Self-Assembled Quantum Dots as Probes for Landau-Level Spectroscopy

M. Russ[1], A. Lorke[1], D. Reuter[2], and P. Schafmeister[2]

[1] *Inst. of Physics, University Duisburg-Essen, Lotharstr. 1, ME245, 47058 Duisburg, Germany*
[2] *Solid State Physics, Ruhr-Univ. Bochum, Universitätsstr. 150, 44780 Bochum, Germany*

We report on capacitance-voltage (CV) measurements of an inverted two-dimensional electron gas with a layer of self-assembled InGaAs quantum dots in its immediate vicinity.

CV-spectroscopy has proved to be a valuable tool for the investigation of self-assembled quantum dots [1]. The "quantum capacitance" (i.e. the part of the capacitance that is directly proportional to the density of states) allows for a detailed study of the energetic structure inside these fully quantized systems [2]. In most cases, a heavily doped (3-dimensional) contact layer is used as a back electrode to study the density of states in the quantum dots.

Here, the back electrode is realized by a 2-dimensional electron gas (see Fig. 1). Thus the capacitance reflects the density of states of both the back electrode, as well as the quantum dots (see Fig. 2). To account for this, we have extended the model in Ref. [2] to include also the quantum nature of the back contact, particularly at high magnetic fields.

This allows us to study the bulk density of states of 2-dimensional electron gases (2DEGs) in the quantum Hall regime: Since the lowest charging peak (s^1-state of the dots [1]) is weakly magnetic-field dependent and only exhibits a well-known, smooth diamagnetic shift, it can be used as an energetic probe for the Fermi-energy of the 2DEG. Small changes in the charging-voltage as a function of the applied magnetic field B can directly be translated into a variation of the Fermi-energy when the Landau levels become populated or depopulated.

The result is shown in Fig. 3, where the typical 1/B-oscillation expected from the Landau fan chart can be observed. Interestingly, however, the shape of the oscillations is not in agreement with the standard models that have been proposed for the density of states of (broadened) Landau levels. As an example, the solid line in Fig. 3 shows the calculated variation of the Fermi energy when Gaussian broadening with a half-width proportional to $B^{1/2}$ is assumed. In particular, the sharp maximum close to filling factor 1 and the slope on its low-field side are not well described by Gaussian or Loretzian distributions with or without background. We therefore also discuss our findings within the framework of recent, more sophisticated theoretical models.

[1] P. M. Petroff, A. Lorke, and A. Imamoglu; *Epitaxially Self-Assembled Quantum Dots*; Physics Today, **54**, 46 (2001).

[2] R. J. Luyken, A. Lorke, A. O. Govorov, J. P. Kotthaus, G. Medeiros-Ribeiro and P. M. Petroff; *The Dynamics of Tunneling into Self-Assembled InAs Dots*; Appl. Phys. Lett. **74**, 2486 (1999).

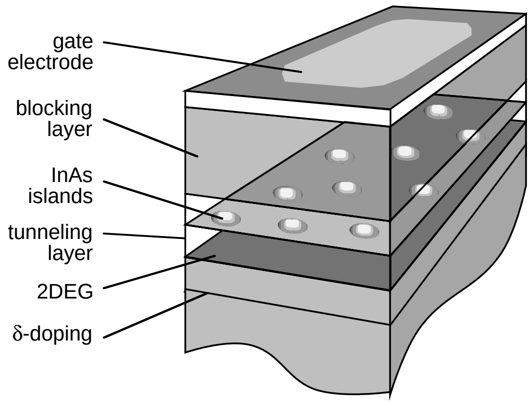

Fig. 1:
Schematic of the inverted heterostructure with self-assembled InGaAs quantum dots, separated from the 2DEG by a 25 nm thick tunneling barrier.

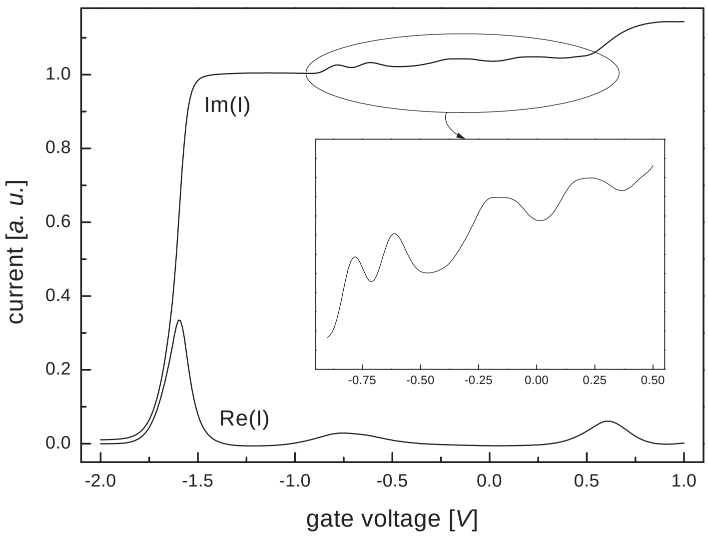

Fig. 2:
CV-spectrum of the sample at 10 T. The capacitance (here displayed as the imaginary part of the AC current) shows the distinct charging pattern of self-assembled InGaAs dots [1]. Note the depletion of the 2DEG at –1.6 V. The maximum in the real part of the current at –0.8 V is caused by an increased resistance at filling factor 2.

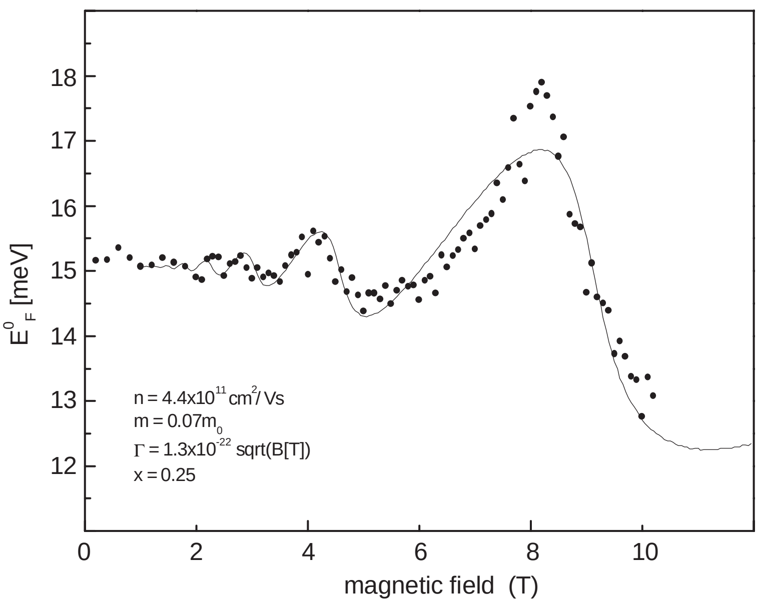

Fig. 3:
Fermi-energy fluctuations in the 2DEG as a function of the magnetic field. The solid line shows an attempt to fit the data to Landau levels with Gaussian broadening.