Supplementary Information: Effects of Transmission Line Geometry on Traveling-Wave Metal-Insulator-Metal Rectenna Infrared Detectors

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Diode I(V) Model

Below we provide a plot of the $I(V)$ curve used to calculate electron tunneling in the post-processing of our TWD model. The plot below was generated using equations (2) and (3) from the main text and the fit coefficients given in section II, specifically, $b = 9.30\ V^{-1}$, $d = 8.31\ V^{-1}$, I_0=1.51 $\times 10^{-4}\ A$, $\alpha = 320\ \frac{\Omega}{V^2}$, and R_s=0 Ω.

In thin MIIM diodes, the conduction of charge carriers occurs via quantum tunneling through the insulators. The fast electron tunneling process through the insulator thickness of several nanometers happens in femtoseconds. The tunnel current is calculated from the electron transmission probability and the Fermi distribution of electrons in the metal and leads to nonlinear current-voltage I(V) characteristics that depend on the shape of the barrier. The experimental I(V) characteristics of a fabricated Ni/NiO/Nb2O5/CrAu diode are compared to simulation results generated using a transfer-matrix method diode simulator, shown in Fig. S2. The simulated I(V) curves are in good agreement with the measured characteristics, indicating that the pure tunneling analysis (including both fowler-Northeim and direct tunneling) provides accurate simulations for thin metal-insulator(s)-metal diodes. As the simulation assumes perfect insulators, differences from the experimental diode can be attributed to charging of the well, defects, surface states, and interface charge.

Possible competing conduction mechanisms include Poole-Frenkel emission, space-charge limited conduction and Schottky emission (Alimardani, Nasir, et al. "Conduction processes in metalinsulatormetal diodes with Ta2O5 and Nb2O5 insulators deposited by

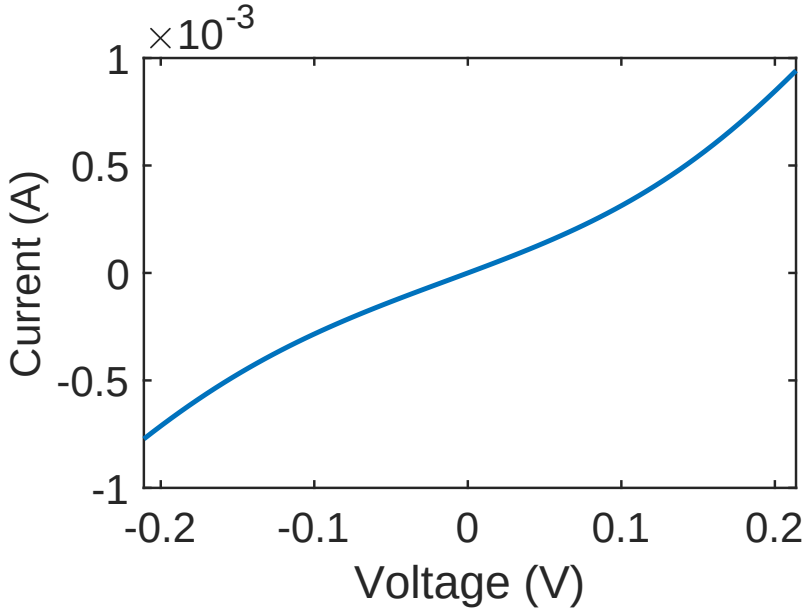

Figure S1: The $I(V)$ curve model used to calculate tunneling in our TWD simulation.

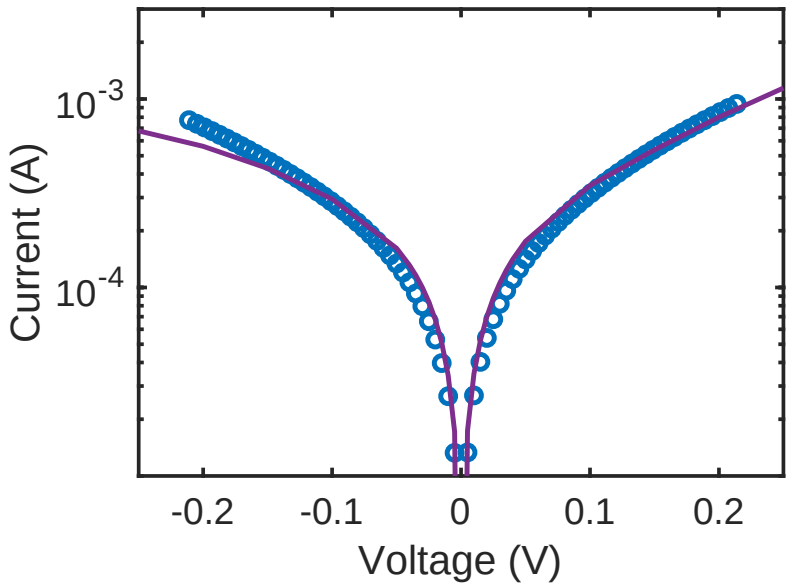

Figure S2: Measured current-voltage characteristics of a Ni/NiO/Nb_2O_5/CrAu diode (blue circles) and simulation results (solid purple) from a quantum mechanical tunneling diode simulator.

atomic layer deposition." Journal of Vacuum Science & Technology A: Vacuum, Surfaces,

and Films 32.1 (2014): 01A122. and Chathuranga, Don Ayendra Dilshan. Engineered High-k Oxides. Diss. University of Liverpool, 2016.). We ruled out space-charge limited conduction as current does not exhibit a V^2 dependence. Schottky emission was studied by looking at ln (I/T2) vs V1/2 curve. Figure S3 presents the linear curve (R2 > 0.999) suggesting that Schottky emission could dominate between 0.1 V and 0.2 V. A similar analysis Poole-Frenkel plots of ln (I/V) vs $V^{1/2}$ demonstrated possible emission from traps at these same voltage ranges (0.1 - 0.2 V). As Weerakoddy discusses in his thesis, further analysis and XPS measurements need to be performed in order to conclusively say whether and Poole-Frenkel emission or Schottky emission actually dominates over tunneling.

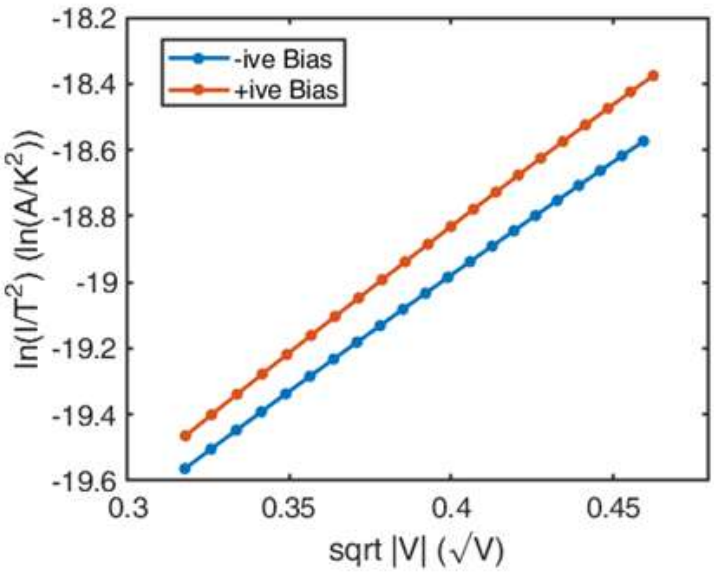

Figure S3: Schottky plots for low voltage regime (V=0.1-0.22V). The curve is highly linear with $R^2 > 0.999$.

Field confinement in antenna to TWD transition region

This supplemental figure S4 shows the field confinement in the transition region as the power EM power transfers from the antenna to the TWD.

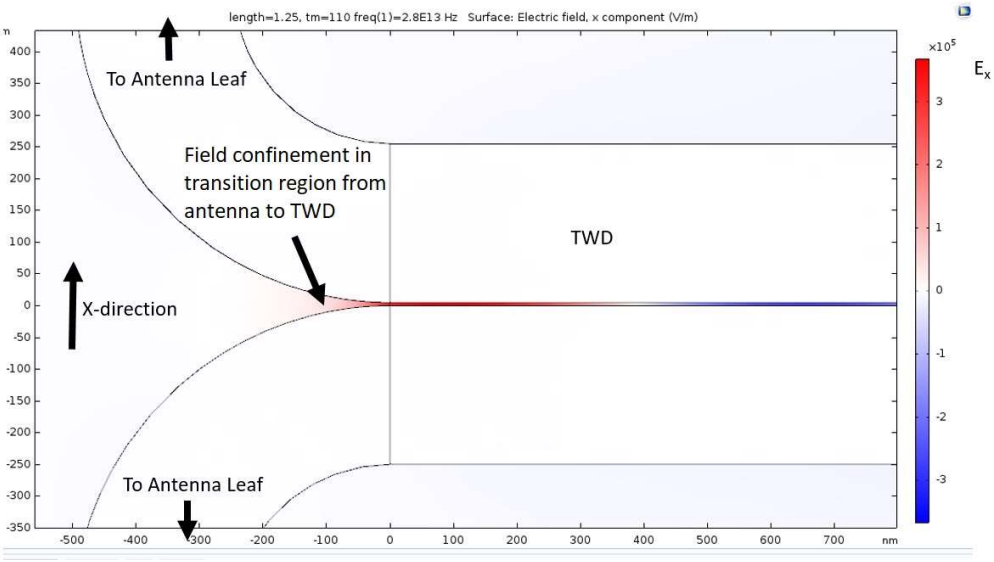

Figure S4: Field confinement in the transition region where power transfers from the antenna to the TWD.