High-Voltage Nanolaminate Metal-Insulator-Insulator-Metal (MIIM) Tunnel Diodes using ALD Al_2O_3 and Ta_2O_5

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ALD nanolaminate tunnel barriers have enabled enhancements of low voltage asymmetry ($\eta_{asym} = I^-/I^+$) and non-linearity (f_{NL}) in MIIM tunnel diodes for applications such as rectenna based energy harvesting.[1,2] In this work, we investigate ALD bi-layers of Al_2O_3 and Ta_2O_5 for use in high-voltage applications such as electrostatic discharge (ESD) protection and high-voltage logic.

Nanolaminate Al_2O_3/Ta_2O_5 stacks were deposited on TaN bottom electrodes via ALD. ALD was performed at 200°C in a Picosun R-150 without breaking vacuum using alternating pulses of H_2O and either TMA or tris(ethylmethylamido)(tert-butylimido)tantalum. Al_2O_3:Ta_2O_5 thickness ratios of 1:1, 1:2, 1:3, 1:5, and 1:9 were fabricated, where the Al_2O_3 thickness is fixed at 30 nm. Bias was applied to Al top electrodes (formed by evaporation through a shadow mask).

I-V behavior (Fig. 1) was found to be a strong function of the Al_2O_3:Ta_2O_5 thickness ratio. Under positive bias, the reverse diode current for all devices remains low until the reverse "breakdown" voltage at which current increases rapidly. The reverse "breakdown" voltage increases with the thickness of the Ta_2O_5 layer, from 15 V for 1:1 to 53 V for the 1:9 devices. For small magnitude negative bias, in the range of 0 to -15V, the diode forward current *is higher* for thicker Ta_2O_5 layers, a somewhat counter-intuitive result. Beyond -15 V, the forward current is lower for thicker Ta_2O_5 layers, in line with expectations. Plots of log$|\eta_{asym}|$ vs. V are shown in Fig. 2. That maximum asymmetry and voltage at which it occurs increases from ~900 at ~19 V for 1:1 to ~10^5 at ~52V for the 1:9 devices.

Multiple changes in slope of the I-V curves at both positive and negative bias reveal a number of competing conduction mechanisms. Overall, conduction and asymmetry are dominated by Fowler-Nordheim tunneling through the Al_2O_3 barrier and defect based conduction through the Ta_2O_5. The trends in conduction and η_{asym} are well explained by the asymmetric barrier (inset Fig. 1) created by the pairing of Al_2O_3 ($E_G = 8.7$ eV, $\chi = 1.4$ eV, $\kappa = 8.7$) and Ta_2O_5 ($E_G = 4.5$ eV, $\chi = 3.2$ eV, $\kappa \sim 26$). The detailed explanation will be discussed at the meeting.

This work demonstrates that ALD bilayers may be used to effectively engineer the reverse breakdown voltage, maximum asymmetry, and operating range of high voltage MIM diodes. These diodes may be of interest for implementation in back end of the line as well as for large area electronics due to low temperature fabrication.

1 Alimardani and Conley, Appl. Phys. Lett. 102 (2013).
2 Alimardani and Conley, Appl. Phys. Lett. 105, 082902 (2014).

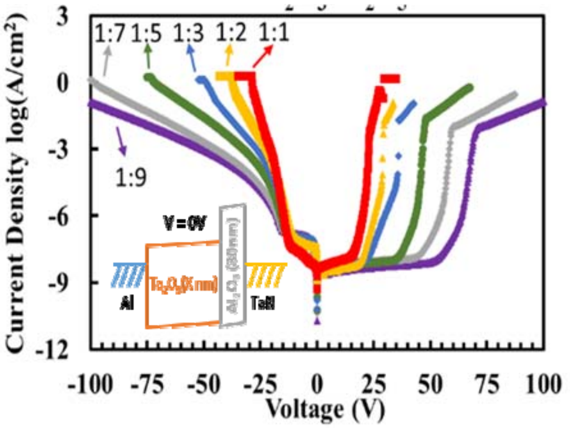

Fig. 1: I-V for various Al_2O_3/Ta_2O_5 thickness ratios.

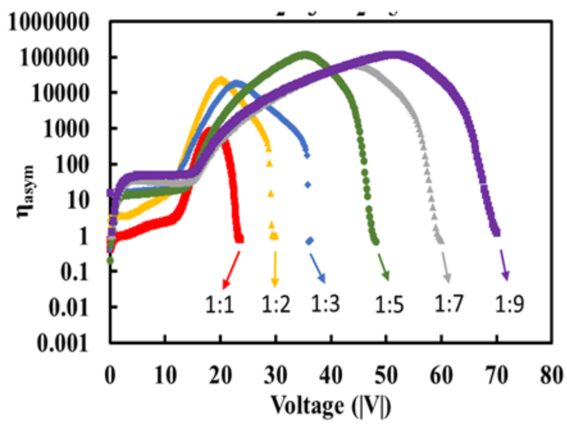

Fig. 2: Log$|\eta_{asym}|$ vs. V for Al_2O_3/Ta_2O_5 thickness ratios.