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Carrier conduction mechanisms in MIS capacitors with ultra-thin Al2O3 at cryogenic temperatures

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The study of the physical mechanisms associated with charge transport through thin Al_2O_3 films and the charge trapping phenomena are of great importance in the development of advanced Al_2O_3-based electron devices. These mechanisms have been studied at ambient temperature, as well as in temperature ranges above 300K. However, it is becoming highly relevant to consider cryogenic temperatures for these physical phenomena in order to develop devices for aerospace and cryoelectronic applications (like superconducting devices applied to sensing and quantum computing). In this work, a study comprising the electrical characterization and analysis of the electrical response of metal-insulator-semiconductor (MIS) Al/Al_2O_3/Si capacitors in a temperature range from ambient temperature down to 3.6 K is presented. Ultra-thin Al_2O_3= 6, 2 nm were used as insulating layers by thermal ALD, thus ensuring high reproducibility in their physical and electrical characteristics. Current-voltage and electrical stress measurements were performed on the capacitors in the specified temperature range, and the experimental data obtained were analyzed using current transport equations to model the conduction mechanisms that allow charge transport through the Al_2O_3. Energetic parameters associated with trap levels within the Al_2O_3 bandgap corresponding to (1) trap-assisted tunneling and (2) direct-tunneling as main conduction mechanisms for 6 and 2 nm of Al_2O_3 respectively, were obtained and their temperature dependences were associated with the presence of physical material defects. Additional phenomena that limit charge transport were also observed, such as (a) charge trapping in the bulk of Al_2O_3 upon the application of electrical stress at ambient temperature and (b) silicon *freeze-out* at cryogenic temperatures. For MIS devices, *freeze-out* represents the universal limit for carrier transport when silicon reaches 25 K. Our findings constitute an effort at understanding the physical phenomena that govern the electrical behavior of thin-film Al_2O_3-based capacitors, especially at cryogenic temperatures, given that these materials and devices are of great importance for applications in CMOS-based cryoelectronics and quantum technologies, among others.

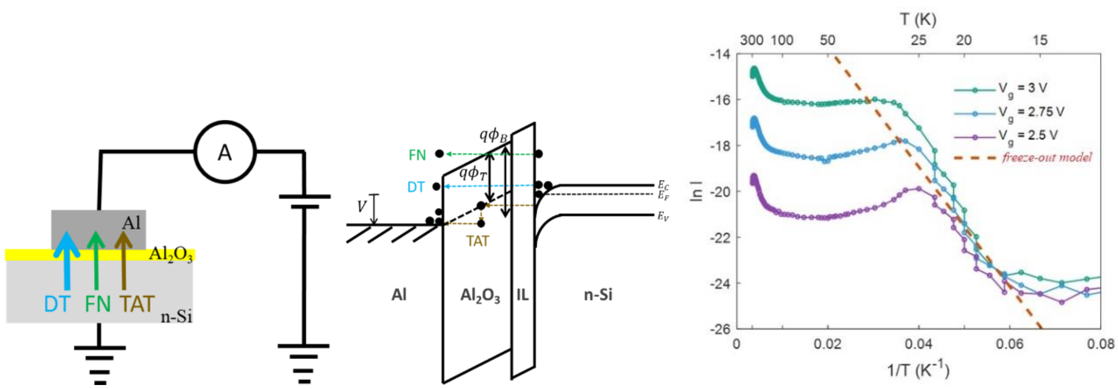

Figure 1. Dominant carrier conduction mechanisms for electrons in a MIS capacitor and its corresponding energy-band diagram. Modeling of the carrier conduction through Al_2O_3 from 300 K down to 3.6 K and limited by the *freeze-out* regime at 25 K.