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Single Photon Detection with Sine Gated Dual InGaAs/InP Avalanche Diodes

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Abstract—**We propose and demonstrate a technique cancel common mode signals of sinusoidally gated single photon avalanche diodes (SPADs). This approach enables the elimination of narrow-band filters that fix the frequency of conventional single photon detection with sine wave gating.**

Index terms— **single-photon avalanche diode, single-photon detection, photon counting, dark count rate, afterpulsing, infrared photons, InP.**

I. INTRODUCTION

Sinusoidal gating is one of recent techniques that have been deployed to realize high-speed single photon detection [1-3]. It has the potential to achieve high bit rate transmission while suppressing the afterpulsing effect in InGaAs/InP SPADs. Afterpulsing is the primary factor that limits InGaAs/InP SPADs for GHz applications. Afterpulses are avalanche events that are initiated by the release of carriers that were trapped on deep levels in previous avalanche events. To achieve high data rates, it is beneficial to reduce the charge flow. With sinusoidal gating, the capacitive response of the SPAD is filtered by narrow band elimination filters. This enables detection of small amplitude avalanche pulses. The filters, however, fix the operation frequency. To remove this limitation, a dual detector approach is proposed and demonstrated in this paper. We utilize two identical SPADs in a balanced configuration to cancel the common mode signals []. Thus we realize the continuous tuning of the operation frequency of sinusoidal gating system without any RF filters.

II. EXPERIMENTAL SET UP

Fig. 1 shows the dual SPAD receiver. The two photodiodes are reverse biased and connected to opposite AC voltage swings. Light is incident on only one of the SPADs. This configuration is similar to differential detection [4] but does not require extra circuitry to realize the comparison of signals [5]. The ultimate performance of this type of receiver depends on how well the common signals are cancelled. One of the major goals is to ensure the symmetry of the device pair and circuit layout. Figs. 2(a) and 2(b) are pictures of the two photodiodes and printed circuit board on which the components have been combined with hybrid integration.

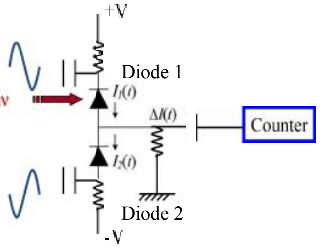
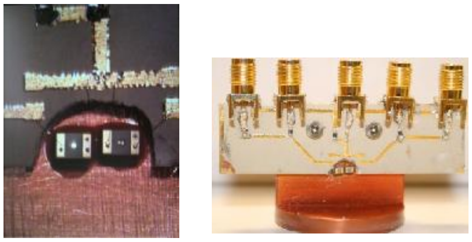


Figure 1. Dual SPADs operated in balanced scenario with opposite applied biases, current difference represents avalanche event in diode 1



(a)

(b)

Figure 2. Images of diode pair under test (a) and completed circuit board (b)

III. RESULTS AND DISCUSSION

The dual SPAD receiver was first tested with pulsed gating [6]. The applied DC biases on Diode 1 and Diode 2 are positive and negative, respectively (Fig. 1). The AC square wave pulses are synchronized to cancel the transient signals at the leading and trailing edges of the pulses. Fig. 3 illustrates the transient cancellation. Dashed curves are the transient responses of the two diodes in the dark. The solid curve is the output signal with a photon-induced avalanche event. The residual noise signal is approximately 5 mV, while the avalanche pulse has amplitude of 12 mV. The amplitude of the avalanche pulse is approximately one tenth that for conventional pulsed gating. To detect the avalanche signal, the counter threshold was set at -20 ~ -23 mV. The degree of transient signal cancellation depends on many factors, such as the dark current of the diode pair, stray capacitance of the pair, coincidence of the bias pulses,

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perturbation caused by avalanche events and mismatch in the transmission lines. To ensure good cancellation, it is necessary to use SPADs with closely matched characteristics. Usually this can be accomplished by choosing two adjacent on the wafer. The subsequent packaging can introduce some unbalance in the stray capacitance, which could account for the mismatched pulse amplitude and residual noise signal in Fig. 3.

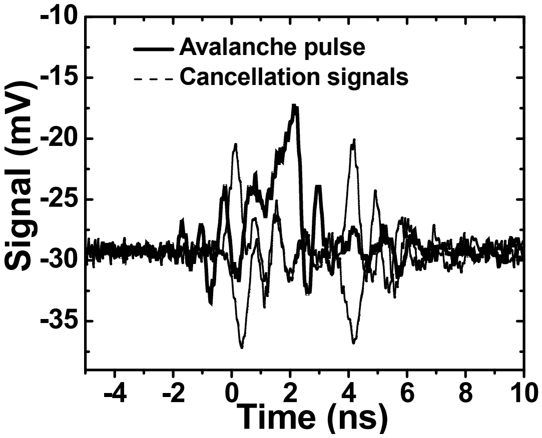

Figure 3. Oscilloscope traces for bias pulses applied individually to either diode 1 or diode 2 (dashed line) and the cancellation when both diodes are biased simultaneously with an avalanche event in one diode (solid line).

The dual SPAD receiver was also tested with sinusoidal gating [7] at 240K. The gating frequency was 80 MHz. The photon source was an attenuated laser with a pulse width of ~ 70 ps, which is shorter than that of the excess bias signal of the sine wave gate. The light intensity was 0.1 photons per pulse. The laser repetition rate can be changed to be submultiples of the gating rate. A variety of laser rates were used to achieve higher photon detection efficiency (PDE) with low dark count rate (DCR). For laser repetition rate equal to or higher than 10 MHz, PDE was less than 30%. This is consistent conventional sine wave gating (Fig. 4). By reducing the laser repetition rate, PDE as high as 50% was achievable. The best result with balanced SPADs was 42.8% PDE and 58.2 kHz DCR with 1 MHz laser repetition rate (Fig. 4).

Afterpulse probability is also compared with the previously reported conventional sinusoidal gating [7]. Fig. 5 shows that the dual SPAD receiver shows lower afterpulse probability. The reduction in afterpulsing probability can be attributed to the cancellation of the coincident dark pulses or afterpulses. This also explains the fluctuation in the afterpulse probability, since the coincidence and cancellation of dark pulses is random.

In conclusion, we report sinusoidal gated dual SPADs with high PDE, low DCR and afterpulse probability. The dual SPADs configuration removes the frequency limitation of conventional sine wave.

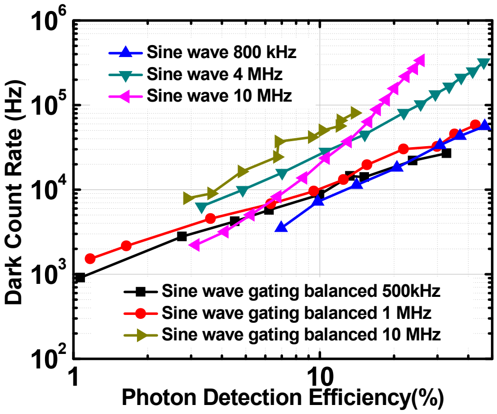

Figure 4. DCR Vs PDE result from single and dual SPADs with different laser repetition rate

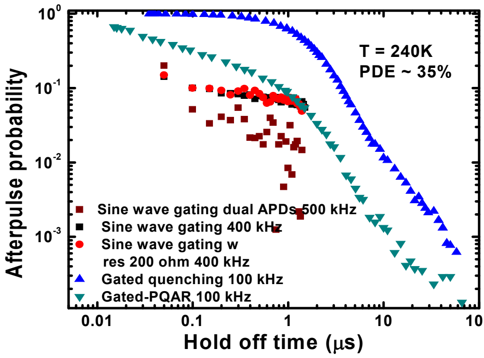

Figure 5. Afterpulse probability of single and dual SPADs with different gating scheme and laser repetition rate and similar PDE.

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