The Inversion Behaviour of Narrow Band Gap MOS Systems: Experimental Observations, Physics Based Simulations and Applications

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Impedance spectroscopy of the metal-oxide semiconductor (MOS) system has played a central role in the development of silicon-based complementary MOS (CMOS) technology over the past 50 years [1, 2]. With current research interest into alternative semiconductor channels to silicon for MOSFET and tunnel FET technologies, the measurement and interpretation of the overall impedance of the MOS structure requires detailed analysis to separate and quantify the contribution of interface states, and near interface traps (border traps), on the capacitance and conductance response, and to separate the contribution of these electrically active defect states from the *ac* response of minority carriers in the case of genuine inversion of the semiconductor/dielectric interface.

There has been considerable progress in recent years in reducing the interface state density (D_{it}) [3-5], in narrow gap $In_xGa_{1-x}As$ MOS structures to the point where genuine surface inversion can be observed for both *n*- and *p*-type $In_{0.53}Ga_{0.47}As$ MOS capacitors, which is confirmed by analysis of the minimum capacitance of *n*- and *p*-type $In_{0.53}Ga_{0.47}As$ MOS structure with doping concentration ranging from approximately $1x10^{16}$ to $1x10^{18}$ cm^{-3} [6]. In this presentation we will provide an overview of the experimental relationship between specific functions of the capacitance (C) and conductance (G) for the case of narrow band gap III-V MOS structures which exhibit genuine surface inversion, where the capacitance and conductance of the MOS system as a function of *ac* angular frequency (ω) are related, and in particular, the peak values of G/ω and $-dC/d\log_e(\omega)$ ($\equiv -\omega dC/d\omega$) are equal, and that these peak magnitudes occur at the same value of ω [7]. The relationship is also confirmed by physics based *ac* simulations of MOS structures and through analysis of the equivalent circuit model in inversion. Results will be presented for InGaAs and InGaSb MOS structures (Al_2O_3 and Al_2O_3/HfO_2 ALD oxides) where genuine inversion of the III-V/oxide surface is confirmed by the G/ω and $-dC/d\log_e(\omega)$ functions, which have peak values of $C_{ox}^2/2(C_{ox}+C_d)$ when the surface is inverted (where C_{ox} is the gate oxide capacitance and C_d is the maximum capacitance of the semiconductor surface in inversion). In the case of *p* type InGaSb MOS structures, it is also notable that the accumulation frequency dispersion is very low (< 0.7 %/decade) indicating a reduced density of border traps at energies in the Al_2O_3 gate oxide aligning with the $In_{0.3}Ga_{0.7}Sb$ valence band edge, which is approximately aligned with the lowest energy in the $In_{0.53}Ga_{0.47}As$ conduction band gamma valley.

Finally, experimental results and physics based simulations will be presented, which indicate that the peak values of G/ω and $-dC/d\log_e(\omega)$ in inversion for any MOS system which demonstrates an inversion response within the typical range of temperatures and *ac* signal frequencies employed in experiments, opens a route to determine the gate oxide capacitance in inversion (where the gate oxide field and gate leakage are reduced), and that the angular frequency associated with the peak values of the G/ω and $-dC/d\log_e(\omega)$ functions allows the determination of the minority carrier generation rate in the semiconductor, which is relevant to the leakage currents in MOSFETs and the optical performance in photonic applications.

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