Surface Plasmon and Geometry Enhanced Asymmetric Rectifying Tunneling Diodes

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Metal-insulator-metal (MIM) tunneling diodes are under active development for detecting and mixing high frequency waves extending into the infrared spectrum. An antenna coupled to a diode is a common configuration for efficiently detecting and rectifying such waves. An RF energy scavenger can be conceived using a MIM diode for rectification and a nanoantenna for detection. In order to improve transduction efficiency, we have focused our effort on improving the current non-linearity and on enhancing current-voltage asymmetry. We have created system-level improvements using geometric field enhancement. The diode geometry is asymmetric, leading to an asymmetric current-voltage curve. The results of this effort have been published.[1]

Another scheme for obtaining high efficiency rectification employs surface plasmon resonances (SPRs) in nanoscale optical antennas. This is the emphasis of the work reported here. Surface plasmon (SP) waves can be generated in these antennas directly without any special coupling schemes. In our optical antenna structure, the tiny gap between two facing antenna patterns is designed to work as a resonating cavity, localizing SPRs inside the gap. The most interesting characteristic of SPRs in our tunneling diode applications is the high electric field intensity of the confined SPRs inside the gap. This allows the diode to "turn on" at relatively low signal input energies. The sharp tip electrode of the developed asymmetric tunneling diodes has the same shape as many optical antennas. The SPRs are, effectively, "trapped" in the tunnel junction.

In this paper we report on the unique rectification performance of our asymmetric tunneling diodes. Figure 1 shows a SEM image of a fabricated asymmetric tunneling diode. The measured asymmetric DC current-voltage relation of the diode and the calculated diode sensitivity are shown in Figure 2. Rectification test results are shown in Figure 3 of the diode. The diode generates currents at almost all frequencies with different rectified current levels.

To confirm that this result is not from "parasitic" antennas (bond wires, bond pads, etc.), which can pick up the incident waves, we conducted the same test on two different Ni/NiO/Ni tunneling diodes fabricated on the same wafer. One diode structure was sharply pointed; the other was a rectangular junction. The fabrication process, the diode gap distance, and all pads and leads contacting the diode were the same.

Figure 4 shows rectification test results for two Ni/NiO/Ni MIM diodes. Only the diode with a triangle electrode responded to incident waves. On the other hand, the rectangular diode did not show any response to the RF waves. Also the polarization dependence was tested for the two triangle diodes by rotating diodes. The maximum rectified current was obtained when the diode was aligned to be parallel to the incident wave's polarization. As the rotation angle is increased, the rectified current was reduced. When diodes were rotated as 90° from the maximum output position, the response was disappeared. Through all results, we infer that the RF response of the diodes is not due to outside interference but to the diode's own intrinsic rectification characteristics.

Our antennas are physically much smaller than the RF wavelengths. This allows SP generation without the need for special coupling geometries. Also, the sharp triangle shape for one electrode is a near-optimal design for achieving SPRs. Once the plasmon is excited, it can carry energy to the MIM diode for rectification. We believe this to be the first report of achieving RF power scavenging using this conversion mechanism. To date, we have achieved a 17% of power conversion efficiency at 5.5GHz. This work was supported in part by NAVAIR Grant No. N00042-1081003, Charles D. Caposell, program manager.

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[1]Kwangsik Choi, Mario Dagenais, and Martin Peckerar, "Fabrication of Thin Film Asymmetric Tunneling Diode using Geometric Field Enhancement," accepted from ISDRS 2009 and will be published.

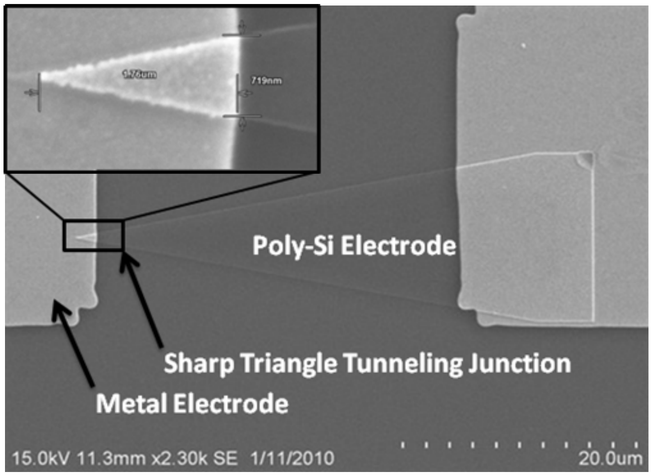

Figure 1. A SEM image of an asymmetric polysilicon tunneling diode. The sharp tip of the triangle electrode was covered by another large metal electrode. The inset image shows the tunneling junction area only.

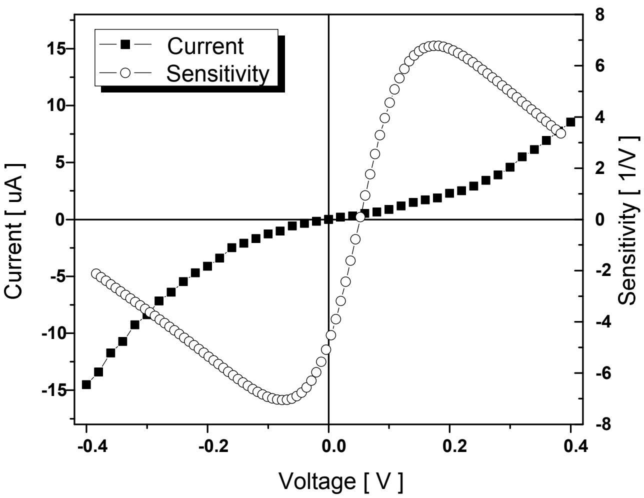

Figure 2. Measured DC current-voltage relation of the asymmetric tunneling diode in Figure 1. For the measurement, the metal electrode was grounded, and bias was applied to the polysilicon electrode. The reverse tunneling current level was much higher than the forward one due to the geometric field enhancement from the sharp tip. The empty circle is the calculated sensitivity (defined as –I″/I′) obtained by a applying polynomial fit to the measured data.

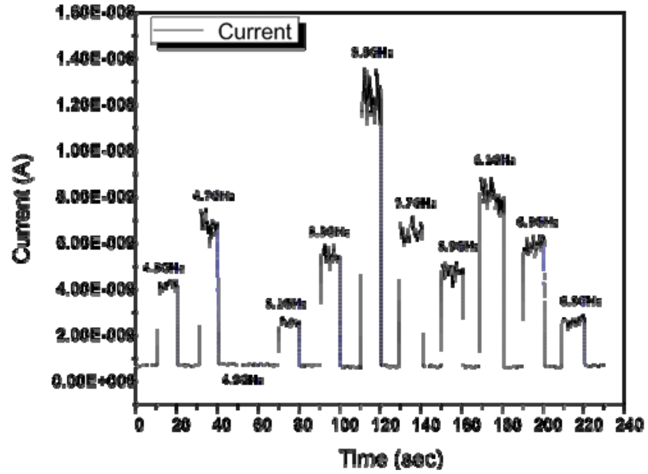

Figure 3. Rectification test results of the asymmetric tunneling diode shown in Figure 1. For incident RF wave generation, a commercial wideband log periodic antenna was used from 4.5 GHz to 6.5 GHz. The provided power to antenna from RF source was 12.5 dBm, and the distance between the sample and the antenna end is about 9 cm. The diode was aligned to be parallel to the incident RF wave's polarization. At zero-bias, the rectified currents were monitored for different wavelength in 200MHz steps.

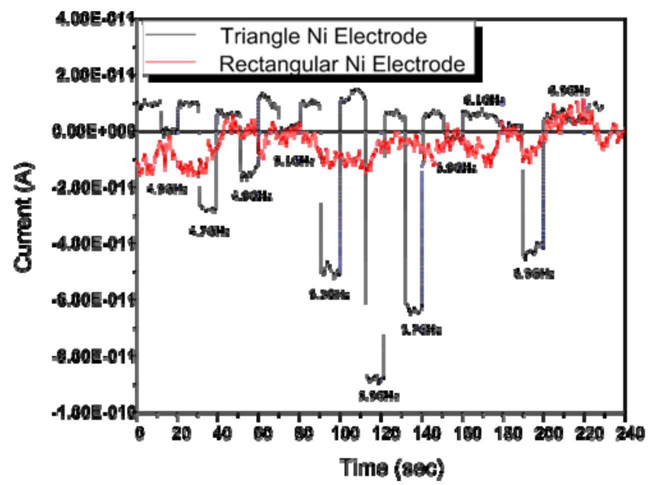

Figure 4. Rectification test results of two Ni/NiO/Ni tunneling diodes. The two diodes were fabricated on the same wafer. The same rectification test of Figure 3 was applied to the two diodes using the same test setup and conditions. One diode with a triangle electrode showed rectified currents at almost all frequencies (black solid line), but another diode with rectangular electrode did not give any response for the entire frequency range (red solid line).