A Silicon Bi-layer System

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There has been a recent revival of interest in two-dimensional systems with valley degeneracy such as Si and AlAs due to the applicability of recent theoretical work on double-layer electron systems. Indeed, recent experimental work strongly suggest that the lifting of the valley degeneracy in high magnetic field cannot be described by single-particle interactions alone [1,2]. Here, we demonstrate that silicon-on-insulator (SOI) MOSFET's which are essentially $SiO_2/Si/SiO_2$ quantum-wells can exhibit a variety of behaviour, in particular, the formation of a bi-layer system with different valley splitting in each layer.

We have measured a series of $SiO_2/Si/SiO_2$ quantum-wells where the width of the well has been varied. The samples consist of MOSFET Hall-bars fabricated on SIMOX (Separation by Implanted Oxygen) substrates [3]. Figures 1 (a) and (b) show grey-scale plots of the resistivity at 350mK as a function of front-gate bias (V_{FG}) and magnetic field at fixed back-gate voltages (V_{BG}) for 25 and 10 nm-wide quantum-wells respectively. For the wide quantum-well (a), at low values of V_{FG}, one set of Shubnikov de Haas (SdH) oscillations can be seen corresponding to the layer of electrons formed at the Si/SiO_2 interface closer to the substrate. As V_{FG} is increased, another fan appears corresponding to the formation of another layer. The SdH oscillations due to the back layer remain as almost vertical lines on the plot, characteristic of two independent layers. For the 10nm-wide sample (b) however, while two sets of fan patterns can be seen, the SdH oscillations originating from the back layer continues to follow the fan. With the back-gate set at a lower value, we have found the SdH oscillations to evolve into a single fan (data not shown). In this sample, the strength of coupling between the two layers can be changed by changing the total carrier concentration.

Figure 2 shows the resistivity of the 10nm-wide sample as a function of both V_{FG} and V_{BG} at a constant magnetic field of 11T. When V_{FG} and V_{BG} are relatively low the system behaves as a single-layer whose wave-function is shifted from one side of the well to the other by the gates. The quantized Hall state corresponding to one fully occupied Landau level ($\nu = 4$) can be seen to survive from one end of the plot to the other. At larger values of V_{FG} and V_{BG}, an interesting pattern emerges due to the system becoming a bi-layer. The system is a double layer of electrons where both the spin and valley splittings of each layer determine its behaviour. A distinct asymmetry can be seen about the line along which we expect the quantum-well to be "symmetric". On the side of high V_{FG} and low V_{BG}, the spin splitting is much more pronounced than the valley splitting, while the opposite is the case for low V_{FG} and high V_{BG}. Since the two oxide layers are formed through different processes, differences in the two Si/SiO_2 interfaces lead to the asymmetry [4]. The system allows the study of both intra-layer and inter-layer interactions and the interplay between them.

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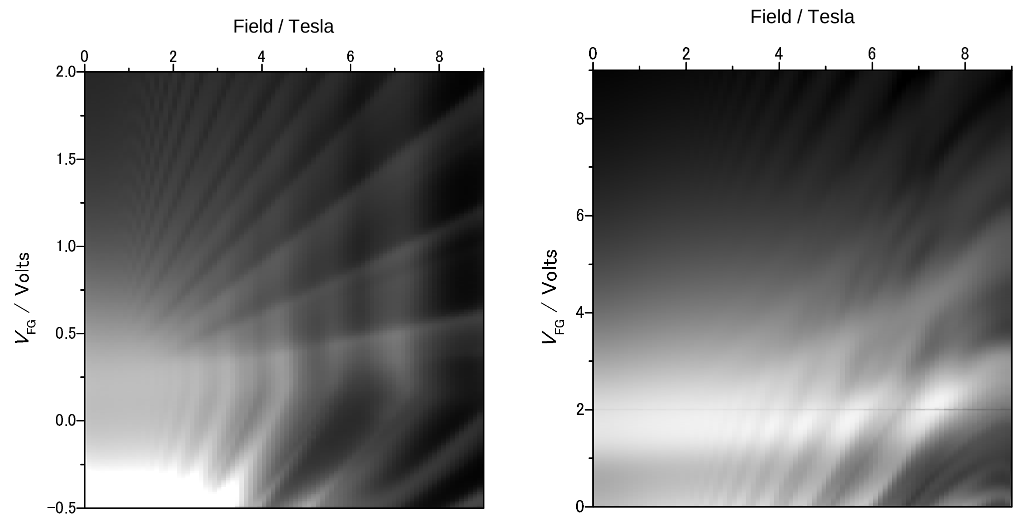

(a) 25nm well (b) 10nm well

Figure 1. Grey-scale plots of the diagonal resistivity (ρ_{xx}) as functions of front-gate bias (V_{FG}) and magnetic field. The back-gate bias (V_{BG}) is fixed for both plots so that at low values of V_{FG} only one layer of electrons exist at the interface closer to the substrate. The light regions represent high values of ρ_{xx} while the dark regions represent low ρ_{xx}. Graphs (a) and (b) show data from 25 and 10nm-wide quantum wells respectively.

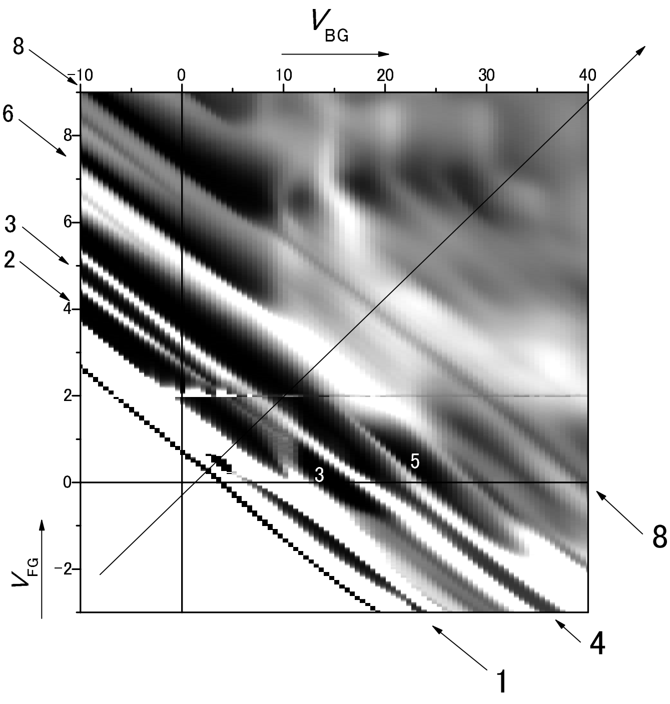

Figure 2. A grey-scale plot of ρ_{xx} as functions of V_{FG} and V_{BG} at 11 T and 350mK. The dark regions representing quantized Hall states are marked with their corresponding filling-factors. The diagonal line represents a loci of points where well is “symmetric”. A distinct asymmetry can be seen about this line due to the difference in the valley splitting. The horizontal line at $V_{FG} = 2V$ is an experimental artifact.