Experimental evidence for screening effects from surface states in GaAs/AlGaAs based nanostructures

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It is well known that a piece of thin metal can perfectly screen an external electric field. This is due to the creation of induced negative/positive electron-hole pairs in the metal. In semiconductors, it was found that a two-dimensional (2D) electron system formed at the interface of a GaAs/AlGaAs heterostructure partially screens an external electric field from an electrode. For example, using a capacitive technique, Eisenstein and co-workers [1] studied a double layer 2D electron systems and measured the fraction of the ac electric field applied by the gate that penetrates one electron layer and impinges the second. Such a study provides important information on the density of states of the screening semiconductor layer.

To date, GaAs/AlGaAs heterostructure based systems have been one of the most commonly used materials for studying low-dimensional electron behaviour. It is also well known that the high density of surface states in GaAs pins the Fermi energy in the mid-gap of an undoped GaAs layer. However, there are few experimental studies on the screening effect from the surface states in GaAs based materials. In this paper, we shall present experimental evidence for screening effects from surface states in GaAs/AlGaAs based nanostructures. The system that we studied is a multilayered gated lateral quantum dot device. In our system, a lateral quantum dot can be electrostatically defined a pair of split-gate (SG) and two overlaying finger gates (F1 and F2) which introduce tunnel barriers Figure 1 shows the conductance measurements $G(V_{SG}\}$ when V_{F1} and V_{F2} are simultaneously decreased. Let us first consider the upper six curves. Consider the 4^{th} single electron tunnelling (SET) peak counted from pinch-off. It is evident that with decreasing finger gate voltage, the same SET peak occurs at a less negative split-gate voltage. Decreasing V_{F1} , V_{F2} and V_{SG} all depletes electrons within the quantum dot. Thus increasing the negative biases on both F1 and F2 reduces the required V_{SG} for observing the *same* SET peak. As clearly shown in Fig."2, the general trend is that all SET peaks shift to less negative V_{SG} with decreasing V_{F1} and V_{F2}.

When we further decrease the finger gate voltage, a striking effect is revealed, as shown in Fig. 1. Over two V_{F1} and V_{F2} ranges as labelled as A and B, decreasing V_{F2} becomes “ineffective" in shifting the SET peak position to a less negative V_{SG}. We ascribe this to screening effects from the surface states near the GaAs cap layer. We now describe the effects for the surface states. The density of surface states results from surface reconstruction giving a peak at mid gap. The states may be mobile on the time scale of the measurements and this screen over even over screen the top gates. The surface states act as a second 2DEG which the electric field can penetrate in the same way as a double 2DEG density of states detector. The voltage is pinned mid gap at the surface, but with large enough negative finger gate voltages we can move the Fermi energy away from the peak in the density of states. The voltage where the screening is greatest gives an idea about the position of the peak in the density of states. We shall discuss measurements of the surface states using a “quantum capacitor” model.

References:

1. J.P. Eisenstein, L.N. Pfeiffer and K.W. West, Phys. Rev. B 50, 1760 (1994).

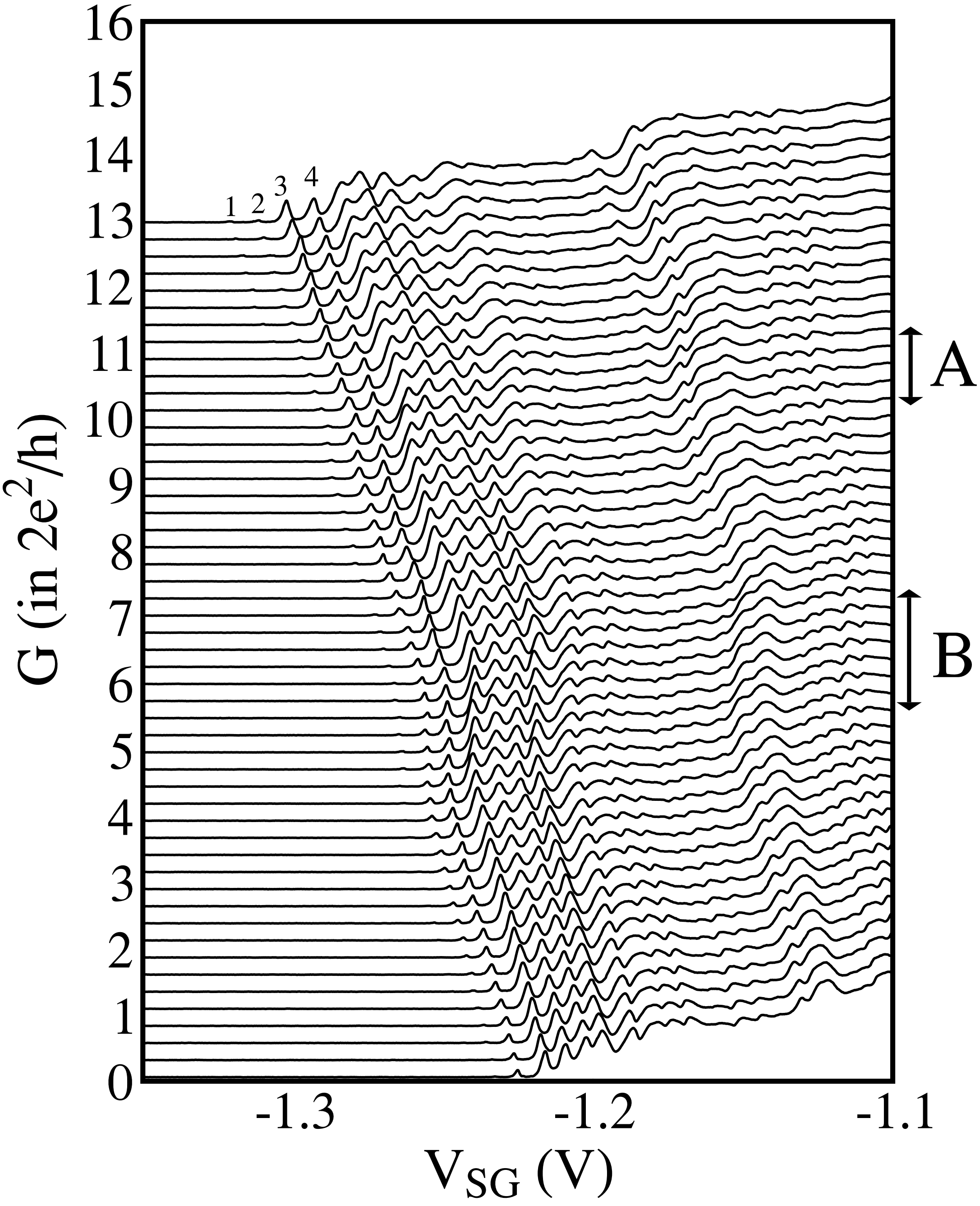

Figure 1 Conductance measurement at different finger gate voltages. Curves have been successively offset for clarity. From top to bottom, we increase the applied negative finger gate voltages in 2 mV steps.