Improving the Zero Bias Performance of MIM Tunneling Diodes by Introducing Traps in the Barrier

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Metal-Insulator-Metal (MIM) tunneling diodes have been under extensive investigation for the application of signal rectifiers of high frequency sensors because of their short response time. Our main goal is to harvest energy out of IR frequency band of the solar spectrum using MIM diodes connected to antennas, also called rectennas. In order to achieve this we not only need to improve the rectifying performance of the MIM diodes, but also we need to improve the rectification efficiency at the zero bias.

We claim that one of the best ways of improving rectifying performance of the MIM diodes is to employ the Trap Assisted Tunneling (TAT) technique. TAT dominates at lower bias operation points and leads to higher tunnel currents because at low bias condition electrons are not yet in the "Fowler-Nordheim" regime where they are swept from one electrode to the other in one step. Each trap located in the barrier contributes to the tunneling current by providing shorter paths to the electrons. As a result, tunnel current density increases and the junction resistance of the MIM diode decreases. Moreover, MIM diodes only enable zero bias rectification when there is asymmetry in the current-voltage relation around this point. We have previously created and demonstrated this asymmetry through a particular asymmetric geometric field enhancement technique[1,2].

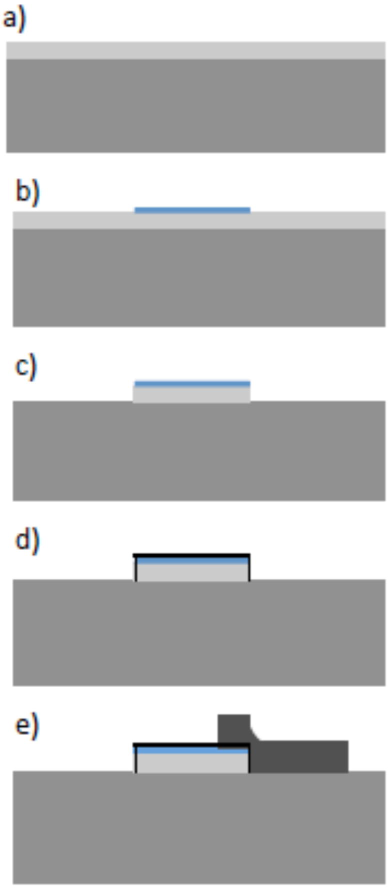
We used a very simple fabrication method to implant traps into the MIM tunnel junction barrier. Fabrication sequence is shown in Figure 1. We used Silicon on Sapphire (SOS) substrate and implemented the first Ni electrode using EBL and metal lift-off processes. Secondly, using dry plasma etching silicon layer is removed from the top of the sapphire. Next, this two-layer electrode made of Ni on silicon is boiled either in DI water or in ZnCl saturated water for 2 minutes, yielding two types of devices (ZnCl-doped and non-doped). During this process the oxide layer is formed all around the first electrode and the Zn+ and Cl- ions are implanted into the oxide creating the traps. Lastly the second electrode, which has an overlap with the first electrode forming the tunnel junction, is deposited using photolithography and metal lift-off processes. Top view SEM image of the final device can be seen in Figure 2.

Performance comparison of the ZnCl-doped and non-doped MIM diodes is made in terms of their zero bias resistance (R_0). Electrical measurements are made on many devices with various tunneling areas. Since the tunneling performance is independent of the physical dimensions, only resistance per unit area results are considered for data evaluation. In Table 1, R_0 values of four devices from each group are shown. According to this data, the ZnCl-doped devices show much less zero bias resistance than the non-doped devices. This experimental result is in good conjunction with the theory we have built.

It is very important to have high tunneling efficiency at low bias conditions at MIM diodes when they are to be used for high frequency rectifiers for energy harvesting rectennas. After showing the applicability of the MIM diodes for rectification at lower bias conditions by using geometric field enhancement technique, in this work we focused on lowering the tunnel resistance by implanting traps in the tunneling barrier. We believe that these traps provide path for the electrons to tunnel and increase the current density. The easiest way of showing this phenomenon is to compare the zero bias resistance of the MIM diodes. The experimental results we obtained agreed well with our claim. Our future work will include repeating the fabrication process in order to eliminate experimental parameter inclusions. In addition, we will try to experiment the same effect with different electrode materials in order to find the best combination that will yield the highest performance in low bias tunnel junctions.

[1] Kwangsik Choi, Mario Dagenais, and Martin Peckerar, "Fabrication of Thin Film Asymmetric Tunneling Diode using Geometric Field Enhancement," in *Semiconductor Device Research Symposium, 2009. ISDRS '09. International*, 2009, pp. 1-2.

[2] Kwangsik Choi, Geunmin Ryu, Filiz Yesilkoy, Athanasios Chryssis, Neil Goldsman, Mario Dagenais, and Martin Peckerar, "Geometry Enhanced Asymmetric Rectifying Tunneling Diodes," Journal of Vacuum Science and Technology B 28, C6O50, 2010



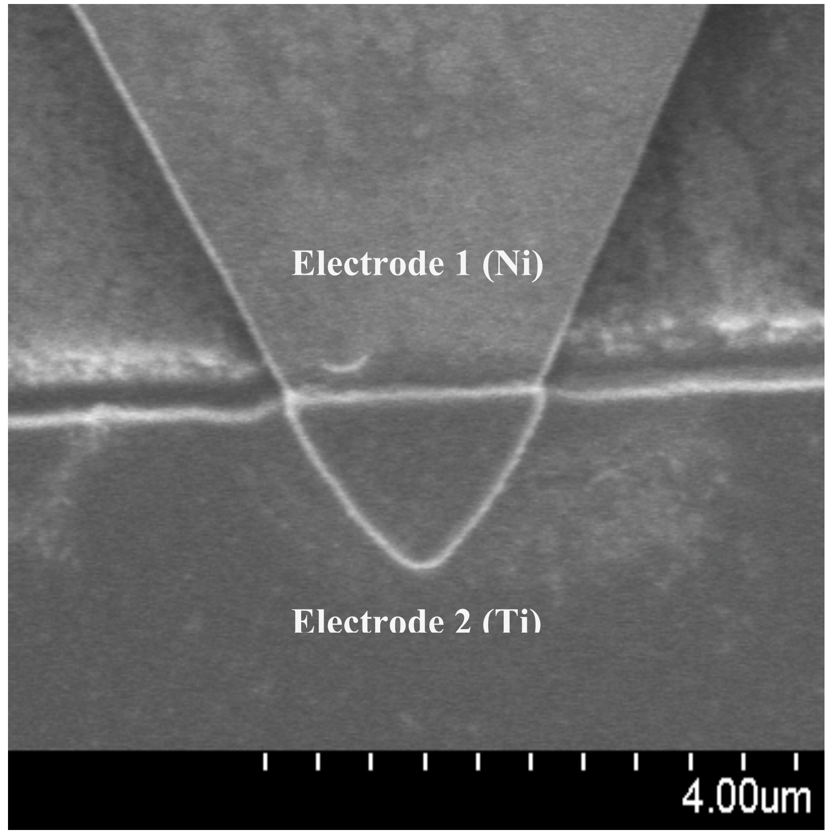


Figure 1. Fabrication sequence a) SOS substrate, b) First electrode (Ni) deposited with EBL and metal lift-off, c) Plasma etching of Si using Ni as metal mask, d) Boiling water oxidation with and without ZnCl, e) Second electrode (Ti) deposition with photolithography and metal lift-off processes.

Figure 2. Top view SEM image of overlap MIM diode with electrode 1 (triangle) made of Ni and electrode 2 made of Ti.

Device type and number	R_0 (Zero Bias Resistance)(Ohm)	A (Tunnel Area) (m^2)	R_0 (Unit Area Resistance)(Ohm/m^2)
Non-doped 1	2.2E11	1.6E-11	3.5
Non-doped 2	1.7E11	1.1E-12	1.9E-1
Non-doped 3	9.5E10	6.1E-13	5.8E-2
Non-doped 4	1.5E11	8.7E-13	1.3E-1
ZnCl-doped 1	8.6E7	1.1E-11	9.5E-4
ZnCl-doped 2	1.5E7	6.9E-12	1.0E-4
ZnCl-doped 3	7.7E6	2.5E-12	1.9E-5
ZnCl-doped 4	1.2E6	2.4E-12	2.9E-6

Table 1. Zero bias resistance values of the ZnCl-doped and non-doped MIM diodes with various tunnel area dimensions.