Summary of Dielectrics and High-κ Properties and Challenges

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I. Structure

Dielectrics are utilised in electrical and electronic applications to provide insulation and regulate electric fields. By exposing these materials to an electric field, they can be polarized and used to store electricity.

The energy band diagram of a MOSFET, which comprises of three different types of materials: a semiconductor, a dielectric (oxide), and a metal, is appropriate for demonstrating this. The metal's valence band and conduction band are clearly at the same level, indicating that there are free electrons in the metal. However, when looking at the oxide, there is a big difference between the valence band and the conduction band, which means that even if the dielectric acquires energy, it will not be enough to release electrons from the valence band to the conduction band.

II. Characteristics

There are many parameters that affect the dielectric behavior and performance of devices using it:

Frequency Response: The relaxation time is the period during which the orientation polarization adjusts to the alternative field. At frequencies above 1000 GHz, the dipole orientation becomes unable to keep up with the alternating field. Polarization in an electric field can be thought of as a combination of ionic and electronic polarization mechanisms. A dip appears in the dielectric constant versus frequency at the resonance frequencies of these modes. This indicates that the system's response is out of phase with the magnetic field.

Atomic Structure : The more a material is available to polarization mechanisms, the larger its dielectric constant. Materials having permanent dipoles have higher dielectric constants than non-polar materials. Furthermore, the easier the various polarization processes can function, the larger the dielectric constant.

Temperature : As the temperature rises, the amplitude of random thermal motion also increases. This means the molecules are less closely aligned with one another, which reduces the orientational polarization and lowers the dielectric constant.

impurities : A small number of impurities, similar to semiconductors, can have a significant effect on the properties of dielectrics. If there are impurities in a material with electronic states inside the gap, the optical properties will change significantly because transitions from or into the impurity states are now possible. Impurities can also be used to make insulators conductive, just like doped semiconductors

III. Basic idea of operation

The idea to use High-κ materials enables the industry fabrication centers to descaling the node size of MOSFET (especially gate thickness and aspect ratio) to apply **Moore's law** and double number of transistors on the same chip by increasing the gate capacitance and enhancing the drain current. Some advantages of using these materials include high permittivity compared to silicon dioxide , reduction of leakage current due to nanoscale of gate thickness, which results in lowering power consumption. On the other hand, there are some challenges to use high-k materials, like thermal instability, channel carrier mobility degradation, charge trapping, and threshold voltage shift.

IV. Practical applications

There Many application applying in industry at manufacturing processes of MOSFET in many applications especially in **Memory devices** which require high dielectric constant reached to 40 like DRAM .This helped drive the cost-effective implementation of semiconductor memory. Moreover, the implementation of SOC (System On Chip) applications