128 Gbps NRZ and 224 Gbps PAM-4 Signals Reception in Graphene Plasmonic PDM Receiver

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Abstract: We report high-data rate reception of polarization division multiplexing signals using graphene-on-plasmonic slot waveguide photodetectors with bandwidth exceeding 70 GHz. 128 Gbps NRZ and 224 Gbps PAM-4 signals reception are experimentally demonstrated at 1550 nm with high quality.

OCIS codes: (060.4230) Multiplexing; (250.5403) Plasmonics; (040.5160) Photodetector; (230.3120) Intergrated optics devices;

1. Introduction

To meet the growing demand for communication capacity, multi-dimensional multiplexing technology is widely used in fiber optics and integrated chips. Especially, silicon-based integrated platforms used for multi-dimensional multiplexing have attracted great interests, owing to their low cost and compatibility with CMOS technology. Among various multiplexing technologies, polarization division multiplexing (PDM) has the capability to double transmission capacity and can be integrated on the silicon platform without increasing the complexity [1]. As an essential part of high-speed silicon-based integrated chips, high-speed optical receiving modules for PDM signals demodulation and detection are highly desirable. In such modules, high-speed photodetectors (PD) and polarization demultiplexer are key devices. However, reception capacity of the reported PDM receivers [2] were typically limited by the bandwidth of the PDs. As one of the promising solution, graphene PD on the silicon platform has been gaining increasing attention due to its ultrafast response and large bandwidth [3]. Particularly, implementation of a graphene PD on a plasmonic waveguide can boost bandwidth to 110 GHz [4, 5] and realize 100 Gbit/s data reception [5]. However, it is essential to keep the performance consistency of the graphene PDs when used for a high-speed PDM receiver, as we demonstrate in this work.

In this work, we report a graphene plasmonic optical receiver for the detection of PDM signals. Our graphene-on-plasmonic slot waveguide (PSW) PDs have a bandwidth exceeding 70 GHz and a response over 0.1 A/W. Line-rate of 128 Gbit/s non-return-to-zero (NRZ) and 224 Gbit/s four-level Pulse Amplitude Modulation (PAM-4) signals reception are achieved using graphene PDs for the first time. The optical receiver has a power penalty of 1 dB for single polarization and dual polarization states detection. The polarization-dependent loss (PDL) of the PDM receiver is less than 0.7 dB in the C-band range of 1530-1563 nm.

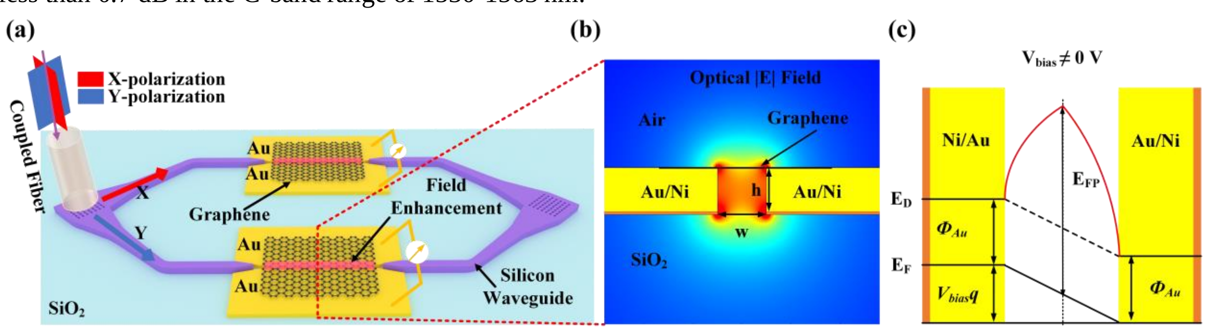

Fig. 1. (a) Schematic diagram of graphene plasmonic PDM receiver. (b) Simulated electric field of the plasmonic mode at 1550 nm (transverse component). (c) Principle of the graphene PD at non zero bias voltage. The E_F is the fermi level, the E_D is the dirac point, and the E_{FP} is the peak Fermi energy point.

2. Device structure design and fabrication

The designed graphene plasmonic PDM receiver is schematically demonstrated in Fig. 1(a). The receiver consists of two two-dimensional (2D) grating couplers (GC) for in/out-coupling and polarization demultiplexing in the test, and two graphene-on-PSW PDs. The PDM signal is demultiplexed by the 2D GC, and directly detected by the graphene-on-PSW PDs. The PD is formed by a plasmonic slot waveguide (PSW) covered by 15-μm long graphene. The plasmonic mode is excited from the silicon stripe waveguide by means of linearly tapered mode converters. The PSW has a thickness of 90 nm and a width of 100 nm as shown in Fig. 1(b). The large field confinement of the designed PSW extremely enhances the graphene-light interaction, which enable efficient photodetection. The two symmetric metallic slabs of Au (90 nm) / Ni (5 nm) lead to the same doping for the covered graphene that is symmetrically distributed on the slot and two metallic slabs. The principle of such a PD is the dominated photoconductive effect under an non-zero bias voltage (Fig. 1(c)) and the photocurrent increase with the increase of incident light power.

The device was fabricated on a commercial silicon-on-insulator sample with a top silicon layer of 220 nm and buried oxide layer of 2 μm. The 2D GC and silicon waveguides were patterned by electron-beam lithography (EBL) (Vistec EBPG 5000plus ES) and fabricated by inductively coupled plasma (ICP) enching (Plasmalab system 100 ICP180). Then, the two metallic slabs were patterned by a second EBL and fabricated by e-beam evaporation (Ohmiker-50B) followed a lift-off process. Finally, a single-layer CVD graphene layer was wet-transferred and patterned by a third EBL and oxygen plasmonic etching to form the required graphene structure.

3. Device characteristics

In order to improve the detection quality of the PDM signal, it is necessary to ensure that the incident light entering the two detectors are consistent. We used the 2D GC reported in Ref [6] to reduce the PDL of the device and designed the optical paths to two PDs with the same length. Fig. 2(a) shows the measured coupling efficiency spectra for two polarization states and the PDL of the device consist of a PSW and two 2D GCs. In the C-band range of 1530-1563 nm, our receiver has a PDL less than 0.7 dB. The peak loss of the 2D GC is ~6 dB at 1548 nm.

The bandwidth of the PDs were quantified by a 70 GHz two-port vector network analyzer. During the measurement, we adjusted the polarization controller (PC) to obtain the polarization state corresponding to the PD under test. In order to improve the signal-to-noise ratio of the frequency response of the PDs, the optical input power entering the 2D GC was set to 13 dBm and the bias voltage was set to 0.8 V. The obtained responsivity is over 0.1 A/W. As shown in Fig. 2(b), the 3 dB bandwidth of the two PDs are both larger than 70 GHz, and the two curves are well matched. The dips in the curves are attributed to imperfect connections to the RF probe.

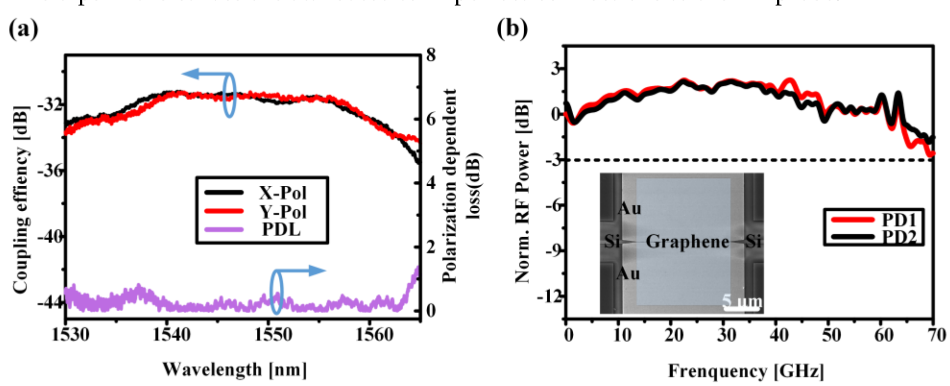

Fig. 2. (a) X/Y-polarized coupling spectra and the PDL of the proposed PSW with 2D GCs. (b) Bandwidth characterization of the two PDs. Inset: the scanning electron microscope image of the graphene-on-PSW PD.

We then demonstrated the capacity of the graphene plasmonic PDM receiver for high-data rate reception. The data reception experiments of 64 GBd NRZ and 56 GBd PAM-4 PDM signals are respectively performed for single polarization (X or Y polarization) and dual polarization (X and Y polarization) states, corresponding to a line rate of 128 Gbit/s and 224 Gbit/s. As shown in Fig. 3(a), two electrical signals with square-root-raised cosine pulse shape spectrum are generated by an arbitrary waveform generator (AWG, keysight M8195A), which are then amplified by two electrical amplifiers (CENTELLAX OA4SMM4), and encoded on the optical carrier of two channels at 1550 nm by two Mach-Zehnder modulators. Assisted by two PCs (PC3 and PC4), the modulated signals are combined by a polarization beam combiner (PBC), forming the PDM signals. By adjusting PC5 before the device, single polarization detection and dual polarization detection can be realized. The generated electrical signal from the PD is amplified by an electrical amplifier (SHF S804A) and recorded by a digital signal analyzer (DSA, keysight DSAZ594A). Digital signal processing (DSP) is performed offline to form the eye diagram and evaluate the bit-error ratio (BER) and signal-to-noise ratio (SNR), including timing recovery, adaptive least mean square equalization, nonlinear pattern dependent equalization, and symbol decision. The results are shown in Fig. 3(b). For the X polarization state, PD1 obtains an open eye diagram, while the PD2 has only noise. For the Y polarization state, the PD2 obtains an open eye diagram, while the PD1 has only noise. When receiving PDM signals with dual polarization states, both PD1 and PD2 obtain the same open eye diagrams. The BERs and SNRs are listed in the Fig. 3(b) below the eye diagrams. For the dual polarization detection, the quality of eye diagrams degrades due to the polarization crosstalk, resulting in 1 dB power-penalty compared to the single polarization detection. The results sufficiently validate that the PDM signals can be detected by the proposed graphene plasmonic PDM receiver.

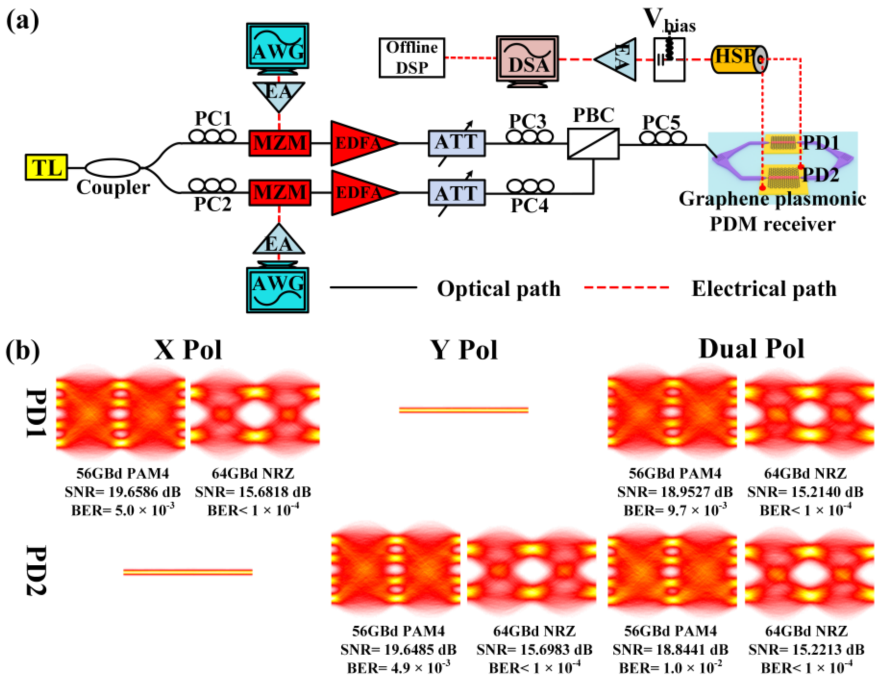

Fig. 3. (a) Measurement setup for the PDM signal reception (b) The measured 56 GBd PAM-4 and 64 GBd NRZ eye diagrams by PD1 and PD2 for the X, Y and Dual polarization states. The measured BERs and SNRs by the offline DSP.

4. Summary

We experimentally demonstrate an on-chip PDM receiver based on high-speed graphene-on-PSW PDs and 2D GCs. The PDM receiver has a PDL less than 0.7 dB in the C band. The receiver shows similar eye diagrams for 64 GBd NRZ and 56 GBd PAM-4 signals in dual polarization states, corresponding to line-rates of 128 Gbit/s and 224 Gbit/s, respectively. Moreover, BERs below a KP4-FEC and a 15% soft-decision FEC threshold are demonstrated for the NRZ and PAM-4 signals, respectively. The PDs combining the PSW and CVD-growth graphene may have potential to receive high-speed advanced modulation format signals in coherent detection scheme.

5. Acknowledgements

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