Wavelength Routing for Transparent Optical Wireless Communications Based on Volume Holography

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Abstract: A 17-Gbit/s wavelength routing system using volume holography beam-steering for all-optical infrared networking is presented. Polarization-independent demultiplexing of four channels is demonstrated with a loss of 14 dB, and crosstalk suppression of 15 dB. © 2024 The Author(s)

1. Introduction

Telecommunications networks are transitioning towards an all-optical core, utilizing a combination of optical fibers in the backbone and wireless access at the edges. In the optical domain, beamsteering devices are typically required for optical wireless communication (OWC) to serve mobile terminals at high data rates. Different approaches have been suggested for the implementation of beam steering, including both active and passive methods. Active beamsteering techniques can be achieved using mechanical steering mirrors, micro-electromechanical systems, optical phased arrays, and spatial light modulators [1, 2]. Passive beamsteering techniques can be implemented using diffraction gratings, arrayed waveguide gratings and virtually imaged phased arrays [3, 4]. An ideal beamsteering base station at the edges of an all-optical network would be solid-state, passive, with a large aperture, wide steering angle, and a short response time [5]. We propose and demonstrate a passive beamsteering technique based on volume holography using the two-lambda method (2LM). Typically, photorefractive materials used in holography exhibit peak sensitivity in the visible spectrum while showing negligible values in the infrared. The 2LM overcomes the limitation by recording the designed gratings in visible range beforehand and implementing beamsteering by reading them in the infrared range. In this work, the holographic gratings are recorded at 532nm, and read at wavelengths spanning the S band to L band (1460nm – 1625nm). In this experiment, we record four holograms in the material, and these steer different C-band wavelengths to different positions. Data transmission at an overall data rate of 17Gbit/s, using wavelength division multiplexing (WDM) has been successfully achieved in the experiment.

2. Experimental Setup

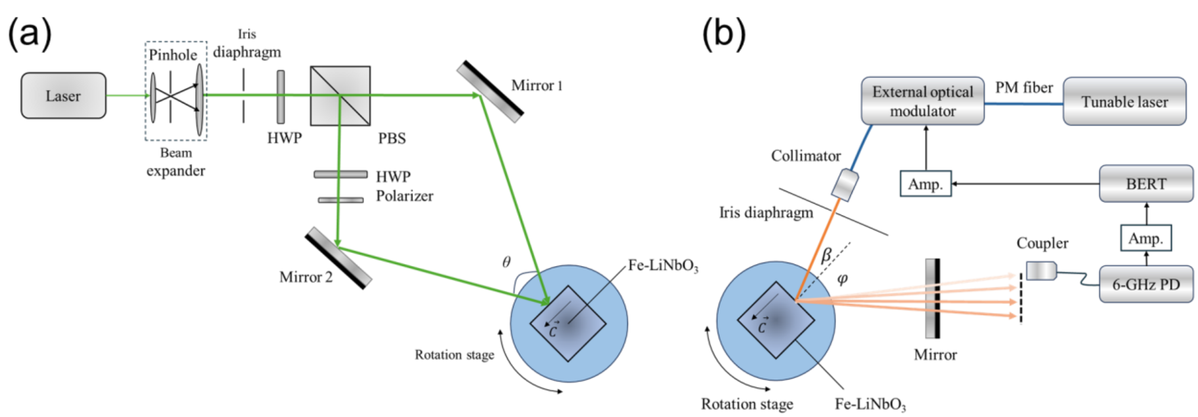

Fig. 1. The schematic diagram of (a) the holography recording system based on 532.2nm light, and (b) the read-out beamsteering system at around 1550nm. HWP: half-wave plate; PD: photodetector; Amp.: amplifier; BERT: bit-error-rate tester.

Fig. 1(a) presents the detailed setup of the recording and reading process, respectively. Light at 532.2nm from a laser passes through an expander and an iris to control its diameter to approximately 4mm, which closely matches the size of the used Fe-doped $LiNbO_3$ crystal (5×5×5mm^3). Light output from a HWP is 45° polarized to the horizontal orientation. Then light is divided into two arms by a PBS. The light with p-state passes through another HWP and polarizer to ensure the same polarization for interference. The intensity of light from the two arms is set to be as close as possible to identical. The crossing angle θ in air between writing beams, is 93.6°, to achieve good wavelength selectivity for transmission holograms at around 1550nm. After recording, the crystal was rotated with a step of 2.5° for each of the four recording positions. The reading process is shown In Fig. 1(b). Here, the recorded holograms are read by multiwavelength beams at around 1550 nm, with a new incident angle β of 2°.

A 10-GHz bandwidth external modulator is used to modulate the beam from the tunable laser, using an OOK signal sent from a BERT. A collimator is used to capture the beamsteered signal, and this is detected using a fibre-coupled 6-GHz photodetector. The received signals are amplified and captured using a BERT. The signals are then compared with those transmitted to evaluate the BER performance. A PRBS sequence with a data pattern length of 2^{31}-1 is used.

3. Results and Discussions

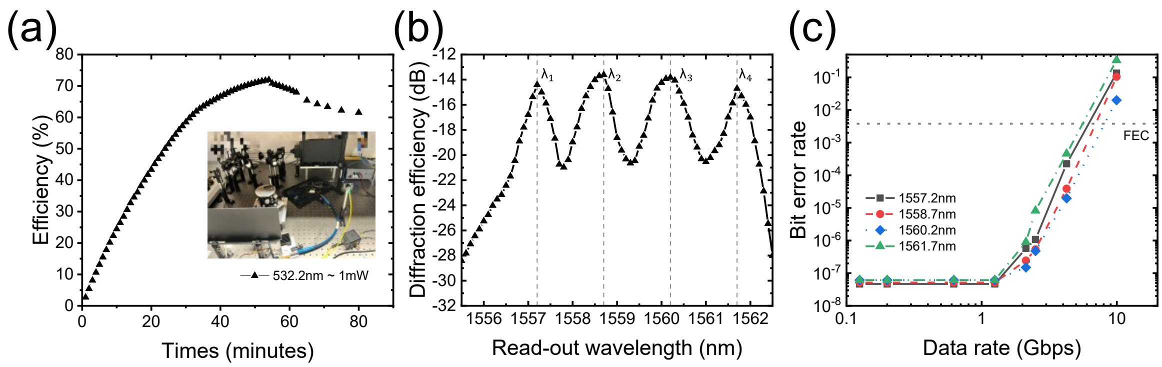

Fig. 2. (a) Diffraction efficiency as a function of time (insert: photography of the setup). (b) Demultiplexing of 1.5 nm λ-spaced channels via angle-multiplexed holograms recorded at 532.2 nm. (c) The BER performance versus data rate at different wavelength channels.

Fig. 2(a) shows the diffraction efficiency variation of diffracted 532.2nm light vs time under recording. The highest diffraction efficiency of up to 70% appears after 52 minutes of recording. A decrease in refractive efficiency is observed as the recording time is further extended, which can be attributed to the erasure of the grating by the visible beam used for reading. Fig. 2(b) shows the diffraction efficiency versus readout wavelength for the recorded holograms. The four peaks correspond to four diffracted holograms, and are observed at the wavelength of 1557.2nm, 1558.7nm, 1560.2nm, and 1561.7nm, respectively. The diffraction efficiency of read-out is defined as the ratio between the power diffracted off the crystal and the power of the reading light that enters it. The diffraction efficiency can reach the highest value of -13.8dB at a wavelength of 1558.7nm. A wavelength demultiplexing of four channels is demonstrated with 14dB loss and a crosstalk suppression of up to 15 dB. Fig. 2(c) presents the bit error rate (BER) performance vs data rates at a 0.5m free-space transmission distance. The input reading power of each channel for optical communication is 10dBm. All four channels can achieve a maximum data rate of 4.25Gbit/s with a BER below the forward error correction limit of 3.8×10^{-3}. Therefore, a total transmission rate of 17Gbit/s can be achieved in this WDM system.

4. Conclusion

In summary, we propose a feasible wavelength demultiplexing technique to program a long wavelength device using short wavelength holography recording. Four channels with a wavelength spacing of 1.5nm at C band are demultiplexed for wireless infrared communication to achieve a total rate of 17Gbit/s. The work provides a potential beamsteering solution for establishing a real all-optical network.

5. Acknowledgements

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6. References

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