Low Noise, High Gain Short-Wave Infrared Nano-Injection Photon Detectors with Low Jitter

Omer Gokalp Memis[1], Alex Katsnelson[1] and Hooman Mohseni[1]

[1]*Dept. of Electrical Engineering and Computer Science, Northwestern University, Evanston, IL 60208*

We present the near-infrared injection photodetectors with high internal amplification exceeding 10,000 and suppressed shot noise levels with Fano factors of ~0.55. When surface-passivated, devices exhibited high-speed response (3+ GHz) with low jitter <15 ps.

There has been a significant amount of research in photodetector technologies towards the optical detection in short wave infrared (SWIR) spectrum, particularly focusing at 1.55 μm wavelength. Spanning a wide range of applications from slow imaging technologies to very high speed fiber telecommunications, SWIR contains both well-established technologies in demand of constant improvement, and emerging applications which require novel, state-of-the-art designs. Over the last decades, the technologies towards short wave detection provide have been improved to satisfy the ever growing needs of these applications, and new types of detectors have been created. Common technologies for SWIR detection are InGaAs/InP based detectors (P-I-N and avalanche diodes) and superconducting single photon detectors (SSPDs). InGaAs/InP diodes [1] have achieved very low leakage current with high-speed response, but they lack of an internal amplification mechanism. This requires pairing P-I-N detectors with preamplifiers, in which case the overall performance is mostly determined by the preamplifier specifications. To overcome this limitation, InGaAs/InP avalanche photodetectors have been designed. These detectors have provided amplification [2], but the unpredictable nature of avalanche multiplication [3] has presented challenges such as high leakage, elevated noise levels or afterpulsing tails. Superconducting single photon detectors can provide extremely high gain and fast response [4], however their operational temperatures are usually less than 10 K, requiring cryogenic cooling systems.

The nano-injection detector was designed to be an alternative to these technologies. It consists of InP/GaAsSb/InGaAs layers grown on InP substrates. The processing details have been published in a previous publication [5]. The structure of the processed device is shown in Figure 1. The operation principle of the device is the based on the controlled lowering of the barrier in conduction band, which is formed due to the band lineup of InP-GaAsSb and GaAsSb-InGaAs. When holes are generated in the InGaAs region, they are channeled towards the InP/GaAsSb injectors. The GaAsSb layer presents a minimum for potential for holes, and the incoming holes get trapped in GaAsSb layer, which alter the local potential, lowering the band structure around GaAsSb. This lowering results in a significant increase in the thermionic emission of electrons across the InP-GaAsSb boundary, releasing thousands of electrons per trapped hole.

In our previous publications about the nano-injection photon detector, we have reported on the achievements of high gain values with low dark current [5]. In these experiments, we have recorded gain values reaching beyond 10,000 at room temperature with bias voltages lower than 1.5 V. The intrinsic dark current at these gain values was ~600 pA at 300 K. The devices had a bandwidth of approximately 4 kHz, and an optically active area of about 25 μm in diameter.

Noise investigations on the devices revealed that the devices exhibited very low noise levels at these high gain values. Compared to predicted spectral noise density due to Poissonian shot noise with multiplication, the measured noise levels indicated significant shot noise suppression. The suppression was quantified by the Fano factor, and Fano factors as F~0.55 was recorded at amplification values (gain) around 5,000. We attribute this suppression to a possible correlation among injected electrons, which is imposed by the internal negative feedback mechanism. In our opinion, provided that the amplification mechanism is fast enough, it can sufficiently regulate the injection to prevent bunching of electrons, thereby decreasing the amplitude-variance of the current, i.e. current noise.

When the devices were surface passivated with polyimide, a drastically different behavior was observed. The gain decreased significantly to values around 10 and the spatial response (optically active diameter) extended to beyond 100 μm. In parallel, the bandwidth of these devices exceeded 3 GHz and risetime values of 200 ps were measured. The jitter (time-uncertainty) at room temperature was recorded as 15 ps RMS. Using a setup with computer controlled instrumentation and motion controllers, a focused laser spot was scanned around the sample to map the delay of the devices versus position. With the delay map information, a Matlab script was used to model the

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statistics of the charge transport inside the detector. This model has shown good agreement with the measured jitter, which indicted that the major source of jitter in our detector is the variation in delay, and not the time-uncertainty of the internal amplification. This result also provides strong evidence on our explanation of how the device can provide suppression of shot noise, showing the high-speed nature of the injection-based amplification mechanism.

In this paper we have presented the low noise and low jitter properties that can be achieved with nano-injection photon detectors. We have demonstrated shot noise suppression with Fano factors of around 0.55 with internal amplification values (gain) of more than 5,000. We have shown that passivated, low-gain devices can exhibit high-speed response with risetime values of 200 ps. The jitter of such devices was measured as 15 ps at room temperature. We have shown that the source of jitter in such devices is the variations in delay, and not the jitter of the internal amplification mechanism. These results provided strong evidence towards the high-speed nature of injection-based amplification, which can explain the suppressed noise results with a temporal stabilization mechanism for injected electrons.

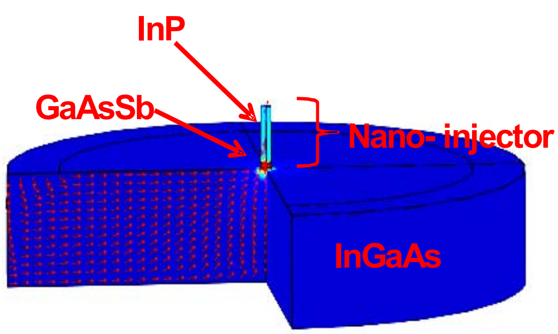

Figure 1 – The geometry and the cross section of device. The device consists of InP/GaAsSb injectors on large InGaAs absorbing regions.

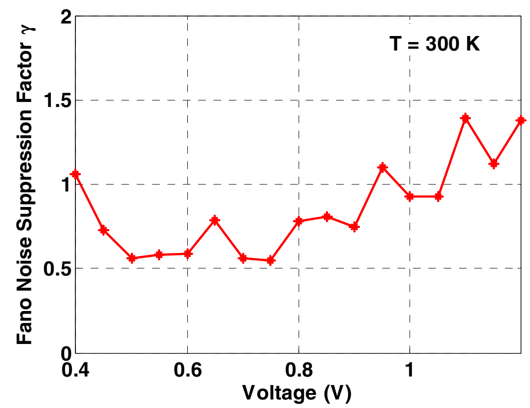

Figure 2 – The variation of the noise suppression factor versus bias voltage.

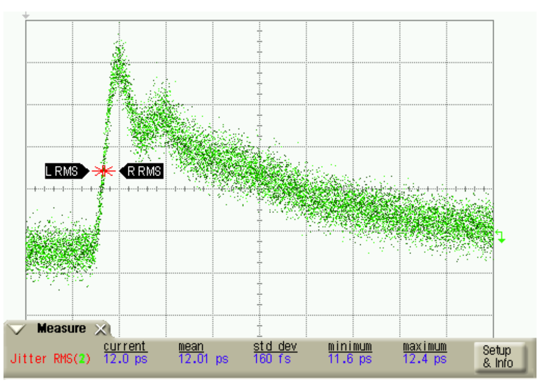

Figure 3 – The measured jitter of the device is less than 15 ps at room temperature.

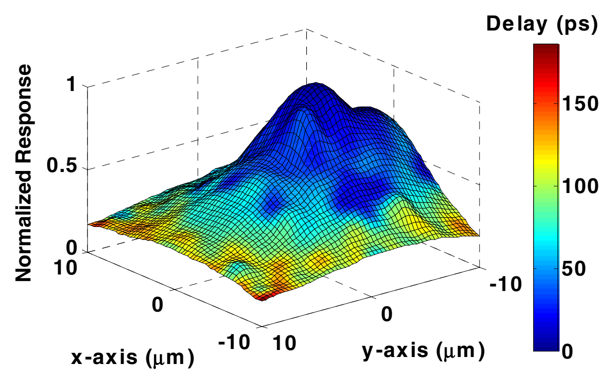

Figure 4 – The delay-response map of the device. Z-axis corresponds to the normalized peak-to-peak response, and the color coding shows the measured delay

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