Two-electron states localized by charged acceptors in GaAs/GaAlAs quantum wells in ultra-quantum regime of magnetic fields

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We demonstrate both theoretically and experimentally that a negatively charged acceptor located inside or near a two-dimensional (2D) quantum well can localize more than one conduction electron. The phenomenon occurs in a strong magnetic field normal to the 2D plane. The energy and wave function of two conduction electrons trapped by an acceptor are calculated variationally as functions of the magnetic field and impurity position. In calculations we use a realistic model for the potential in doped quantum wells (QWs) and include the effect of screening by mobile carriers. The investigated two-electron state is analogous to the well-known state of D^- center composed of two electrons and a positively charged donor. However, in contrast to the donor case, the electron pair is localized by the acceptor, but not bound. The theory is compared with magneto-transport measurements on n-type GaAs/GaAlAs QWs, additionally doped in the well with beryllium. In such structures, a dramatic increase of resistance is observed at high currents and strong magnetic fields (corresponding to the filling factor $\nu<1$), as shown in Fig.1. This effect was called the "magnetic boil-off" and was interpreted as a result of electron transitions from the delocalized (conductive) states to the localized (nonconductive) states on acceptors caused by the Hall electric field [1]. A detailed analysis of the resistance data at intermediate currents (≈ 1 μA) reveals a two-step character of the boil-off process. We attribute the first resistivity step, which appears at lower magnetic fields (and thus at smaller Hall voltages), to a localization of electrons into single-particle states. The second resistivity step. which arises when all acceptors are occupied by electrons, is assigned to the formation of two-particle localized states. Our model explains well both the magnetic field and current dependences of the boil-off effect. We also show that the electric fields necessary to localize electrons are consistent with the measured Hall voltage, although an intrinsic inhomogeneity of the Hall field (see for example [2]) prevents a detailed comparison with the theory.

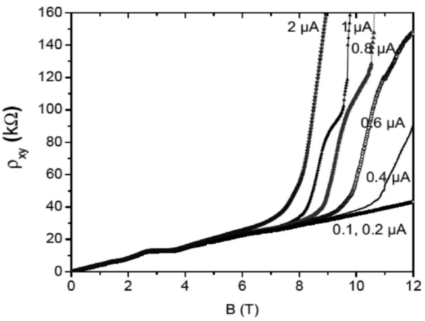

FIG. 1. Transport characteristics of sample 35A55 measured for high currents in dc experiments. The sharp increase of ρ_{xy} observed in the ultra-quantum limit of magnetic fields is caused by a localization of conduction electrons by negatively charged acceptors.

[1] I. Bisotto et al., Phys. Rev. B **86**, 085321 (2012).
[2] P. F. Fontein et al., Phys. Rev. B **43**, 12090 (1991).