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The role of spin polarization on the quantum Hall effect in 2DEG with periodically modulated filling factor

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Abstract

We report quantum magnetotransport experiments in novel 3 μm-period V-grooved GaAs/AlGaAs heterojunctions. In such structures a periodic spatial variation of the *normal* component of magnetic field is realized. We observe anomalous features in both weak and strong magnetic fields. The quantum Hall effect step-like Hall resistance is replaced by an oscillatory variation when the current is applied parallel to the grooves. The longitudinal resistance peaks attain unusually high values $\gg h/e^2$ when the current is applied perpendicular to the grooves. Most of the features can be explained by a model of serial and parallel connection of stripes with different filling factors and different spin polarization at the adjacent stripes. © 2002 Elsevier Science B.V. All rights reserved.

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Recently, many groups reported on strong anisotropic longitudinal resistance in high half-filled Landau levels [1,2]. The reported anisotropy being quite small at zero magnetic field becomes very strong for fields at which integer quantum Hall effect (IQHE) regime is established. This effect gave us a strong motivation to study IQHE in artificially produced anisotropic two-dimensional electron gas (2DEG). As will be shown below a 2DEG grown on V-grooved substrate allows us to obtain samples consisting of stripes with alternating filling factors. Our IQHE studies on these samples indeed show that strong anisotropy in longitudinal resistance develops at high magnetic field, however, in contrast to the previously reported results [1,2] also the Hall resistance exhibits both anomaly and anisotropy.

The regrowth of GaAs–AlGaAs heterostructures on V-grooved pre-patterned GaAs substrate is the well-known technique [3] for obtaining V-shaped 2DEG. The TEM cross section of 3 μm-period V-grooved GaAs/AlGaAs heterojunction used in this research is given in Fig. 1. The tops of the grooves are 320 nm wide (1 0 0) planes, whereas the bottoms are much sharper with a typical curvature radius of ∼ 15 nm. We have patterned Hall bar geometry samples using standard photolithography procedure. The length of the mesa between the current pads is 750 μm, the length and the width between voltage probes are 250 and 120 μm, correspondingly. We

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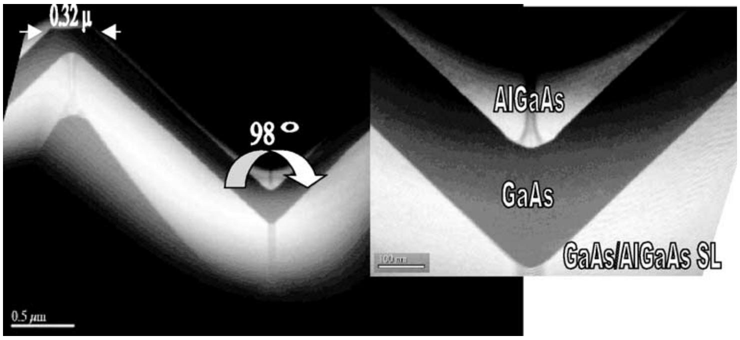

Fig. 1. A TEM cross section of the 3-μm-period V-grooved GaAs/AlGaAs heterojunction.

have fabricated samples with both orientations of the mask with respect to the V-grooves, parallel ("parallel samples") and perpendicular ("perpendicular samples") to the direction of the channel between the current leads.

At zero magnetic field and at room temperature the resistance is higher for the perpendicular samples than for the parallel samples by factor of 5, which is larger than what can be accounted for by the geometrical factor (note that the actual length to width ratio of 2DEG layer is about twice larger in perpendicular samples than in parallel ones). The anisotropy of the resistivity becomes more prominent as the temperature T is lowered. Below 4.2 K the anisotropy ratio saturates at the value ≈ 12.

Low field analysis of the magnetotransport data gave us the two-dimensional electron density $n \approx 4.5 \times 10^{11}\ \mathrm{cm}^{-2}$ for both tops and sidewalls regions [4].

In weak magnetic fields the Hall resistance R_{xy} is linear for the perpendicular samples, whereas strong deviation of R_{xy} from a linear dependence on B is observed for parallel samples, see Fig. 3 in Ref. [4]. The difference in the behavior of R_{xy} becomes even more noticeable at higher fields, where the step-like variation of R_{xy}, typical for QHE, occurs in perpendicular samples; it is replaced by an oscillatory variation of the Hall resistance in parallel samples. The longitudinal resistance R_{xx} also exhibits unusual features. The peak values of R_{xx} for a perpendicular sample are more than three orders of magnitude larger than those for parallel one, Fig. 4 in Ref. [4].

The magnetotransport data was taken within the wide range of temperatures from 4.2 K down to about 50 mK. It was found that the temperature dependence of the Hall resistance saturates below 100 mK whereas above this temperature a strong temperature dependence of minima and maxima was observed. The temperature dependence of R_{xy} for parallel sample in the temperature range from 280 mK to 4.2 K is given in Fig. 3(a).

Application of the uniform magnetic field perpendicular to the substrate leads to different filling factors ν_t and ν_w of the Landau levels in the tops and sidewalls regions of the 2DEG due to the different normal components of the magnetic field.

Most of the features of the magnetotransport curves could be explained within the previously suggested model [4], which assumes that when the difference between the filling factors in the adjacent regions is larger than unity, the internal edges appear at the borders between them. Such internal edge channels have an immediate consequence for the Hall effect in the samples where the stripes with different filling factors are connecting one current pad to another (parallel samples). It was shown that for a number of such stripes the total $R_{xy} = (h/e^2)[\nu_w + N(\nu_w - \nu_t)]^{-1}$ provided $\sigma_{xx} = \sigma_{yy} = 0$ in each stripe, where N is the number of stripes with lower filling factor, surrounded on both sides by the stripes with higher filling factor. However, the latter is rarely satisfied for our experimental conditions, see Fig. 2. On the contrary, there are some minima that correspond to the case, where both stripes are dissipative. Therefore, the model has to be extended to include the dissipation in the stripes. The only way to get strong suppression of R_{xy} relative to the classical value is by having the stripes electrically disconnected one from another in the interior of

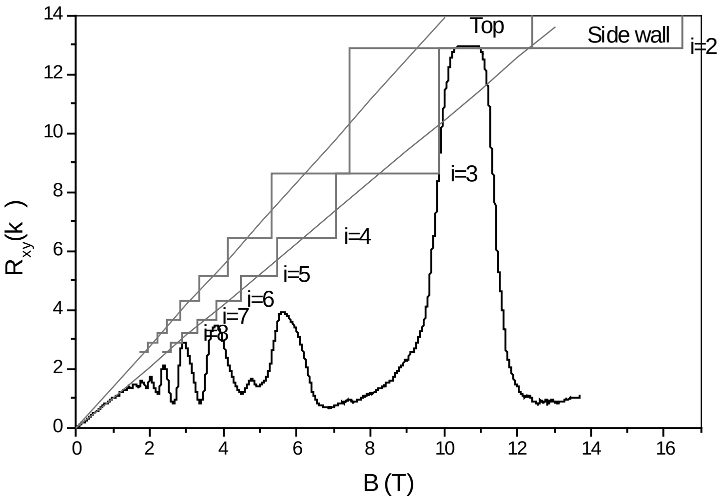

Fig. 2. The positions of R_{xy} plateau calculated separately for both stripes.

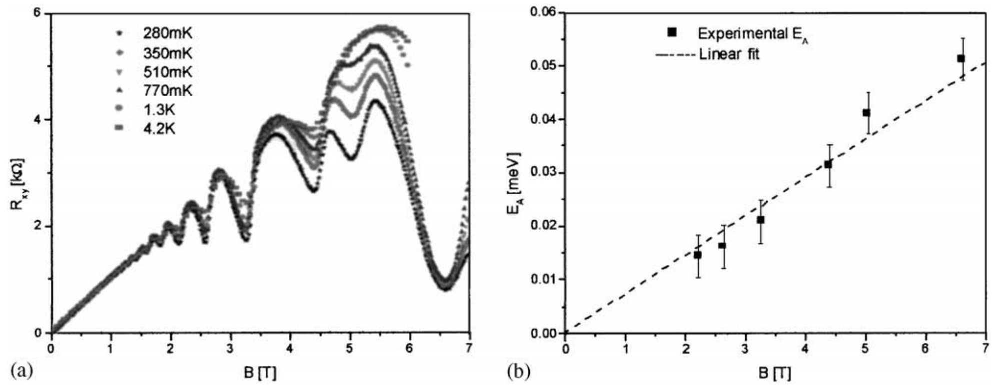

Fig. 3. (a) Temperature dependence of the R_{xy} for parallel sample; (b) the activation energy E_a versus magnetic field.

the sample. This condition is automatically realized, whenever the electrons at the Fermi energy in adjacent stripe have different spin polarizations, and there are no spin-flip processes. It is obvious, that in such case the total Hall resistance is defined by the total resistance of N stripes with lower filling and $N+1$ stripes with higher filling factor being connecting in parallel:

$$R_{xy} = (h/e^2)[(N+1)v_w + Nv_t]^{-1}$$
$$= (h/e^2)[v_w + N(v_w + v_t)]^{-1}.$$

The electronic transfer between the stripes can occur only by activation to the nearest Landau level with the same spin direction. Indeed, the temperature dependence analysis of R_{xy} indicates that the values of the minima have exponential dependence, with activation energy $E_a \approx \frac{1}{2} g\mu_B B$ (Fig. 3(b)) with $g \approx 0.4$ [5].

In conclusion, we demonstrated that artificially produced modulation of the Landau filling factor results in strong anisotropy of longitudinal resistance, R_{xx}. We proposed the models, which can explain the main features of the anomalous R_{xy} behavior. We conclude that, if the suggested "stripe-phase" is responsible for the observed anisotropic R_{xx}, than it is clear that this phase cannot propagate from one end of the sample to the other, because it would lead to the anomalous R_{xy} behavior (like in our case) which was not observed in the reported experiments [1,2].

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