Process Development for a Traveling Wave Terahertz Detector

Benjamin D. McPheron

Electrical Engineering, Ohio Northern University

NNIN REU Site: Colorado Nanofabrication Laboratory, University of Colorado, Boulder, CO
NNIN REU Principal Investigator(s): Dr. Garret Moddel, Electrical Engineering, University of Colorado
NNIN REU Mentor(s): Sachit Grover, Electrical Engineering, University of Colorado
Contact: b-mcpheron.1@onu.edu, moddel@colorado.edu, sachitelectric@gmail.com

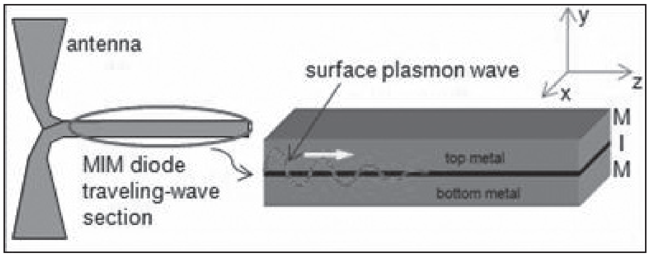

Figure 1: Traveling wave detector.

Abstract and Introduction:

The terahertz region has been untapped in the electromagnetic spectrum due to limitations in photonic and semiconductor devices. It has been proposed to use antenna coupled traveling-wave diode detectors to achieve high performance in the infrared. These devices channel radiation received by an antenna into a parallel plate waveguide: a metal-insulator-metal (MIM) diode that rectifies the carrier, producing a signal voltage. This arrangement facilitates a better impedance match between the antenna and the rectifying MIM diode than a lumped-element diode connected to the antenna.

The focus of this project was to develop process steps to fabricate these detectors. An example of such a detector can be seen in Figure 1. These were designed to receive radiation in the wavelength range of 9 to 12 μm. Potential applications for these devices include communications and infrared imaging.

Theory:

One of the essential components of these detectors is the MIM diode, which relies on the quantum tunneling of electrons. Tunneling implies that an electron will travel between metal electrodes without being excited over the insulator's band-gap barrier. This allows MIM diodes exhibit the non-linear I(V) characteristic required for signal rectification: the conversion of an alternating current (AC) signal into a direct current (DC) level. Tunneling characteristics vary with shape and size of the insulator barrier [1].

We chose a bow-tie antenna for its wider bandwidth and greater response. We designed an arm length of 6 μm, which should respond to wavelengths, including the 10.6 μm radiation of the CO_2 laser test radiation.

To achieve maximum power output, the antenna and waveguide should have reasonably matched impedance. The characteristic impedance of the 120° bow-tie antennas we fabricated can be calculated to be 40Ω. [2-3] The MIM waveguide used has an expected impedance of 20Ω at the testing frequency.

Process Development:

The first step was to deposit contacts and electron-beam alignment marks. We spun NR9-1000PY negative resist and exposed for 10 seconds. After developing the resist, we used a thermal evaporator to deposit a 10 nm chromium adhesion layer followed by 40 nm of gold. We performed the lift off in acetone and isopropyl alcohol.

We extensively employed electron-beam lithography for the next steps. For every e-beam step, we used a bi-layer resist recipe with 9% MMA/MAA co-polymer and 2.75% MMA in anisole. To develop, we used 1:3 MIBK:IPA and developed

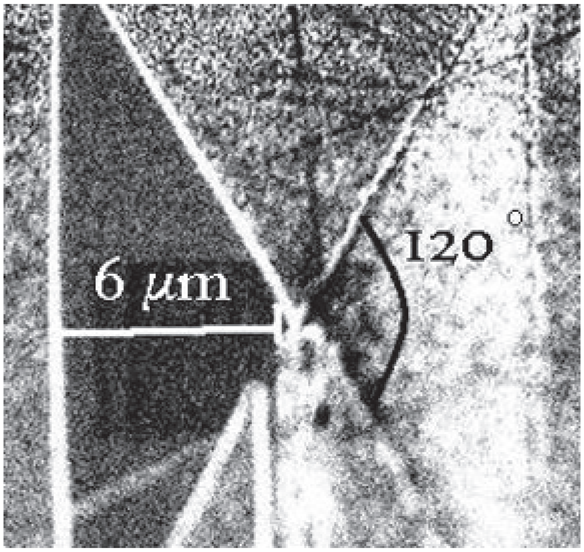

Figure 2: Dimensions of antenna arm.

for two minutes. With each e-beam layer, we deposited a new set of alignment marks in order to align future steps. We also wrote dosing patterns with e-beam lithography to find proper exposure conditions.

The first antenna arm was patterned using e-beam lithography and 10 nm of chromium (Cr), and 40 nm of gold (Au) were deposited after a short oxygen plasma ash, then lifted off. We confirmed that the antenna arm was 6 μm in length using a scanning electron microscope (SEM). This image can be seen in Figure 2.

Next, the MIM stack was deposited everywhere using an RF sputter system. We used a Nb/Nb_2O_5-Ta_2O_5/Nb MIM recipe with an oxide thickness of 2 nm and a total stack height of 82 nm. Subsequently, we used e-beam lithography to pattern a reactive ion etch (RIE) mask for the MIM waveguide on the first antenna arm. We deposited 40 nm of aluminium (Al), etched the excess MIM away, and passivated the sidewalls in the RIE.

Another experiment in the development of the process outlined parameters for removing the Al etch mask using the weak acid AZ-400K developer. After removing the etch mask, SiO_2 was deposited everywhere using an RF sputter system, and etched down in the RIE to prevent the final metal from shorting the diode. We experimented with etch parameters for the SiO_2 to avoid over-etching.

The final antenna arm was patterned and an atomic force microscope confirmed that the antenna was aligned properly. This alignment verification can be seen in Figure 3. We etched away aluminum oxide from the substrate with an ion mill and deposited and lifted off 10 nm of Cr and 40 nm of Au. Finally, we etched away excess MIM to achieve an undercut waveguide width of 100 nm.

We also fabricated large area MIM diodes using photolithography techniques and the same MIM recipe as the antenna to test and characterize them.

Results and Conclusions:

While developing the process for fabricating traveling wave detectors for the terahertz frequency range, we learned several lessons related to the optimization of the process. We had initially planned to use a Cr mask for the RIE etch of the MIM, but we realized that we would not be able to remove the Cr mask and then would not achieve the waveguide feature size that we desired, so Al was substituted. We found that dipping the substrate for 5 seconds in AZ-400K removed the Al mask completely. Also, we found that it would be beneficial to deposit larger alignment marks for the e-beam lithography steps with an ‘L’ shape to aid in the alignment of the waveguide and second antenna arm.

Acknowledgments:

This project has taught me essential fabrication skills and has improved my understanding of micro-electronic circuits, as well as introduced me to the quantum physical theory of electron tunneling. Ultimately we were successful in developing a process to fabricate these detectors.

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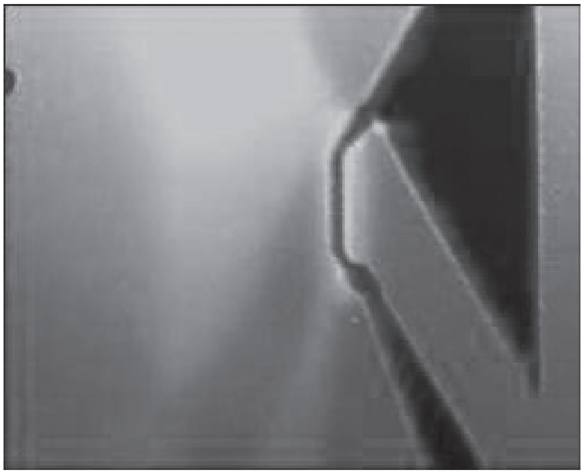

Figure 3: AFM verified arm alignment.