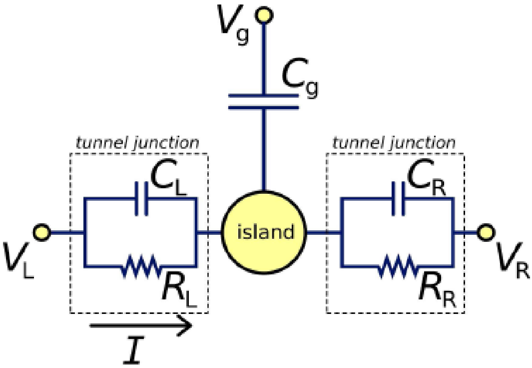
SET
Single **E**lectron **T**ransistor

Jürgen Wurm, Teresa Lermer

Universität Regensburg

27. Juni 2006

Setup



V_g
C_g
tunnel junction
C_L
V_L
R_L
island
tunnel junction
C_R
V_R
R_R
I

Coulomb Blockade

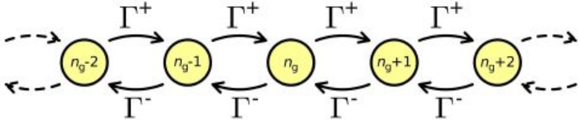
- *Equilibrium Charge*

$$Q_0 = C_L \cdot V_L + C_R \cdot V_R + C_g \cdot V_g$$

- *Total energy* of the island with n electrons

$$E_{ch}(Q) = \frac{(Q - Q_0)^2}{2C_\Sigma}$$

Transition Rates and Master Equation



- Rates Γ can be calculated via Fermi golden rule
- p_n: propability to find the system in a state with n electrons
- → *Masterequation*

$$\frac{d}{dt}p_n = \Gamma_{n+1\to n}p_{n+1} + \Gamma_{n-1\to n}p_{n-1} - (\Gamma_{n\to n+1} + \Gamma_{n\to n-1})p_n$$

Steady State and Current

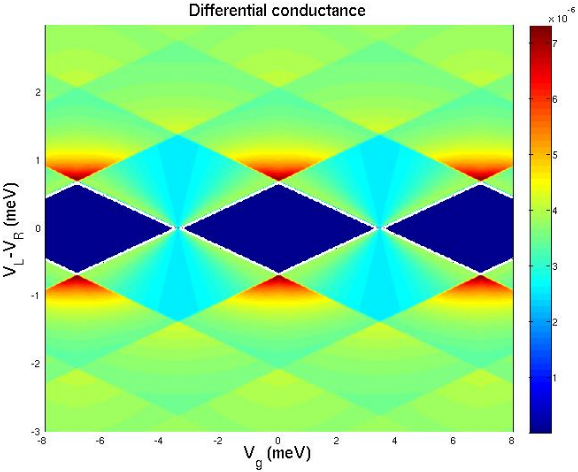
- Condition of *Detailed Balance*

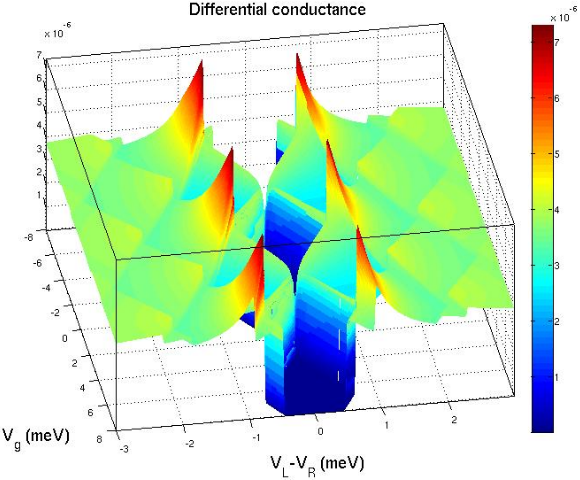
$$\Gamma_{n\to n+1} p_n = \Gamma_{n+1\to n} p_{n+1}$$

- $\Rightarrow \quad p_n$
- *Current* through the left junction

$$I = -e \sum_n p_n (\Gamma^L_{n\to n+1} - \Gamma^L_{n\to n-1})$$

Stability Diagram *for* $T = 20mK$




Differential conductance
x 10^-6
7
6
5
4
3
2
1
-8
-6
-4
-2
0
2
4
6
8
V_g (meV)
-3
-2
-1
0
1
2
V_L-V_R (meV)
x 10^-6
7
6
5
4
3
2
1

Conservation of Energy - Tunneling

- from left junction onto island

$$\epsilon_i = \sum_k^{k_{max}^L} \epsilon_k + E_{ch}(n) + \sum_k^{k_{max}^R} \epsilon_k$$

$$\epsilon_f = \sum_k^{k_{max}^L} \epsilon_k - \epsilon_{k'} + E_{ch}(n+1) + \sum_k^{k_{max}^R} \epsilon_k$$

- $\epsilon_i = \epsilon_f$

$$\Delta E_{ch} = \epsilon_{k'} \leq \epsilon_{k^L_{max}} = e\frac{V}{2}$$

- from island to right junction

$$\Delta E_{ch} \geq -e\frac{V}{2}$$

- from right junction onto island

$$\Delta E_{ch} \leq -e\frac{V}{2}$$

- from island to left junction

$$\Delta E_{ch} \geq e\frac{V}{2}$$

Tunneling condition - straight lines in stability diagram

- calculate ΔE_{ch} for positive population n and consider equal signs
- from left to island and v.v.

$$V = \frac{(2n+1)e}{C_\Sigma} - \frac{2C_g}{C_\Sigma} \cdot V_g$$

- from right to island and v.v.

$$V = -\frac{(2n+1)e}{C_\Sigma} + \frac{2C_g}{C_\Sigma} \cdot V_g$$

- calculate ΔE_{ch} for negative population -n and consider equal signs
- from left to island and v.v.

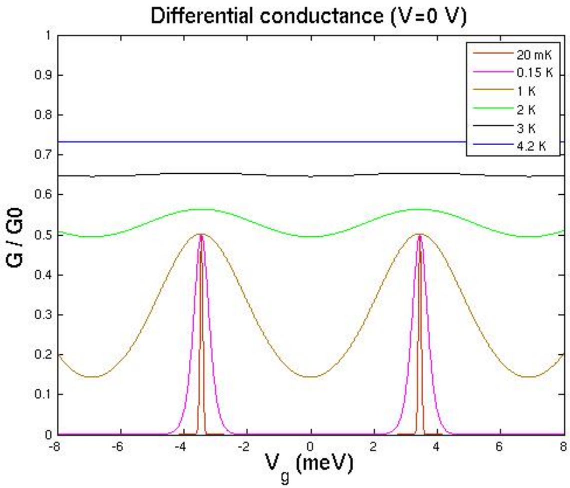
$$V = \frac{(2n+1)e}{C_\Sigma} + \frac{2C_g}{C_\Sigma} \cdot V_g$$

- from right to island and v.v.

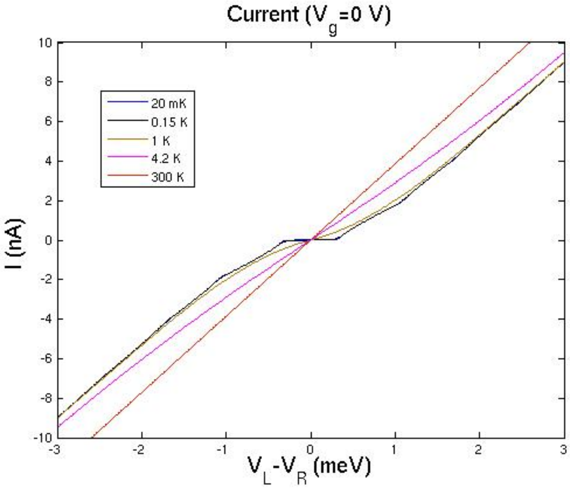
$$V = -\frac{(2n+1)e}{C_\Sigma} - \frac{2C_g}{C_\Sigma} \cdot V_g$$

- slope and axis intercept yield C_Σ and C_g

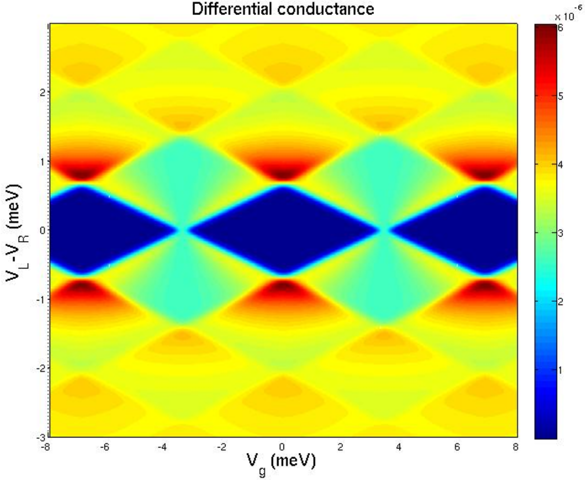
Coulomb Oscillations $\quad for\ V = 1nV$

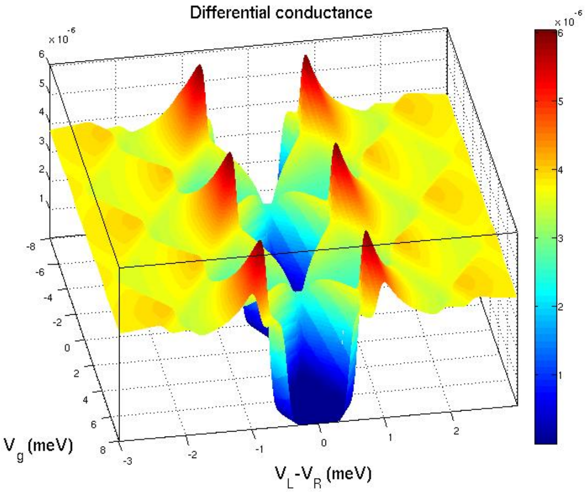


I vs. $V = V_R - V_L$ for $V_g = 0$

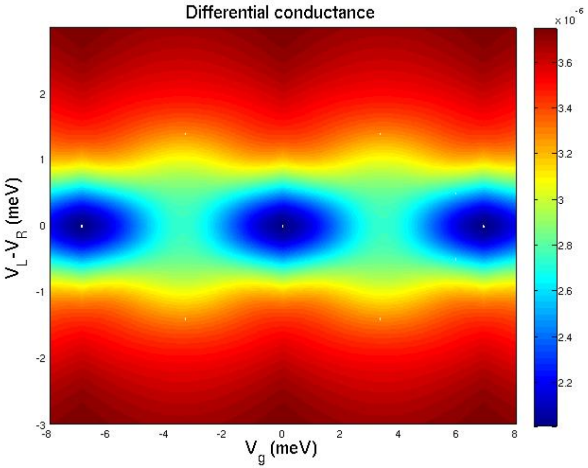


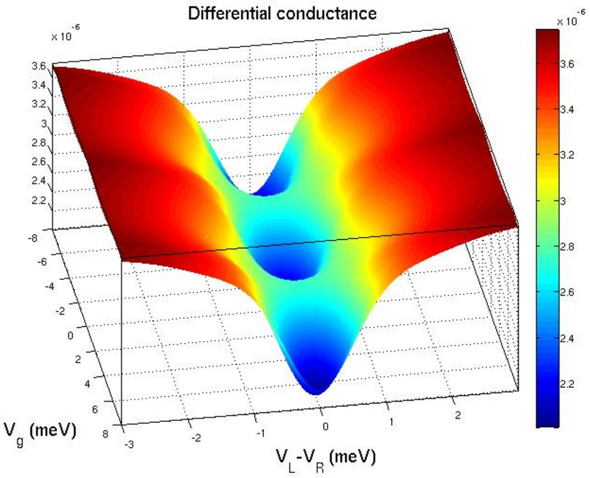
Stability Diagram $\quad for \;\; T = 0.15K$



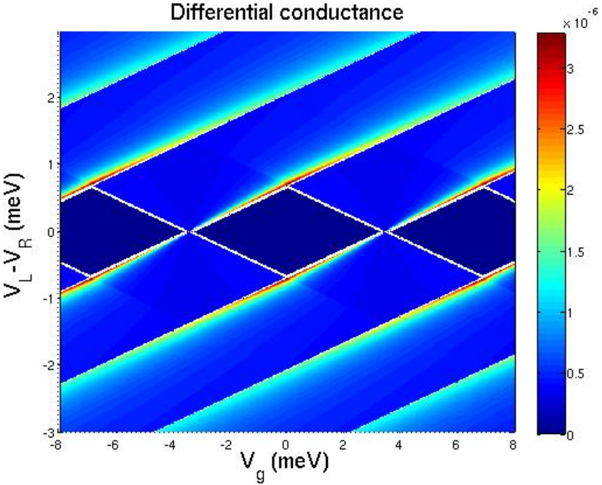

Differential conductance
x 10^-6
6
5
4
3
2
1
-8
-6
-4
-2
0
2
4
6
8
V_g (meV)
-3
-2
-1
0
1
2
V_L-V_R (meV)
x 10^-6
6
5
4
3
2
1

Stability Diagram *for* $T = 2K$




Differential conductance
x 10^-6
3.6
3.4
3.2
3
2.8
2.6
2.4
2.2
-8
-6
-4
-2
0
2
4
6
8
Vg (meV)
-3
-2
-1
0
1
2
VL-VR (meV)
x 10^-6
3.6
3.4
3.2
3
2.8
2.6
2.4
2.2

Different resistance: $R_R = 100\Omega, R_L = 10\Omega$



Conclusion

- We learned the basics of the Coulomb Blockade Effect and the concept of the Single Electron Transistor
- We gained insight into numerical working with matlab and its graphical features