the captured light at the receiver PD, is measured across a wide wavelength range between 1520 and 1570 nm, with the results shown in Fig. 3. The optical link propagation loss ranges from 5.3 dB to 6.1 dB for different optical carrier wavelengths.

B. Optical Wireless Data Transmission via 45° TFG-Based Optical Beam Steering

To verify the utility of the 45° TFG in wavelength-controlled optical beam steering in OWC, a proof-of-concept experiment based on the setup shown in Fig. 4 is performed. A data stream to be transmitted is first generated using an arbitrary waveform generator (AWG). After being amplified by a radio frequency amplifier (RFA), the data stream modulates the continuous-wave optical carrier at a Mach-Zehnder modulator (MZM), which is biased at quadrature point to minimize modulation nonlinearity.

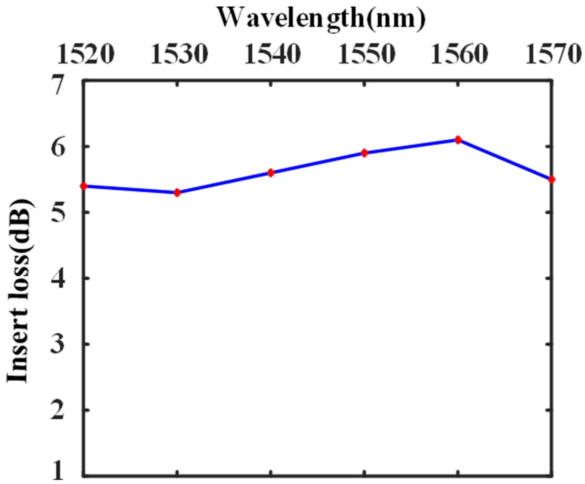

Fig. 3. Measured insert loss between the 45° TFG and an optical receiver with wavelength from 1520 to 1570 nm.

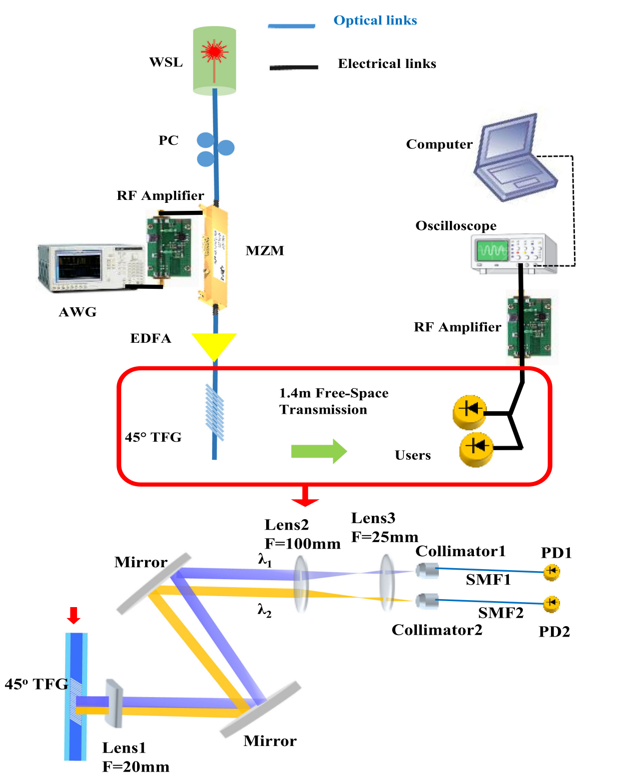

Fig. 4. Schematic of beam steering system for free space indoor OWC using a 45° TFG. AWG: Arbitrary Waveform Generator; RF: Radio Frequency; MZM: Mach-Zehnder Modulator; WSL: Wavelength Swept Laser; EDFA: Erbium Doped Fiber Amplifier; 45° TFG: 45° Tilted Fiber Grating; PD:Photodetector.

An optical fiber polarization controller (PC) is used to ensure that the incident light into the 45° TFG is *s*-polarized, which guarantees the maximum diffraction efficiency over a broad bandwidth from 1530 to 1570 nm. The 45° TFG diffracts light of different wavelengths into different directions thanks to its inherent angular dispersion. Optical beam steering is obtained by tuning the wavelength of the optical carrier using a wavelength-swept laser (WSL) source.

The diffracted light beam has a horizontal beam width as same as the length of the 45° TFG. In all the following experiments, only the first 8 mm length of the TFG is used as it provides

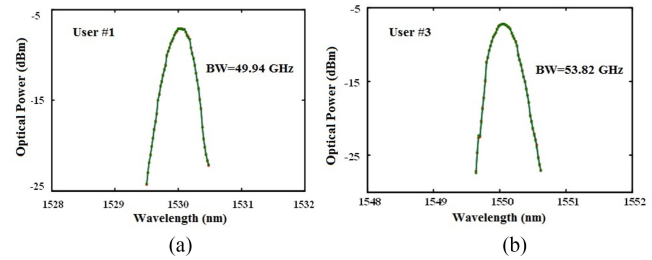

Fig. 5. Measured spectral response of two beam steering channels with allocated optical wavelengths of 1530 nm (a) and 1550 nm (b) after a 1.4 m free space trasmission.

dominate light diffraction and produces good received optical power considering the trade-off between tolerance to optical alignment and signal-to-noise ratio (see Discussion).

A 1.4 m free-space optical link is then implemented for beam steering data transmission. Here three optical carrier wavelengths of 1530, 1540 and 1550 nm were selected to serve three remote users. After 1.4 m indoor free-space transmission, the laser beam is received by each of the remote users. In order to obtain high data rate, a single mode fiber (SMF) coupled high-speed PD with a receiving bandwidth of 45 GHz is used at each user site. Light reception is realized using a telescope set for beam shrinking and a SMF collimator (NA = 0.49) at the receiver end for light coupling into the PD. The measured optical link propagation loss ranges from 6.8 dB to 10.4 dB for different channels.

In wavelength-controlled optical beam steering, the optical receiver at each specific remote user site can only capture light with a given wavelength. This functions as an equivalent narrow bandpass filter to suppress amplified spontaneous emission (ASE) noise from the broadband optical amplifier used in the system. Receiving bandwidth for individual remote users are measured and spectral response of the receivers for two users are shown in Fig. 5(a) and (b) respectively. The full width at half maximum (FWHM) spectral response of the receivers are 0.40 nm (49.94 GHz) and 0.42 nm (53.82 GHz) for allocated wavelengths of 1530 and 1550 nm, respectively. The developed optical wireless link would support extremely high data rate transmission due to the broad bandwidth. In addition, it also offers good tolerance to optical carrier wavelength drift and allows low-cost laser source with broader linewidth to be deployed.

A proof-of-concept wireless data transmission experiment is carried out based on the setup as shown in Fig. 4. An orthogonal frequency-division multiplexing (OFDM) 16-quadrature amplitude modulation (16-QAM) encoded data stream is created offline in MATLAB. Data from a random data generator (RDG) is mapped using QAM modulator block. QAM-mapped symbols are then converted into parallel stream in order to perform inverse fast Fourier transform (IFFT) operation, which is equivalent to the OFDM process of multiplying multiple data streams with their adjacent subcarriers. IFFT is implemented with a length of 512, of which 392 subcarriers are used as data carriers, 8 for the pilot tones, and 112 for zero padding (guard bands). The streams are then combined together to form an OFDM symbol. 12.5% (1/8th part of the data symbol) of cyclic prefix (CP) is appended to each OFDM symbol. Preambles are

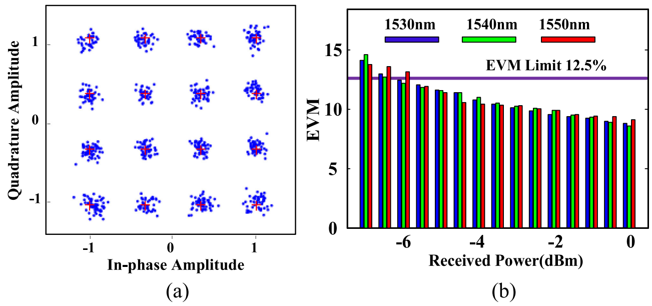

Fig. 6. Experimental results for optical wireless data transmission. (a) Constellation of OFDM 16-QAM signal received by one user with allocated optical wavelength of 1550 nm. The received power is −2 dBm, and the EVM is estimated as 9.6%. (b) EVM performance of all three channels (16-QAM) with optical wavelengths of 1530, 1540, and 1550 nm with received optical power ranging from −7 dBm.

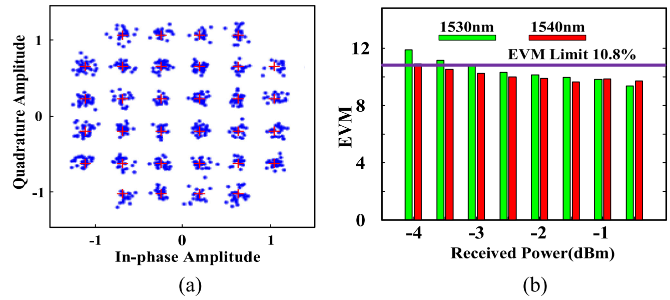

Fig. 7. Further expeirmental results for 32-QAM . (a) Constellation of OFDM 32-QAM signal received by one user with allocated optical wavelength of 1530 nm. (b) EVM performance of two wireless links with optical wavelengths of 1530 and 1540 nm.

also added to the training sequences to perform the synchronization of timing in packet detection process at the receiver. The complex OFDM symbols created in MATLAB are used to generate a 2.4 GHz bandwidth signal through an AWG (Tektronix 7122C) at an intermediate frequency (IF) of 2 GHz. The AWG operates based on 10-bit digital-to-analog conversion (DAC) with a sampling rate of 12GS/s. Data blocks contains 16-QAM modulated data offers an aggregate data rate of 9.6 Gb/s.

After 1.4 m free-space transmission, the received light is detected by a 45 GHz photodetector (PD) at the remote user sites. The recovered RF signal is amplified by a second RFA and sampled by a 100 GS/s real-time digital oscilloscope (OSC, Tektronix DPO72304DX). Recorded data is analyzed using MATLAB for off-line digital data processing. Preambles are first extracted for carrier synchronization. Then the cyclic prefix is removed after serial to parallel (S/P) conversion followed by the process of correlating the received OFDM signal with subcarriers using fast Fourier transform (FFT) operation. To compensate the channel distortions, pilot tones which comprise a training sequence are used to estimate the channel using least square algorithm. The equalization process balances the linear distortions and frequency offset resulted from the chromatic dispersion effects presented in the received signal, and provides phase tracking for the EVM calculations.

The constellation of received 16-QAM OFDM signal for one remote user with allocated optical wavelength of 1550 nm is shown in Fig. 6(a). Here the received optical power is -2 dBm. The error vector magnitude (EVM) is estimated as 9.6%.

Three optical wavelengths of 1530, 1540 and 1550 nm have been selected to serve the three users. EVM performance for all the three channels have been measured with respect to the received optical power with the results shown in Fig. 6(b). The EVM limit for 16 QAM is 12.5%. Using a bandwidth of 2.4 GHz, our system demonstrates a data rate of 9.6 Gb/s per beam, which is only limited by the sampling speed of the AWG used in the experiment.

Optical wireless data transmission with more advanced modulation format, such as OFDM 32-QAM, is also implemented. Fig. 7(a) shows the constellation of 32-QAM signal received by one user with optical wavelength of 1530 nm. The received

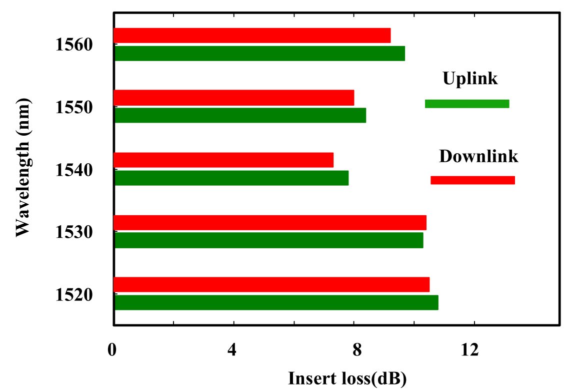

Fig. 8. The measured optical transmission loss in both uplink and downlink channels for five different optical carrier wavelength of from 1520 to 1560 nm in our OWC system.

power is −1 dBm and EVM is calculated as 9.8%, which is below the EVM limit for 32-QAM, 10.8%. EVM performance for two users with allocated wavelengths of 1530 and 1540 nm is shown in Fig. 7(b). With 32-QAM, a data rate of 12 Gb/s has been achieved.

C. Full Duplex Optical Wireless Communication Based on 45° TFG

A full-duplex optical wireless transmission system using a 45° TFG for laser beam steering has been investigated and demonstrated. The 45° TFG can work as a perfect optical transceiver as well for duplex transmission due to reversibility of light path. The in-fiber diffraction device has advantages of low cost, high diffraction efficiency, and low uplink coupling loss from free-space to existing optical fiber links, making it a promising optical beam steering candidate in full-duplex indoor optical wireless communication system. Uplink transmission loss is also evaluated by launching laser beam from the remote users and measuring the collected optical power at the 45° TFG. For the 1.4 m free-space wireless transmission link, uplink transmission loss is measured for five different user channels and compared with the downlink case. Results are shown in Fig. 8. It is therefore verified that the 45° TFG produces similar transmission loss for uplink and downlink channels at a given optical carrier wavelength.

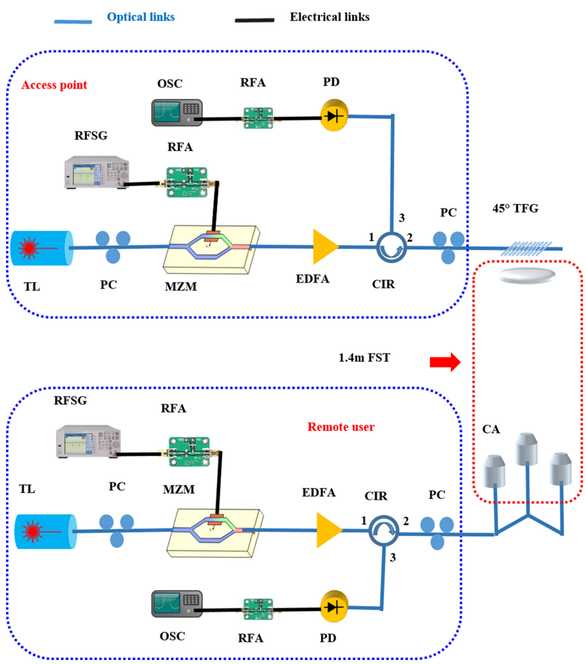

Fig. 9. Schematic of duplex bidirectional indoor OWC system using a 45° TFG. WSL: Wavelenth Swetp Laser; PC: Polarization Controller; MZM: Mach-Zehnder Modulator; RFSG: Radio Frequency Signal Generator; RFA: Radio Frequency Amplifier; EDFA: Erbium Doped Fiber Amplifier; 45° TFG: 45° Tilted Fiber Grating; OSC: Oscilloscope; PD: photodetector.

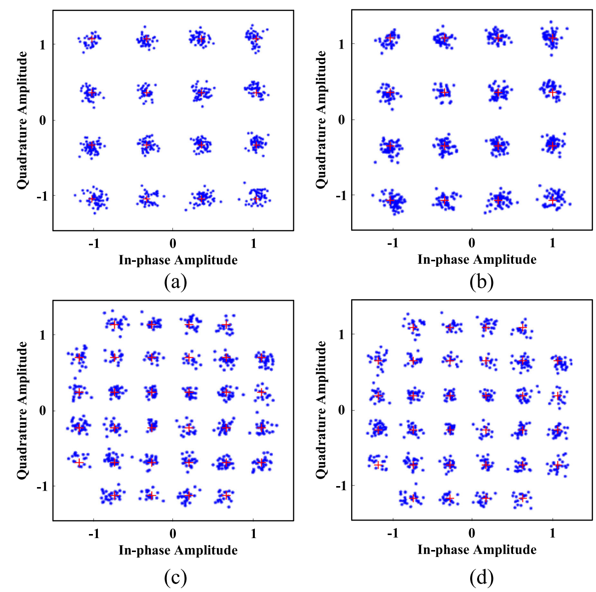

Fig. 10. Constellation of received 16-QAM OFDM signals for (a) uplink channel with 10.1% EVM and (b) downlink channel with 9.8% EVM with optical wavelength of 1550 nm and a received optical power of −2 dBm; Constellation of received 32-QAM OFDM signal for (c) uplink channel with 10.7% EVM and (d) downlink channel with 10.3% EVM with optical wavelength of 1550 nm and a received optical power of −1 dBm. QAM: Quadrature Amplitude Modulation; OFDM: Orthogonal Frequency-Division Multiplexing; EVM: Error Vector Magnitude.

The schematic of full duplex OWC system using the 8 mm 45° TFG for beam steering is shown in Fig. 9. The access point and remote user sites share similar setup. Optical circulators are employed in both sites to allow full duplex operation. RF signals with encoded data stream using OFDM 16/32-QAM and bit rates of 9.6 Gb/s or 12 Gb/s are generated using the RFSG.

Performance for downlink and uplink wireless transmissions using TFG-based optical beam steering is tested and the results are shown in Fig. 10. The constellations of received 16-QAM OFDM signals for uplink channel and downlink channel are shown in Fig. 10(a) and (b), respectively. The optical carrier wavelength is 1550 nm and the received optical power is −2 dBm. EVMs are estimated as 10.1% and 9.8% for uplink and downlink channels, respectively. The constellations of received 32-QAM OFDM signals are shown in Fig. 10(c) and (d), with a 10.7% and 10.3% EVM for uplink channel and downlink channel respectively. Here the received optical power is −1 dBm at 1550 nm.

Further evaluation results of EVM performance with respect to different received optical power for both uplink and downlink links are presented in Fig. 11. Three user channels are included in 16-QAM experiment while two users in 32-QAM system.

IV. Discussion

The key metric parameter in designing a 45° TFG for optical beam steering is the length of the TFG. A longer TFG will always lead to higher diffraction power. However, there is an exponential decay in the diffracted optical power along the grating direction [31]. Fig. 12 presents the measured total diffracted optical power from a 45° TFG with different grating length. The

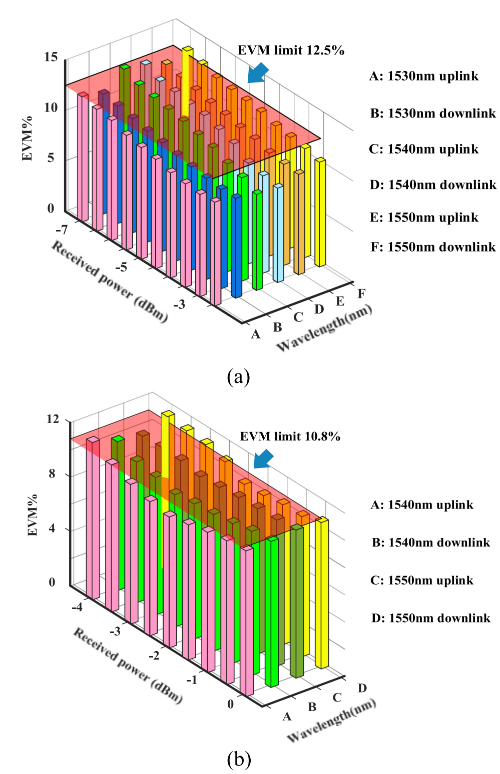

Fig. 11. (a) The EVM performance of 16-QAM setup for full duplex OWC with three user channels at the optical wavelengths of 1530, 1540, and 1550 nm. (b) The EVM performance of 32-QAM setup with two user channels at the wavelengths of 1540 and 1550 nm. QAM: Quadrature Amplitude Modulation; EVM: Error Vector Magnitude.

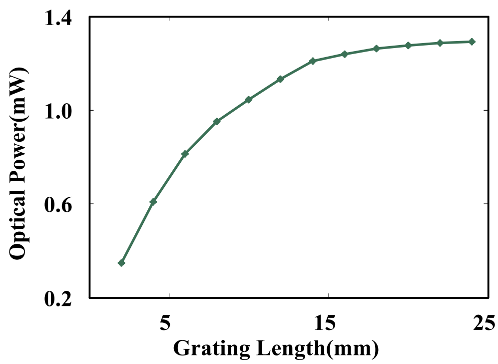

Fig. 12. Total diffracted optical power with different lengths of 45° TFG. A 24 mm long TFG was used and measurements were done by blocking part of the TFG region.

whole TFG is 24 mm long and a single input optical wavelength of 1550 nm is used in the measurement. On the other hand, as the length of the TFG also determines the horizontal beam size of the diffracted light, a longer TFG produces a bigger optical beam size at the receiver end. This may improve the tolerance for laser beam alignment and wavelength drift. However, if the receiving detector has a smaller size than the incident beam, the detected electrical power, and hence the signal-to-noise ratio, will be greatly reduced.

In our experimental demonstrations, only the first 8 mm of the TFG is used. It seems the best option considering the trade-off between light emission from the TFG and light detection at the PD in our specific experiment setup. Comprehensive analysis on the effects of TFG length and light beam pointing error on the performance of TFG-based beam steering indoor optical wireless communication is out of the scope of this paper and will be conducted in future study.

V. Conclusion

For the first time we have presented and experimentally demonstrated a full duplex indoor optical wireless communication system using a 45° TFG as the highly efficient wavelength controlled beam steering device. The 45° TFG offers significant compactness due to its in-fiber structure, and improved diffraction efficiency up to 93.5% due to strong polarization dependence without other orders of diffractions and reflection. In addition, the proposed TFG-based beam steering solution provides inherent compatibility with existing fiber links, which is particularly attractive in achieving seamless interface with fiber-to-the-home (FTTH) access networks. The considerable coupling loss between optical fibers and free-space or waveguide beam steering devices in conventional OWC systems is also completely eliminated. The proposed all-fiber optical beam steering technique is successfully verified by proof-of-concept experiments, in which full duplex optical wireless transmission over 1.4 m serving multiple users with data rate of up to 12 Gbps per beam has been demonstrated using 2.4 GHz bandwidth OFDM signals. Note that the data rate is only limited by the bandwidth of our arbitrary waveform generator. The demonstrated beam steering optical wireless links have a receiving optical bandwidth of 50 GHz, which enables high data rate wireless transmission and offers better tolerance for laser linewidth and central wavelength drift. The presented 45° TFG based laser beam steering holds great promise in indoor optical wireless transmission toward future high data-rate home area networks.

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