Metal-semiconductor-metal electron detectors

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Metal semiconductor metal (MSM) junctions are a standard photon detector [1] for high speed applications due to: fast response time (sub ps) and long device lifetime, high gain (QE > 100%), small device area and reduced capacitance per area.

Here we characterize how such devices perform as electron detectors, performing preliminary gain and frequency response experiments on MSM illuminated by an electron beam. A definition and micrograph of the devices can be found in figure 1. Experiments were performed on both a Hitachi Scanning Electron Microscope SEM 2500, and a custom-made vacuum system used for analog to digital conversion experiments [2]. The research is motivated by the use of these detectors in the aforementioned ADC system.

A DC gain experiment was performed directing the SEM small beam onto the trench between two fingers. The results are show in fig. 2, indicating a dependence of the optimal gain to the square of the accelerating voltage, as well as a optimal bias voltage of 4-5V. The metal chosen (Au) is opaque to the incoming electrons, so directing the electron beam on the metal causes a reduction of the output current (from 1.6 μA to 0.5 μA using a 300 pA 25 kV beam and 5V bias). Thus the effective gain when used illuminating the whole area will be lowered by the fingers fill factor.

As expected the gain increases with landing energy but the effect is more than linear (fig. 2). This might be explained by a 'dead layer' near the surface whence collection of the generated hole-electron pairs (hep) is less efficient. The downside to higher energy is that the heps are generated further from the metal because of the deeper penetration, which could degrade the speed performance.

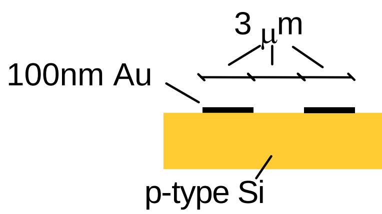
Experiments were performed to test the frequency response of the detectors in the custom made vacuum system, using high speed (1Ghz capable) deflectors, a 100 μm blanking aperture, and trans-impedance amplifiers to adjust the 100s of nA detector signal into a regime detectable with an oscilloscope (fig. 3). The landing energy was 5KeV. Results show speeds at least beyond 200MHz, limited by the electronics readout. The speed is expected to be in the GHz range as the transit time for the carriers to be swept is around 0.1 ns.

This preliminary experiment was limited by the quality of the in-house made electronic trans-impedance amplifiers, using Analog Devices AD8002 TIA chips and 4 layer Printed Circuits Boards, and BNC feedthroughs with low frequency cables. The experiments will be done again using commercially available amplifiers Martin, Froeschner & Associates Mod 422A with bandwidth of 2.7GHz, and SMA cables and feedthroughs rated to 18 GHz.

The preliminary results show the MSM detectors are very promising, with exceeding 100 and a probable speed >2 GHz, which are the requirements for the analog to digital converter. Using other semiconductor materials (GaAs) as well as e-beam lithography to define the fingers will lead to faster response times.

[1] K. S. Mobarhan, J. Valdmanis., *Faster photodiodes meet variety of applications*, Laser Focus World vol 35 n 8, 1999.

[2] R.F.W. Pease, K. Ioakeimidi, R. Aldana, R. Leheny, *Photoelectronic ADC using miniature electron optics: basic design considerations*, Journal of Vacuum Science & Technology B21, 2003



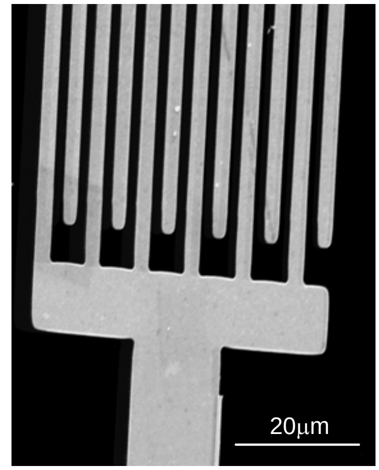


Figure 1. The detectors consist of 2 interdigitated pairs of 6 fingers 3 μm wide 138 μm long, forming an overall detector active size of 144 μm by 69 μm. They were fabricated using optical lithography on a Si L-prime p-type doped (B) substrate followed by lift-off of 100nm Au on 10nm Ti. To reduce leakage a second generation of detectors were made on an oxidized Si substrate (100 nm thick oxide), with windows etched for the active area.

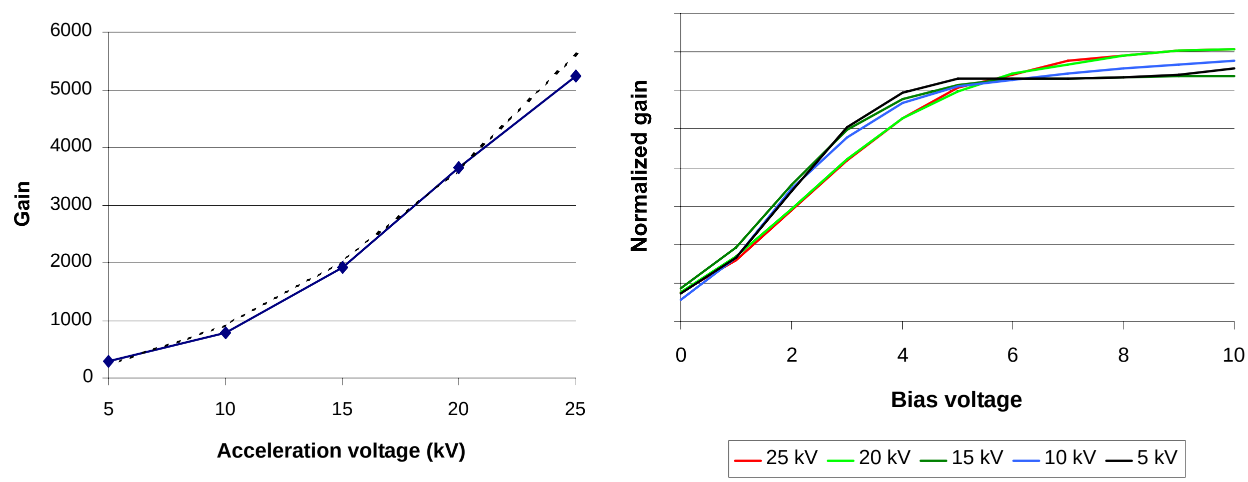
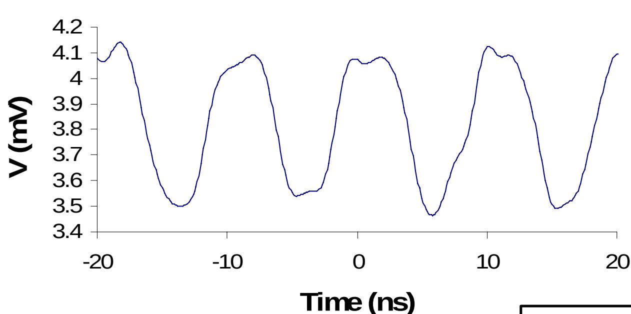


Figure 2. DC experimental results performed in a Hitachi SEM 2500. The gain with the optimum bias voltage of 5V is proportional to the square of the acceleration voltage. For 5kV it is on the order of 300.



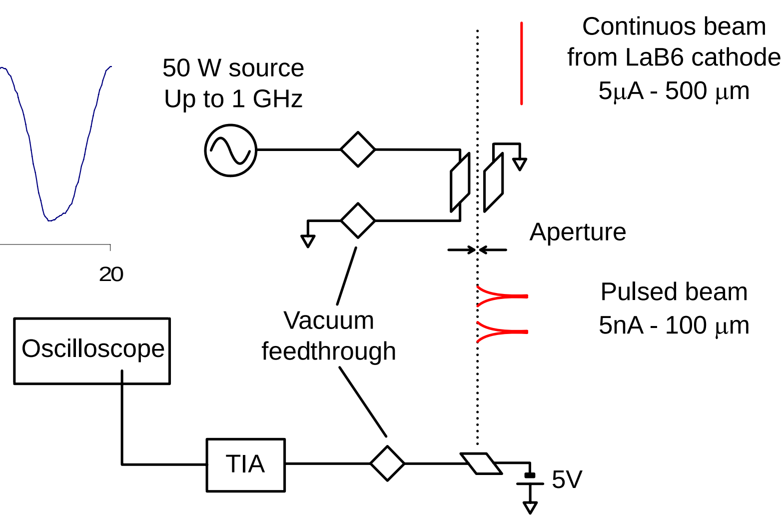


Figure 3 . Speed experimental results. Experimental setup, and oscilloscope output of a MSM detector after transimpedance amplifier.