Fabrication of High Speed Nanoscale Metal-Semiconductor-Metal Photodetector

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Abstract and Introduction:

Introduced in 1975, metal-semiconductor-metal (MSM) photodetectors consist of two metal electrodes with interdigitated "fingers" deposited onto a semiconducting substrate [1]. Using substrates, such as low temperature grown gallium arsenide, MSM photodetectors with bandwidths over 500 GHz have been successfully fabricated [2], making it a viable source for ultra-fast optical pulse measurements.

To increase speed, we introduced an array of metal nanodot electrodes between the fingers of the photodetector. The dots decreased the capacitance of the device with larger finger spacing while also allowing us to lower the transit distance to meet this lower resistance/capacitance (RC) time constant by acting as artificial recombination centers. We were also able to increase maximum applicable bias voltage before causing dielectric breakdown between the electrodes, which is important as the maximum output voltage is limited by the bias voltage applied.

In addition, we added an epitaxial layer of aluminum gallium arsenide to prevent electron-hole pair generation deep in the substrate, in order to further improve speed [3].

A 10 × 10 μm device, with three rows of dots between the fingers, was chosen as a balance between speed and signal strength (Figure 1). The size of the device was limited by the minimum beam size of the 775 nm excitation laser used to test the device. The addition of more rows of dots would speed up the device, but the loss of signal would be too great.

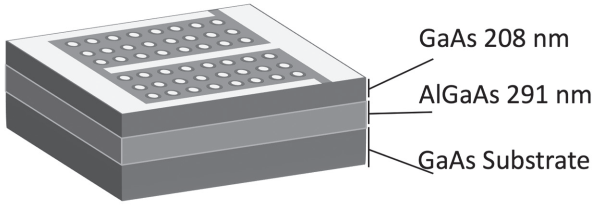

Figure 1: MSM photodetector with nanodots and epitaxial layer.

Experimental Procedure:

To fabricate our device, we started with a cleaning step with acetone and isopropyl alcohol (IPA) followed by a one-minute dip in hydrochloric acid:water ($HCl:H_2O$) 1:1 solution to remove any arsenic oxide present on the wafer surface, and therefore improve electrical contact. Photolithography was used to fabricate a coplanar waveguide necessary for measurement purposes. 20 nm of titanium was evaporated as an adhesion layer, followed by 100 nm of gold. Liftoff using RR2 resist remover completed the fabrication of the waveguide followed by another cleaning step with acetone and IPA then $HCl:H_2O$ 1:1 to remove any remaining residue.

Due to the small anticipated feature sizes of approximately 350 nm, electron beam lithography (EBL) was necessary to fabricate the actual photodetector.

A bilayer resist of copolymer methyl-methacrylate-co-methacrylic acid (MMA-MAA) and poly(methyl methacrylate) (PMMA) was used to create a good liftoff profile [3]. An alignment structure around the device writing area ensured that the exposed device would be properly aligned.

After development in a methyl isobutyl ketone:IPA 1:3 solution, the use of an IPC Asher followed by an $HCl:H_2O$ 1:1 bath removed any remaining resist in the exposed areas. Seven nm of titanium and 35 nm of gold were evaporated to create the device. Finally liftoff was performed using PG remover to finish the fabrication of the device.

Speed testing of the devices was performed at the National Institute of Standards and Technology (NIST) using an electro-optic sampling setup with a 100 fs laser at 775 nm wavelength. The laser pulse was much shorter than the speed of our device and so the impulse response of our photodetector could be found. The photogenerated current traveled down the transmission line from the device causing a change in voltage between the signal and ground electrodes. This voltage caused the change in polarization of a 1550 nm sampling beam traveling through the substrate between the electrodes, which was measured to determine the impulse response (Figure 2, left).

Results and Conclusions:

A device with line widths of 450 nm, dot diameters of 250 nm and spacing of 200 nm was successfully fabricated and tested (Figure 2, right, inset). The impulse response of the device was found to have a full width at half max of 4.5 ps (Figure 3), which corresponds to a bandwidth of approximately 100 GHz.

A relatively low signal to noise ratio was observed, pointing to a low responsivity in the device, which is most likely explained by the addition of nanodot arrays and the epitaxial layer. All carriers that would have been generated deeper into the substrate are lost due to the epitaxial layer and those that recombine at the dots do not contribute to the output current.

However, the bias voltage applied during testing was only four volts due to fear of causing dielectric breakdown, which was still in the range that may be applied to normal MSM photodetectors. The much higher bias voltage allowed by the larger finger spacing [1] should be able to make up for some of the lost responsivity.

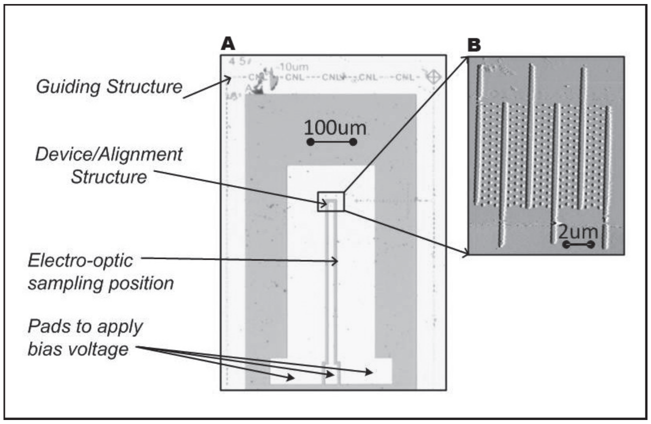

Figure 2: (left) Optical image of fabricated wave guide, (right, inset) Atomic force microscope image of final device.

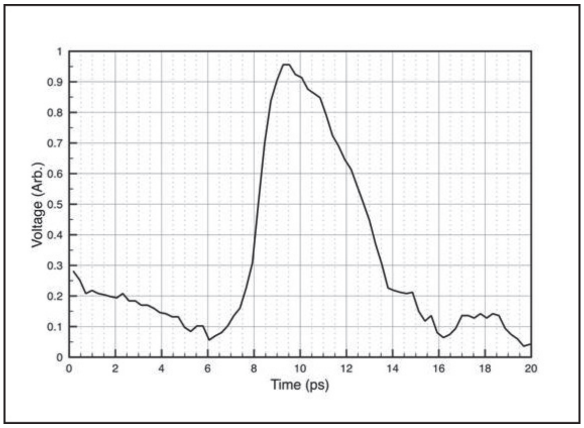

Figure 3: Impulse response of device.

Future Work:

More work must be done on the fabrication of the device to increase speed, such as implementing feature sizes that are more optimized towards faster speeds.

Extensive direct current testing can be done to find the maximum bias voltage that can be applied to maximize the output voltage though many improvements such as the addition of an anti-reflective coating on the surface of the substrate may be used to increase responsivity.

Once the device is optimized, we will be able to package it into a system designed by collaborators at NIST to measure ultra-fast optical pulses at 775 nm wavelength.

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References:

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