Student Paper

A Type-II Near-Infrared Detector with Very High Stable Gain and Low Noise at Room Temperature

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For decades, humankind has tried to harness the power of invisible light to image or communicate beyond what our eyes can see. Significant attention has been focused on near infrared (NIR) spectrum, and different types of infrared detection methods have been proposed and developed. Here, we report a new NIR detector based on a type-II band alignment and nano-scale sensing volumes.

Among the current technologies, the most common NIR detectors for single-photon detection are avalanche photodiodes based on InP/InGaAs material system [1]. They provide stable gain values of less than a few hundreds, and their small footprint makes them the preferred choice for many applications. However, they have inherent problems that limit their use: They suffer from high leakage currents due to required high internal electric fields. They show elevated noise levels due to high excess noise factors inherent to avalanche multiplication [2]. Afterpulsing effects are also observed [3], increasing the dark counts and preventing high speed operation. Therefore, APD applications are mainly limited to synchronized systems [4], and they are not suitable for asynchronous systems such as real-time imaging.

To overcome the limitations of current technologies, we have designed an avalanche-free infrared detector. Each device consists of an InP/GaAsSb injector on top of a large InGaAs absorption volume as detailed in Figure 1. The bottom of the injector is a separate layer (GaAsSb) with type-II band alignment to the upper part of the injector (InP) and to the absorption layer. Due to this alignment, the GaAsSb region presents a valance band trap for holes and a conduction band barrier for electrons. The operation principle of the detector is based on exploiting this band alignment: When a photon gets absorbed in the large absorption volume, the internal electric field attracts the hole towards the GaAsSb trap where it raises the voltage. The small volume of the GaAsSb trap ensures that the voltage change due to even a single charge would be significant. The elevated voltage results in a lowered conduction barrier and an exponential increase in the number of electrons from the InP injector into the InGaAs absorption. The collection of all optically generated holes into a nano-scale sensing volume and exponential electron injection with even a slight change in barrier height creates the internal gain mechanism. This gain mechanism allows very high stable gain values with insignificant excess noise due to the statistical stability. Furthermore, it does not require high bias voltages.

The designed devices were fabricated on MOCVD grown InP wafers. They were patterned with e-beam lithography and metalized. The injectors were formed by dry etching with reactive ion etcher. The fabricated devices were characterized under different tests. The dark current performance of the detectors was evaluated, and photo-response was measured under calibrated laser light at 1.55 μm wavelength. The devices showed decreasing dark current with decreasing injector size: Devices with 15 μm injector diameter showed more 35 μA at 1 V bias; whereas 1 μm diameter devices had less than 100 nA at the same voltage (Figure 2-a). Measured optical gain also showed a strong dependence on size, big 10 μm devices had gain values exceeding 10000 in contrast to 1 μm devices with gain values around 1000 (Figure 2-b).

We believe that the high gain is linked to surface states and the traps. Bandwidth measurements at room temperature showed that the devices have an electrical bandwidth of around 10 kHz. However, we have also developed an additional passivation process that results in a trade-off between speed and gain: Passivated devices have bandwidth exceeding several GHz with lowered gain values around 100. Rise time in the passivated devices is less than 250 ps with jitter values around 14 ps RMS at room temperature (Figure 3). Pulse response does not exhibit any afterpulsing and hence the devices have negligible deadtime.

Excess noise measurements were also performed on these devices. The devices were probed with a high frequency shielded RF probe, with which dark current, photocurrent and noise power were acquired. The measured data was compared to the expected shot noise with that particular gain and

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showed no measurable excess noise, which confirmed our predictions about the low noise nature of this multiplication process.

We have designed and fabricated a novel type-II near-infrared detector without avalanche multiplication. The fabricated devices showed stable gain values exceeding 10000 for large devices at room temperature. In contrast, devices with smaller injectors showed less than 100 nA leakage current at gain values as high as 1000. The bandwidth of unpassivated devices with high gain was measured to be around 10 kHz. However, we have also developed a process for trading the gain with speed, and the resulting devices had electrical bandwidths exceeding several Ghz, with rise times less than 250 ps and jitter values of 14 ps RMS. Finally, the noise measurements on the devices confirmed that the multiplication method is low noise, with no excess noise observed in our experiments.

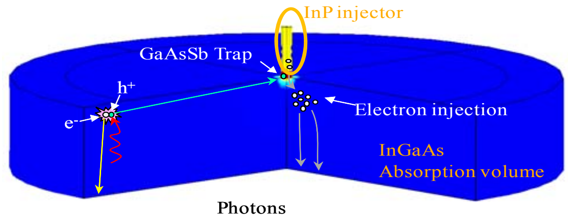
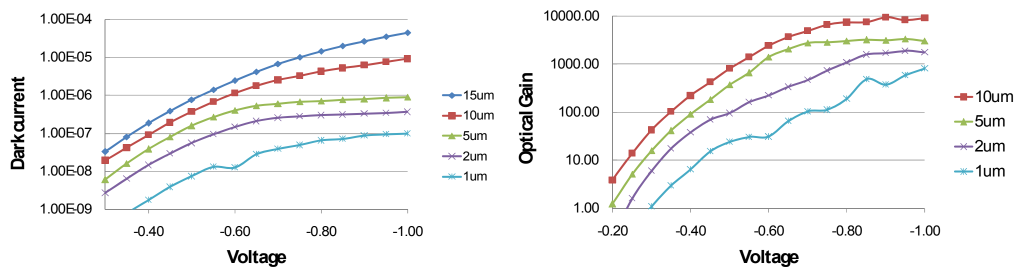


Figure 1 – The device structure: The nano-injector (InP/GaAsSb) is connected to a large InGaAs absorption volume.



(a) **(b)**

Figure 2 – (a) Dark current versus voltage plots for unpassivated devices of injector diameters 15 µm to 1 µm at room temperature. (b) The measured optical gain values at different voltages for different devices. The large devices with 10 µm diameter show stable gain values exceeding 10000. In contrast, 1 µm devices have stable gain values around 1000.

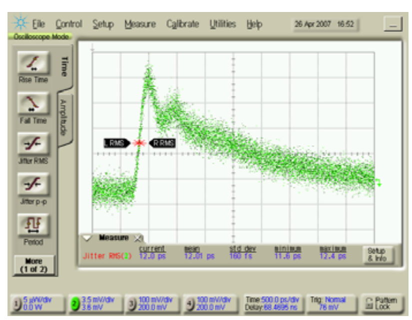


Figure 3 – The transient response of the detector under 300 fs pulsed laser illumination.

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