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MAGNETIC BREAKDOWN IN THE TIPPED Si 'SUPERLATTICE'

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> Digital filtering of the Shubnikov - de Haas oscillations in Si MOSFETS tipped from (100) demonstrates the persistence of the circle orbit above the minigap. The field sweep spectrum displays peaks which correspond exactly to the combination orbits expected from magnetic breakdown of the peanut and lens orbits.

The observation by Cole et al [1] of low frequency - low mass Shubnikov - de Haas oscillations in Si MOSFETS whose surface was tipped slightly from (100) attracted wide interest[2-5]. The new frequency component corresponded to Fermi surface overlap across a new Brillouin zone edge formed by a superlattice of roughly 100 A periodicity. A "minigap" of a few meV formed between the two bandswas produced by the Brillouin zone remapping. The origin of the superlattice was unknown. An alternative explanation [2] was proposed that involved projection of the bulk Si band structure onto two dimensions, and coupling between two equivalent orbits. This "valley splitting" model correctly predicted the position of the minigap in k-space, and is generally accepted. The resulting band structure with its small minigap provides a simple magnetic breakdown system, much in the same way that other inversion gas structures have demonstrated simple quantum well behavior. The band structure is similar to that used by Ruvalds and McClure in their magnetic breakdown calculations[6]. We have applied spectral analysis techniques to the complex magnetic breakdown spectrum that is experimentally observed in this system. We report here preliminary measurements on a Si MOSFET with Corbino disc geometry tipped 8° from (100)[7].

In the gate sweep of Fig. (la), the second band lens emerges as the low frequency component visible above $N_{inv} = 1.8 \times 10^{12} \text{ cm}^{-2}$. The first band circle oscillations also persist at high N_{inv} , which is not possible after Fermi surface contact with the Brillouin zone unless magnetic breakdown is occuring. Digital filtering [8] of the data shows the separated components due to the lens (Fig. 1b), which does not emerge until Fermi surface overlap has occured, and the circle (Fig. 1c). The amplitude varies strongly within the window due to the combined effects of magnetic breakdown and the variation of the electron lifetime with N_{inv} .



Fig. 1 Gate sweep: a) Transconductance oscillations as a function of N_{inv} with H = 18.26 kG. b) Lens contribution and c) circle contribution to data shown in a), extracted through digital filtering

The data at fixed gate bias as a function of magnetic field (Fig. 2a) displays a rich spectrum of Fourier components (Fig. 3). Once the lens and circle (peaks 1 and 2) are identified, the other peaks correspond exactly in frequency (within 0.6%) to simple addition and subtraction of these orbits. This suggests that the separation between the Fermi surfaces is very small. Shown in Fig. (3) are peaks due to circle plus lens, "peanut" (two circles minus lens, corresponding to no magnetic breakdown), circle second harmonic, etc. The combination orbits correspond to those predicted by Ruvalds and McClure. Since the Fermi level is well into the second band in the data shown, the large amplitude of the circle orbit suggests that tunneling across the minigap is very likely. This and the small separation between the Fermi surfaces are both connsistent with the small size of the minigap.

The major spectral components may be separately viewed as a function of H by digitally filtering the data (Fig. 2b-f). The field dependence of the amplitude of the oscillations is strongly dependent on lifetime effects, while the <u>relative</u> amplitudes of the different orbits is strongly dependent on coupling probabilties. We are currently studying these effects. Magnetic Breakdown in the Tipped Si 'Superlattice'

Fig. 2 Field sweep: a) Transconductance osillations as a function of 1/H with $N_{inv} = 3.67 \times 10^{12} \text{ cm}^{-2}$. Also shown are the contributions due to b) lens, c) circle, d) lens + circle, e) peanut, and f) circle second harmonic and peanut + lens

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Fig. 3 Fourier transform of field sweep shown in Fig. 2a: Peaks marked are 1) lens and 2) circle. The other peaks identified are, in order: circle + lens, peanut, circle second harmonic (which is the same frequency as peanut + lens), peanut + circle, and circle third harmonic. Additional combination orbits can easily be identified

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8) Digital filtering consists of doing a FFT on the data, multiplying the FFT by a bandpass window, and then performing an inverse transform, with attention given to the convolution theorem.