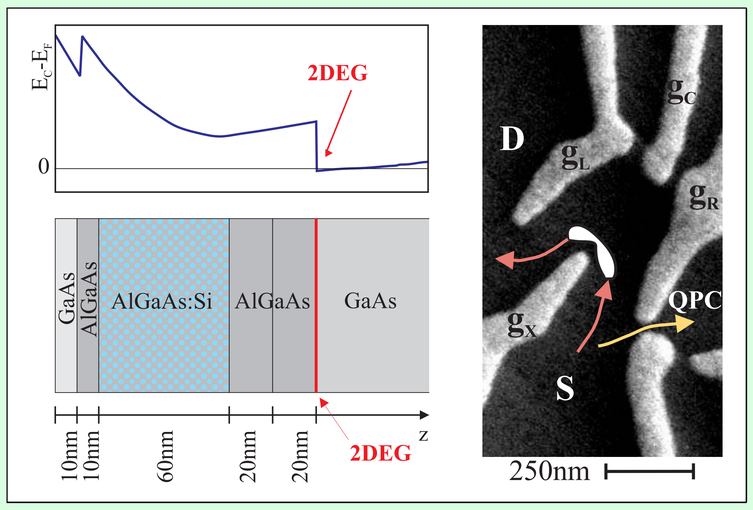
Tunnel splitting in a one–electron double quantum dot[1]

A.K. Hüttel[1], S. Ludwig[1], K. Eberl[2], and J.P. Kotthaus[1]

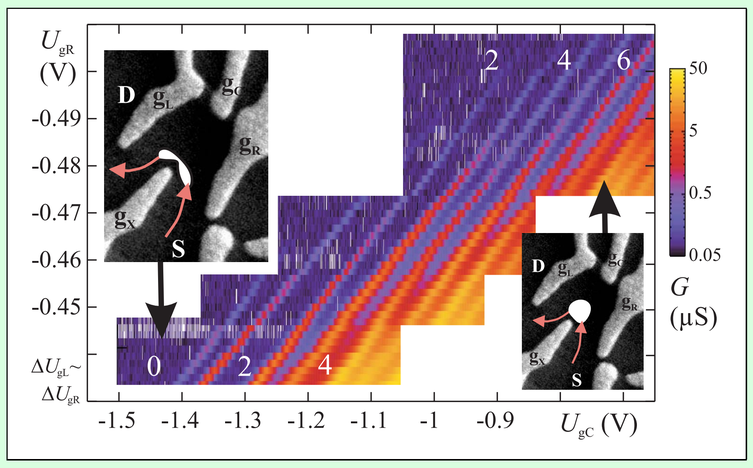
[1] *Center for NanoScience and Department Physik, Ludwig-Maximilians-Universität, Geschwister-Scholl-Platz 1, 80539 München, Germany.*
[2] *Max-Planck-Institut für Festkörperforschung, Heisenbergstraße 1, 70569 Stuttgart, Germany.*

Material system



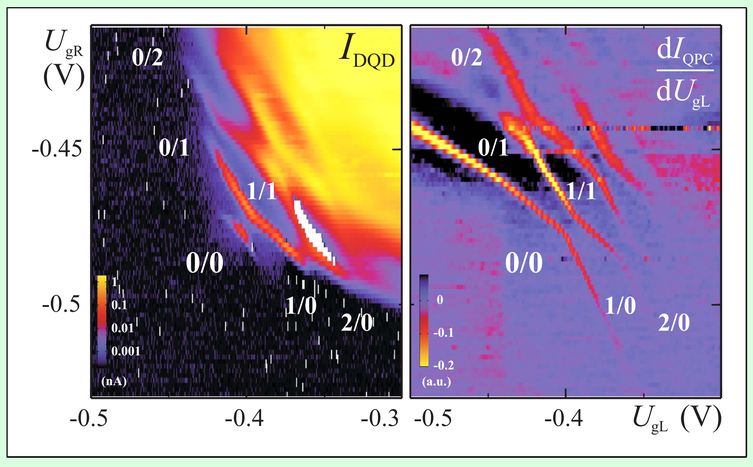
- GaAs/AlGaAs heterostructure
- Top gates written by SEM lithography
- Triangular geometry for low electron numbers [2]
- Quantum point contact (QPC) for electrostatic charge detection [3-4]

Transformation into a double dot



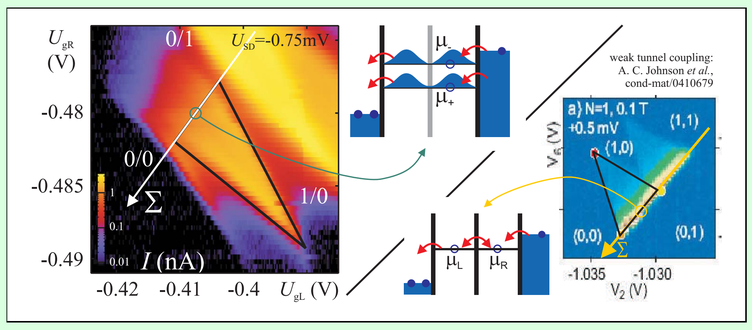
- $|U_{gC}|$ on the center gate is increased
  → Coulomb blockade peaks pair up
  → Quantum dot gradually deforms into a double quantum dot (DQD)

Double dot charging diagram



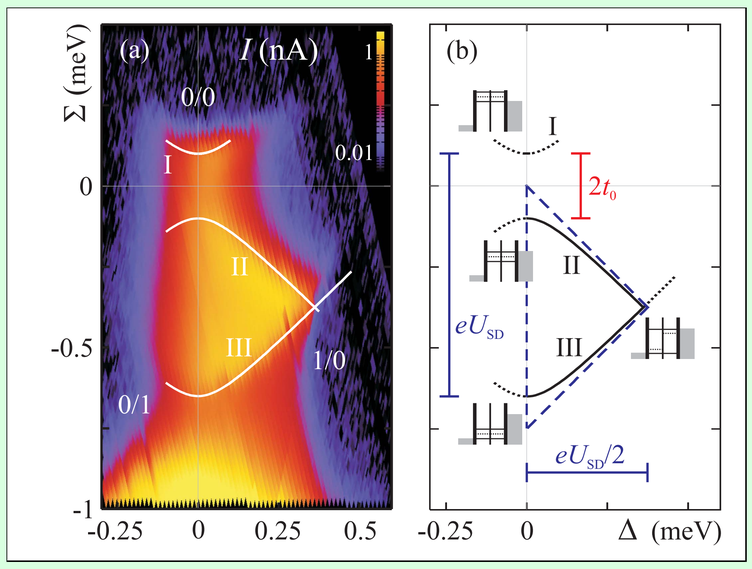
- Sweep of right versus left side gate
- Direct dc-current measurement (left plot)
  → Strong interdot coupling, delocalization
- Quantum point contact charge detection (right plot)
  → Double quantum dot can be emptied completely
  → Delocalization, continuous charge redistribution between dots at the symmetry line $0/1 \leftrightarrow 1/0$
  → No maximum in $\left|\frac{dI_{QPC}}{dU_{gL}}\right|$ at this line [5]

Anticrossing at finite U_{SD}, $N \leq 1$



- $U_{SD} = -0.75\,\mathrm{mV}$ → transport window
- Coordinate transformation U_{gL}, $U_{gR} \rightarrow \Sigma$, Δ

$$\Sigma = \frac{\mu_R + \mu_L}{2}, \qquad \Delta = \frac{\mu_R - \mu_L}{2}$$

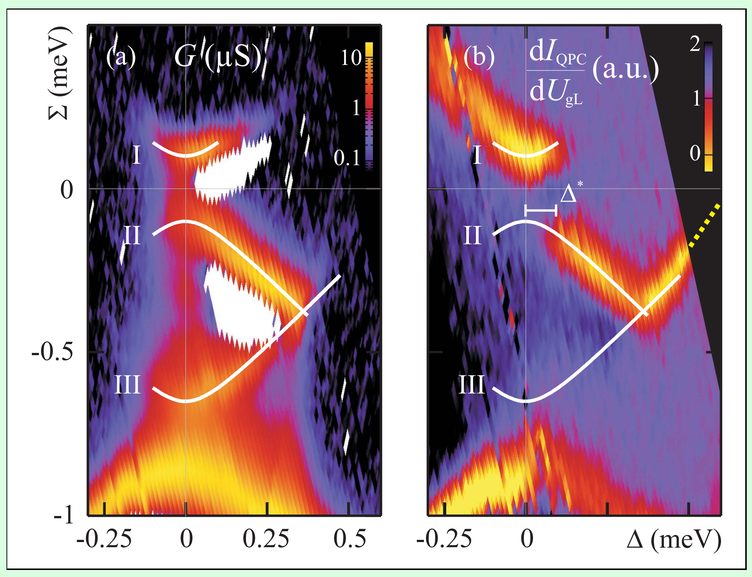


- Weak coupling case: triangle expected
- Here: **strong tunnel coupling**
- Edges of current onset follow **molecular states**

$$\mu_\pm(\Delta) = \mp\sqrt{\Delta^2 + t_0^2}$$

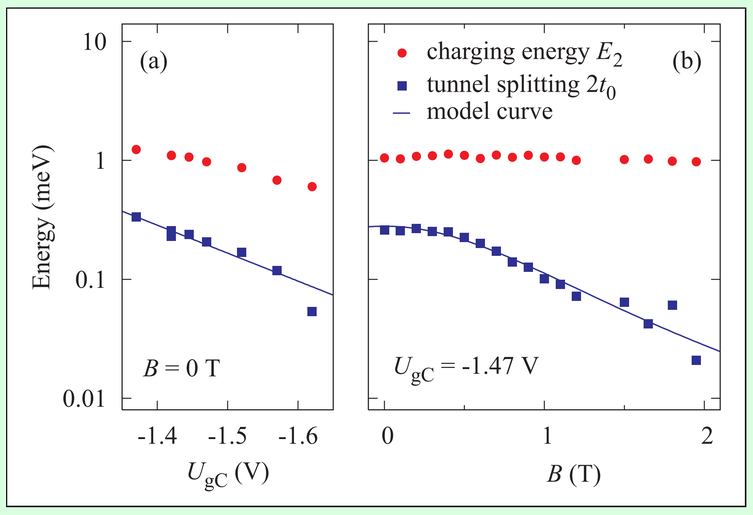
- Tunnel splitting $2t_0$ clearly visible and easily quantified (via comparison to eU_{SD})
- Bottom of plot: onset of two-electron charging

Conductance and average charge



- Discontinuity of charging line at $\Delta^* > 0$ (rhs plot)
  → $t_S/t_D \sim 5$;
  $t_{S/D}$: tunnel rate between DQD and source / drain
- Additional features, e.g. negative G (white, lhs plot)
  → Comparison of t_S, t_D, and the energy relaxation rate τ from excited to ground state

Controlling the tunnel splitting

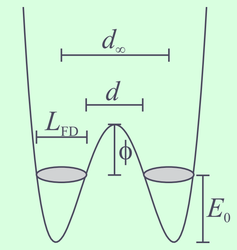


- E_2: charging energy for the second electron
- Higher $|U_{gC}|$ pushes the two dots apart
  → smaller $2t_0$, smaller E_2
- $B_\perp$ compresses the quantum dot states
  → smaller $2t_0$, constant E_2
- Qualitative model using the WKB–approximation

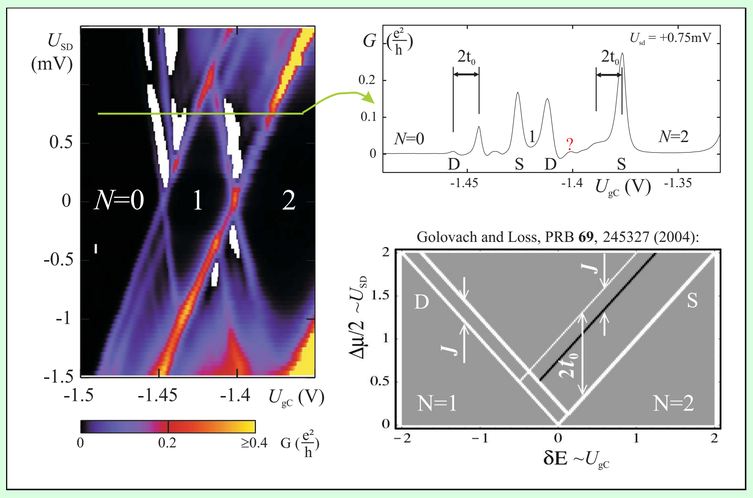
$$2t_0 \simeq \frac{2E_0}{\pi}\exp\left(-\frac{\sqrt{2m^*\phi}\,d}{2\hbar}\right),$$

$$d(B) = d_\infty - L_{FD}(B),$$

$$L_{FD}(B) = \sqrt{\frac{\hbar}{\omega_c m^*}}\,\frac{1}{\sqrt[4]{1+\frac{4\omega_0^2}{\omega_c^2}}}$$



Transport spectrum for $1 \leq N \leq 2$



- rhs lower plot: predictions by Golovach and Loss for the $1 \leq N \leq 2$ region [6]
- J: spin exchange interaction
- Tunnel splitting $2t_0$ clearly visible in measurement
- No proof of J yet, expected: $J \lesssim \frac{4t_H^2}{U_H} \lesssim 0.1\,\mathrm{meV}$

References

[1] A. K. Hüttel, S. Ludwig, K. Eberl, and J. P. Kotthaus, Direct control of the tunnel splitting in a one–electron double quantum dot, `cond-mat/0501012` (submitted).
[2] M. Ciorga *et al.*, PRB **61**, 16315 (2000).
[3] M. Field *et al.*, PRL **70**, 1311 (1992).
[4] J. M. Elzerman *et al.*, PRB **67**, 161308 (2003).
[5] J. R. Petta *et al.*, PRL **93**, 186802 (2004).
[6] V. N. Golovach and D. Loss, PRB **69**, 245327 (2004).

Many thanks to...

the German National Academic Foundation for support. This project has been funded by the DFG and the BMBF.