The effect of charged quantum dots on the mobility of a two-dimensional electron gas: How strong is Coulomb scattering?

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An electrical read-out of spin and charge states of self-assembled quantum dots (QDs) can be realized by a nearby two-dimensional electron gas (2DEG) [1], where the coupling mechanisms determine the strength of the detection signal. Therefore, we have investigated the coupling mechanisms between a layer of charged QDs and the 2DEG with single electron resolution [3] using Transconductance Spectroscopy (TCS) [2]. We are able to separate all contributions to the change in conductance by the charged electrons and find, surprisingly, that the influence of the charged QDs as Coulomb scatterers on the mobility is negligible for a 2DEG that is separated by a 30 nm barrier to the charged QDs.

The device is a high electron mobility transistor (HEMT) with an embedded layer of InAs QDs, separated by a 30 nm thick tunneling barrier from the 2DEG. By applying a suitable gate voltage we can charge the s- and p-shell with electrons (see Fig. 1, red line). Using Hall measurements, the influence of both mobility and charge carrier concentration on the 2DEG conductivity can be determined. They have almost equal contributions [3]. The overall change in mobility $\Delta\mu$ (see Fig. 1, black line) is on one hand caused by a decrease of the charge carrier density $\Delta\mu_n$ (see Fig. 1, blue line) by depletion of the 2DEG when the QDs are charged. On the other hand, the mobility decreases as a result of Coulomb scattering, induced by potential fluctuations by the charged QDs $\Delta\mu_{QD}$ (see Fig. 1, green line). The results in Fig. 1 show that the effect of the charged QDs as Coulomb scatters on the mobility is negligible, in very good agreement with calculations using the Stern-Howard-model.

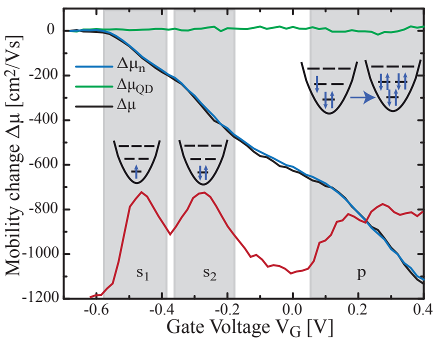

Figure 1: Measured overall change in mobility in the 2DEG $\Delta\mu$ due to Coulomb scattering by the charged QDs $\Delta\mu_{QD}$ and the change in charge carrier concentration $\Delta\mu_n$.

These results are of great interest for future devices. The read-out signal in a QD-HEMT device is almost independent of the distance between QDs and 2DEG for such devices; it will be only influenced by the ratio between the distance QD-2DEG and QD-Gate (the lever arm), as every electron loaded into the QDs is either "screened" by charge depletion on the gate or in the 2DEG.

[1] B. Marquardt et al., Nat. Commun. **2**, 209 (2011).
[2] B. Marquardt et al., Appl. Phys. Lett. **95**, 022113 (2009).
[3] B. Marquardt et al., Appl. Phys. Lett. **99**, 223510 (2011).