Integrated Spectrometer Based on Arrayed Waveguide Grating and PbS Colloidal Quantum Dot Photodiode Array

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Abstract: An integrated spectrometer based on arrayed waveguide grating and PbS colloidal quantum dot photodiode array was demonstrated on the silicon nitride photonic platform, operating around 1300 nm, which might be an attractive low-cost integration routine.

1. Introduction

Integrated spectrometers have attracted large interest in recent years, in the context of various applications, such as portable and wearable health monitoring and smartphone-based spectroscopic analysis. Such a device typically consists of a dispersive element such as an arrayed waveguide grating router or planar concave grating, combined with a photodetector array. However, for some photonic platforms such as SiN, there is no obvious solution to integrate a photodetector array. Colloidal quantum dot (CQD) based photodetectors [1,2] might be a possible candidate. They exhibit strong and tunable absorption, cheap chemical-based synthesis, solution-based processing, and good compatibility with different kinds of substrates. Here, we integrated a PbS CQD-based photodiode (PD) array on the output channels of an arrayed waveguide grating (AWG), demonstrating a cost-effective on-chip spectrometer operating around 1300 nm.

2. Integration of photodiode

The device was fabricated starting from a Si substrate with a 300 nm PECVD SiN-layer deposited on top of a 3 µm thermal oxide layer. The PD was put on top of a 30 µm wide SiN waveguide covered with a 350 nm thick SiO_2 spacer, as shown in Fig. 1(a). The waveguide width and spacer thickness were designed sufficiently large to compensate for the relatively low saturation threshold of the CQD PD. The 20 nm ZnO / 60 nm PbS-PbI2 / 60 nm PbS-EDT PD stack served as a n-i-p heterojunction for carrier extraction. The ZnO electron-transport layer was grown with atomic layer deposition (ALD). It is naturally n-doped and has high enough conductivity to support horizontal electron transport. The PbS CQDs were deposited by spin-coating. PbS CQDs with an exciton peak around 1300 nm were used as the absorption layer. The surface ligands were exchanged for iodine (PbS-PbI_2) to increase the carrier mobility and make them slightly n-doped. Then PbS CQDs with exciton absorption around 900 nm were spin-coated on top as the hole-transport and electron-blocking layer. For this layer, the original ligands were replaced by 1,2-ethanedithiol (EDT) to make the film p-doped. Ti/Au was put on ZnO as n-contact metal. Patterned Au on top of the PD stack worked as p-contact. The metal and CQD films were patterned by photo- and ebeam-lithography respectively, combined with liftoff in acetone.

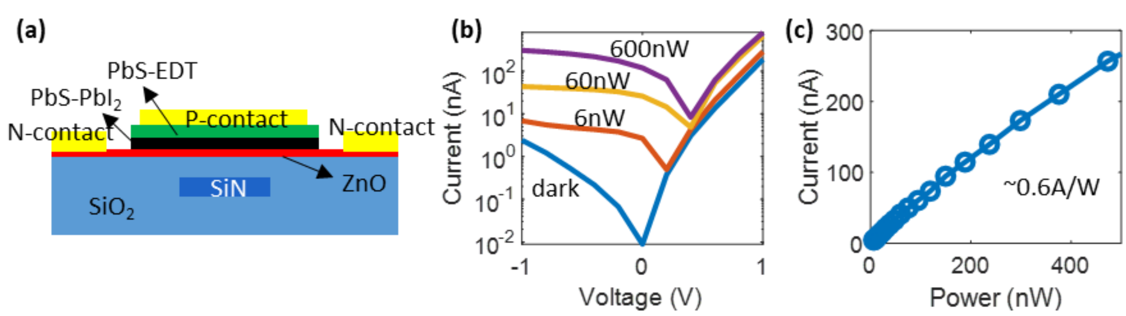

Fig. 1. (a) Cross-section of the waveguide-integrated photodiode. (b) I-V curves of WG-PDs under dark condition and illumination (power in waveguide). (c) Photo-current vs. optical power with -1V bias, at 1275 nm.

The integrated PD was characterized at 1275nm. Fig. 1(b) shows the current response at different illumination power. The dark current was as low as 2 nA at -1V bias. The responsivity of the integrated PD was almost linear when the input optical power was below 500 nW, as shown in Fig. 1(c).

3. Integrated spectrometer

The AWG was designed with IPKISS [3], with eight output channels and 7.5 nm channel spacing. The PbS CQD PD array was connected to the output waveguides of the AWG, as shown in Fig. 2(a). The response of the integrated spectrometer was characterized by injecting light through the input grating coupler and measuring the photocurrent with 0 V bias to assure a low dark current floor. The measured photocurrent was normalized to the maximum of each channel to remove the non-uniformity induced by the grating coupler, as shown in Fig. 2(b). The crosstalk was around 15 dB. We believe this could be further improved by optimizing the design and fabrication of the AWG. All diodes of the PD array worked, indicating the potentially high yield of CQD-PD integration.

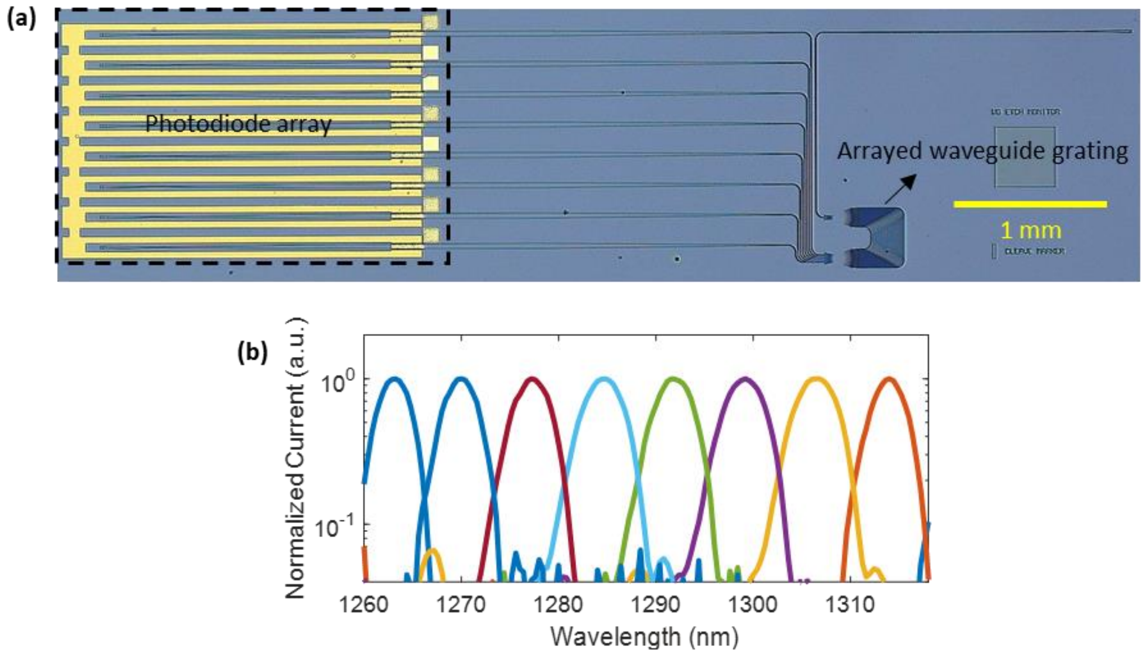

Fig. 2. (a) Top view of the integrated spectrometer with CQD PD array and arrayed waveguide grating. (b) Response of 8 channels with zero bias. The response of each channel was normalized to its maximum.

To sum up, an integrated spectrometer consisting of a PbS CQD PD array and an AWG was demonstrated, using standard processing techniques. The low-cost integration routine proposed might be attractive to massive production.

4. Acknowledgement

This project received funding from the European Research Council (ERC) under the innovation program grant agreement No. 884963 (ERC AdG NARIOS). Chao Pang acknowledges support from the China Scholarship Council (CSC).

5. Reference

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