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LOW-DIMENSIONAL SYSTEMS

Quantum Hall Effect in (Cadmium Fluoride)-Based Nanostructures

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Abstract—Shubnikov–de Haas oscillations and a ladder of quantum steps in the Hall resistance were observed in a p-CdF_2 quantum well confined by δ-like barriers for CdB_xF_{2-x} on the surface of n-CdF_2. Due to the small effective mass of two-dimensional holes, observation of the quantum Hall effect became possible at room temperature.

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The quantum Hall effect (QHE) is a quantum phenomenon that manifests itself at the macroscopic level and has attracted a lot of attention since its discovery in 1980 [1]. The QHE, which is characteristic only for two-dimensional (2D) metals, revealed a number of important aspects for quantum physics and provided for a deeper insight into the processes in interacting systems. This effect also resulted in the introduction of a new metrological standard, the one for the resistance quantum h/e^2, which only contains a combination of fundamental constants (the elementary charge e and the Planck constant h) [2]. As a rule, observation of the QHE, similar to many other quantum effects, requires ultralow temperatures and ultrahigh magnetic fields [1, 2]. Nearly all attempts at observing the QHE at high temperatures using semiconductors with small effective masses yielded no significant results [3, 4]. These efforts were motivated both by a natural desire to directly observe quantum effects in ambient conditions and by a practical demand for the ability of carrying out measurements at room temperature or, at least, at liquid-nitrogen temperature. If stability of the quantum states were attained at high temperatures, new possibilities would appear for studying the more subtle features of the QHE. It has been demonstrated recently that the QHE can be observed up to room temperature in graphene, which represents a single layer of carbon atoms closely packed in a honeycomb-like crystal lattice. This fact owes its existence to the quite unusual nature of the charge carriers in graphene, which behave like massless relativistic particles (Dirac fermions) and, in conventional cases, experience very low scattering [5, 6]. In this paper we show that the QHE can also be observed at room temperature in ultranarrow p-type quantum wells (QWs) fabricated on the surface of an n-CdF_2 crystal. This becomes possible owing to the small value of the effective mass for 2D holes, related to the presence of CdB_xF_{2-x} δ-like barriers that confine the QW [7].

The structure used for the QHE measurements (see Fig. 1) is based on an ultranarrow p-CdF_2 QW confined by CdB_xF_{2-x} δ-barriers on the surface of an n-CdF_2 crystal; details for the fabrication technology are described in [7]. At room temperature (T = 298 K), the Hall resistance R_{xy} exhibits a series of plateaus at $h/2\nu e^2$ (where ν is the Landau-level number) for 2D holes, while the longitudinal resistance ρ_{xx} approaches zero

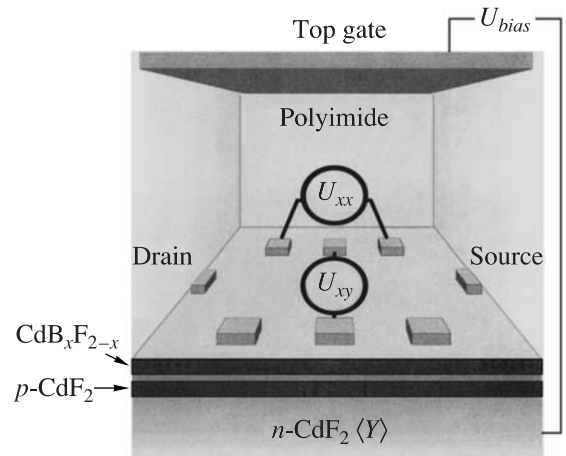

Fig. 1. Geometry of Hall measurements on 2D hole gas in a p-CdF_2 QW confined by δ-barriers of CdB_xF_{2-x} on the surface of an n-CdF_2 crystal.

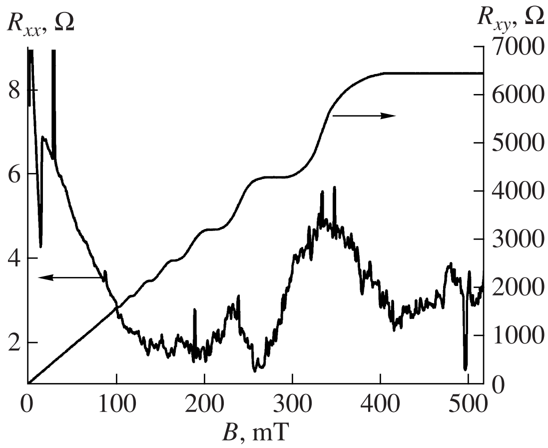

Fig. 2. The Shubnikov–de Haas oscillations and the Hall-resistance ladder in a p-CdF_2 QW confined by δ-barriers of CdB_xF_{2-x} on the surface of n-CdF_2; $T = 298$ K.

(<10 Ω), showing Shubnikov–de Haas oscillations (Fig. 2). Apparently, observation of the QHE at room temperature is possible due to the large energy spacing between the Landau levels $\hbar\omega_c$, which is related to a very small effective mass for 2D holes in a p-CdF_2 QW. The effective mass in a CdB_xF_{2-x}/p-CdF_2/CdB_xF_{2-x} sandwich structure on the surface of an n-CdF_2 crystal is $m_{eff} = 3.44 \times 10^{-4} m_0$, as determined from the period of Aharonov–Casher oscillations for conductivity at room temperature [7]. This means that, at room temperature, $\hbar\omega_c$ becomes comparable to the thermal energy k_BT at 100 mT. For this reason, it is possible in CdF_2-based QWs that only one 2D subband is occupied for hole densities as high as 10^{14} m^{-2}, which is important for the observation of the Hall-resistance ladder in relatively low magnetic fields, unlike conventional 2D semiconductor systems. It should be noted that the mobility μ in the samples under study remains nearly constant in the range of temperatures from liquid-nitrogen to room temperature and equals ≈1500 m^2 B^{-1} s^{-1}; thus, the transport time $\tau \approx 2.3 \times 10^{-12}$ s, and the high-field condition $\omega_c\tau = \mu B \gg 1$ is attained in the fields on the order of tens of millitesla.

One of the factors responsible for the very small value of the effective mass for 2D holes in CdB_xF_{2-x}/p-CdF_2/CdB_xF_{2-x} sandwich structures—a factor crucial for the observation of the QHE at room temperature—is, presumably, the formation of a quantum-sized p^+–n junction. Under these conditions, the band gap for CdF_2, which is as wide as 7.8 eV, nearly vanishes, and, as a result, inversion of the hole and electron states takes place in the vicinity of the p^+–n junction region (see Figs. 3, 4). Apparently, an additional factor contributing to the stabilization of this state inversion is the Fermi-level pinning caused by the formation of an energy gap near the valence band of CdB_xF_{2-x} δ-like barriers (Fig. 4) [7]. Other explana-

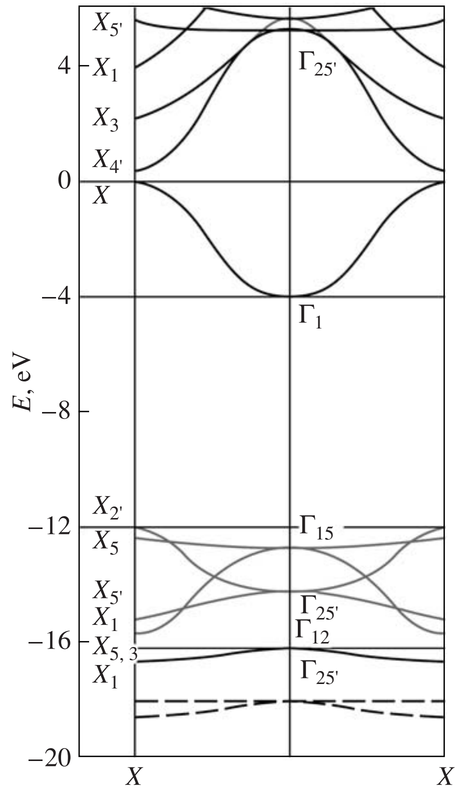

Fig. 3. The band diagram of CdF_2.

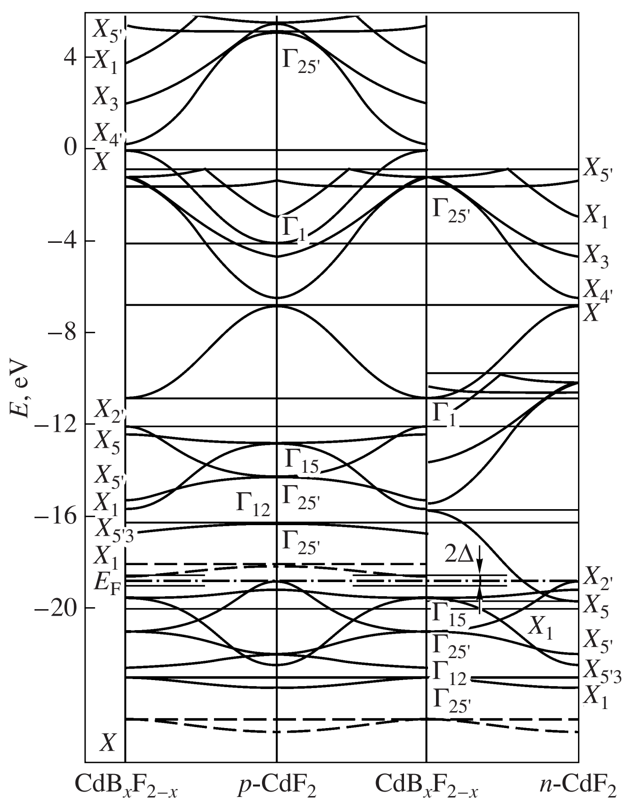

Fig. 4. The band diagram of a CdB_xF_{2-x}/p-CdF_2/CdB_xF_{2-x} sandwich structure in the conditions when a quantum-sized p^+–n junction is formed at the interface with n-CdF_2.

tions for the formation of 2D holes with a very small effective mass as a result of their interaction with boron dipole centers in δ-barriers can be put forward [7], which require further studies.

Thus, we observed for the first time Shubnikov–de Haas oscillations and a ladder for quantum steps in the Hall resistance in a p-CdF_2 QW confined by δ-like barriers for CdB_xF_{2-x} on the surface of n-CdF_2. Because of the small effective mass for 2D holes, observation of the quantum Hall effect was possible at room temperature.

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REFERENCES

1. K. von Klitzing, G. Dorda, and M. Pepper, Phys. Rev. Lett. **45**, 494 (1980).
2. S. Das Sarma and A. Pinczuk, *Perspectives in Quantum Hall Effects* (Wiley, New York, 1997).
3. S. Q. Murphy, J. L. Hicks, W. K. Liu, et al., Physica E **6**, 293 (2000).
4. G. Landwehr, J. Gerschütz, S. Oehling, et al., Physica E **6**, 713 (2000).
5. A. K. Geim and K. S. Novoselov, Nature Mater. **6**, 183 (2007).
6. Y. Zhang, Y. W. Tan, aH. L. Stormer, and P. Kim, Nature **438**, 201 (2005).
7. N. T. Bagraev, O. N. Gimbitskaya, L. E. Klyachkin, et al., Fiz. Tekh. Poluprovodn. **43** (2009, in press).

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