106 Gb/s Normal-Incidence Ge/Si Avalanche Photodiode with High Sensitivity

Bin Shi, Fan Qi, Pengfei Cai, Xueping Chen, Zengwen He, Yanhui Duan, Guanghui Hou, Tzungi Su, Su Li, Wang Chen, Chingyin Hong, Rang-Chen Yu and Dong Pan*

SiFotonics Technologies Co., Ltd., 400 Trade Center, Suite 4950, Woburn, MA 01801, USA,
**Corresponding author: dp7u@sifotonics.com*

Abstract: 106 Gb/s (53GBaud PAM4) normal-incidence Ge/Si APDs were demonstrated with sensitivities of -16.8 dBm. To our knowledge, this is the best sensitivity reported for 100G APD.

OCIS codes: (040.1345) Avalanche photodiodes (APD); (060.4510) Optical communications

1. Introduction

Prevalent internet web applications and mobile networking are driving optical networking speed increase at ever faster pace, while covering ever larger physical geographies. For example, hyper data centers around the globe is facing another round of speed transition from 100G to 400G, while size of data centers are growing rapidly from one single building to large campus with interconnected data centers over several to 10s of kilometers. On the other hand, emerging 5G mobile networks are driving front haul optical networking from 10 Gb/s to 25 Gb/s, and middle-haul and aggregation to 50 Gb/s and 100 Gb/s. With speed increase, optical link budget is shrinking due to limitation of conventional detection technologies, such as PIN diode, and more advanced cost effective detection technologies are needed to support this fast-paced growth. Avalanche photodiodes (APD) are one of the excellent candidates to meet this challenge.

Traditionally, III-V materials such as InGaAs/InP are used for APDs. A 106 Gb/s PAM4 link using InGaAs/InP APD with a sensitivity around -11.79 dBm at BER = 2E-4 was reported previously [1]. At the working point, the APD had a bandwidth of near 30 GHz and responsivity of 1.50 A/W (primary responsivity 0.5 A/W), showing a gain-bandwidth product (GBP) of ~90 GHz. Recent developments in Ge/Si APDs have demonstrated higher GBP performance at high speed due-to combination of Ge broad optical absorption spectrum and silicon's intrinsic lower ionization coefficient ratio. In 2016, we demonstrated an O-band 25.78 Gb/s Ge/Si APD with a sensitivity of -22.5 dBm at BER = 1E-12 using a normal-incidence device structure [2]. This APD had shown good yield and long-life time in mass production, and had been deployed in 5G networks. Recently, Ge/Si APD with higher GBP have been realized in our lab [3] and by others [4,5]. Among these, a 50 Gb/s PAM4 link with a sensitivity of -16dBm at BER = 2E-4 was demonstrated [4].

In this work, we report record breaking results of a Ge/Si APD with 53GBaud PAM4 modulation to achieve better than -16.8 dBm sensitivity at 106 Gb/s, with BER = 2E-4. The bandwidth and responsivity (1310nm) can reach 28 GHz and 6.54 A/W, respectively. The GBP is estimated to be 180 GHz at the working point. As a comparison, a Ge/Si PIN PD was measured under the same condition, and the PAM4 sensitivity of a 53 Gb/s APD with large aperture were also presented in this paper. Both the 53 Gb/s and 106 Gb/s APD show record-breaking sensitivity and the latter had a 4~6 dB sensitivity improvement comparing with its PD counterpart.

2. Results

Fig. 1(a) shows photograph of the APD chip. The APD structure was similar to our previous reported structure [2].

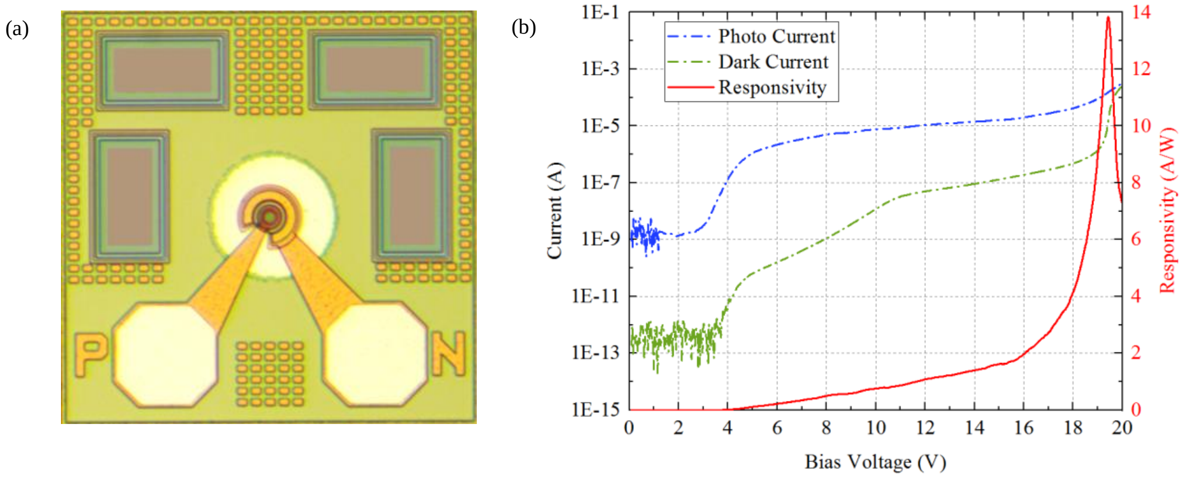

Fig. 1. DC measurements of the APD Chip. (a) Optical image. (b) Photo current, dark current and responsivity curves at 25ºC.

DC measurement results are shown in Fig. 1(b). The breakdown voltage (V_{BR}), defined as the applied voltage leading to 100 μA room temperature dark current, was 19.6 V. The typical dark current of the APD chip at V_{BR} – 1 V was about 0.84 μA at room temperature. The responsivity of 1310 nm was 6.54 A/W at V_{BR} – 1 V and 3.53 A/W at V_{BR} – 2 V, with primary responsivity estimated to be 0.55 A/W. Comparing with our previous 25G APD [2] , the typical device capacitance decreased from 70 fF to 35 fF.

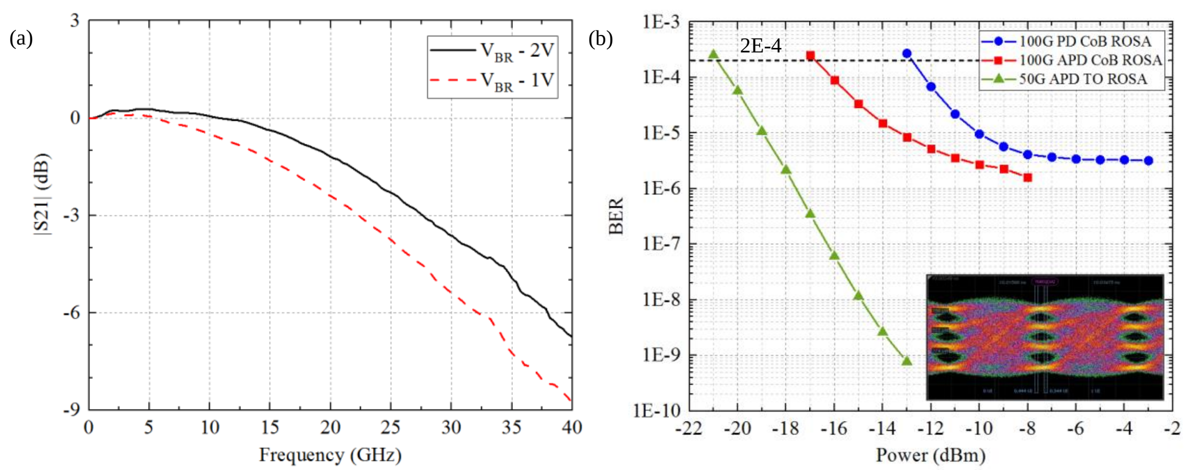

Fig. 2. (a) RF response of the APD chip. (b) BER measurements in a back-to-back configuration for three different types of ROSA, insert is the optical eyediagram of the DR1 light source.

We also performed RF measurement with Cascade 40 GHz GSG probes, and the measured S21 curves are shown in Fig. 2(a). The 3-dB bandwidth was 23 GHz at V_{BR} – 1 V and 28 GHz at V_{BR} – 2 V. Then the chip was packaged with a commercially available TIA in a Chip-on-Board (CoB) type ROSA and the total 3-dB bandwidth was 32 GHz. The increase of observed bandwidth is due to the pre-designed transfer function of TIA to enhance the over-all bandwidth. A 100G commercial DR1 transceiver (λ=1310 nm, PAM4) was used as light source, with TDECQ = 2 dB and outer ER = 7.5 dB, and the optical eyediagram of the DR1 light source is shown as the insert of Fig. 2(b). The bit error rate (BER) was measured with a BER tester which had a build-in receiver equalizer and the result is shown in Fig. 2(b). Under the bias of V_{BR} – 2 V, the sensitivity was -16.8 dBm at BER = 2E-4. The measurement using a commercial DSP instead of the BERT as the Rx port obtained a similar result. To our knowledge, this is the best sensitivity reported for 53 GBaud PAM4 APD.

The sensitivity of a normal-incidence Ge/Si PIN PD (in the same CoB package) was measured to be -12.8 dBm at 106 Gb/s with the same DR1 light source. Bandwidth and responsibility of the PD ROSA were about 27GHz and 0.8A/W, respectively. The structure and fabrication of the PD was similar with the APD, except that there was no Si avalanche layer. Generally, PD exhibits -10 ~ -11 dBm sensitivity under this condition, and transmission distance will be limited to ~10km. The APD shows much improved sensitivity to -16.8 dBm, with reasonable transmitter power of +3 dBm, it is possible to extend single channel transmission distance up to 40 km.

BER measurement of 26 GBaud APD TO ROSA with larger optical aperture was also conducted to be compared, which had a 3-dB bandwidth of 24 GHz at V_{BR} – 1 V and almost the same responsivity. This measurement is performed by using an EML light source with TDECQ = 1.41 dB and outer ER = 5.7 dB. The sensitivity with a 53 Gb/s PAM4 signal was -21 dBm at BER = 2E-4, which is also the best result reported for 50G APD to our knowledge.

3. Discussion

Ge/Si APD has excellent GBP and very low ionization coefficient ratio due to silicon's intrinsic material properties. The GBP of this device is about 270 GHz at V_{BR} – 1 V, and 180GHz at V_{BR} – 2 V, which means we can get high gain and high bandwidth simultaneously for 100G application. As a comparison, the InGaAs/InAlAs or other III-V APD usually have a lower GBP about 100GHz at working point [1].

On the other hand, BER floor level in Fig.2 can be further improved to less than 1E-6 by using better light source and DSP optimization. Moreover, device and system simulation results show sensitivity of 100G APD chip can be further improved by fine tuning device parameters. We believe that Ge/Si 100G APD devices are very promising for extended reach 10 km to 40 km optical interconnect applications for DCI and 5G mobile networks.

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