Double quantum dot as a thermoelectric generator

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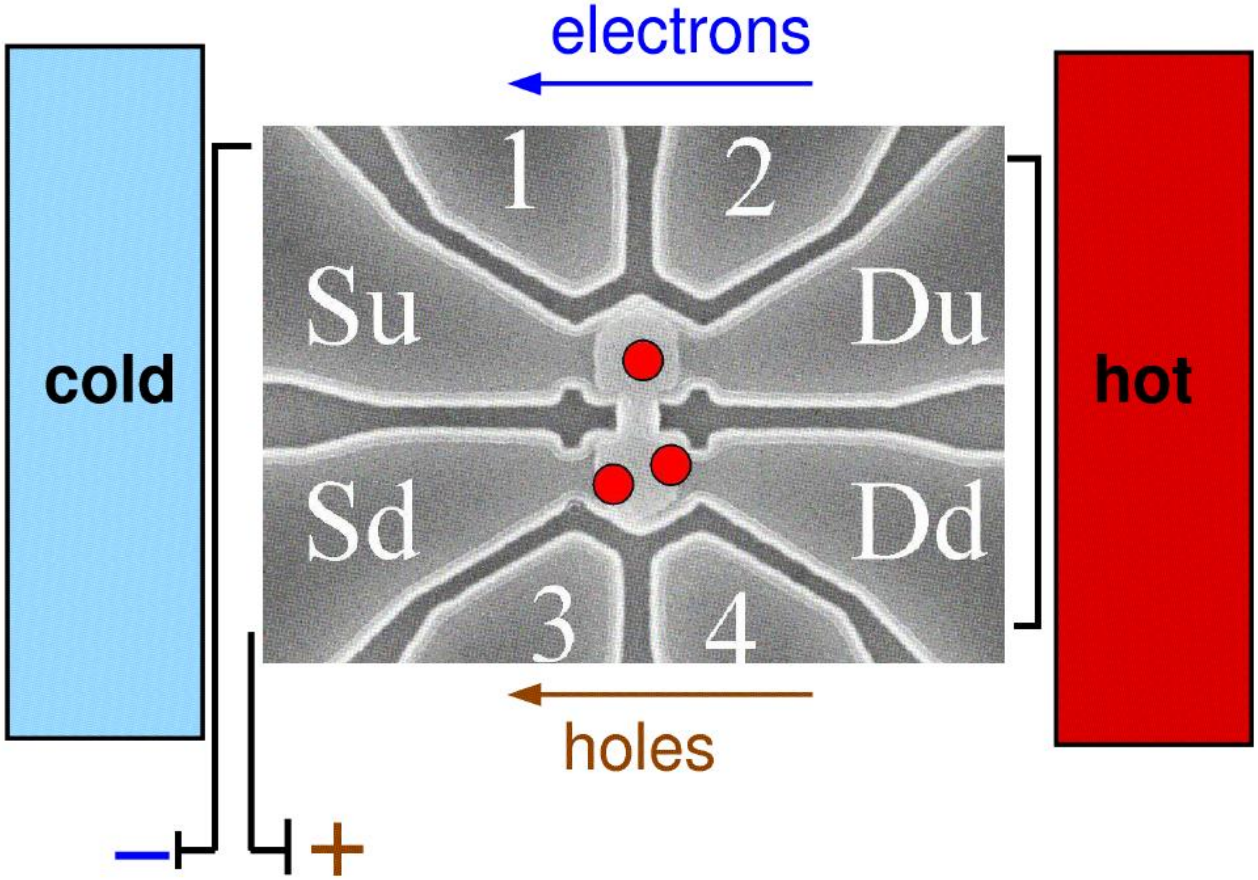
Starting Point

- Modelling of an experimental realized double quantum dot in a GaAs/$Al_{0.33}Ga_{0.67}As$ heterostructure (Hübel et. al. 2007, 2008)
- Good match of theory and experiment for the conductivity
- Calculate other thermoelectric coefficients; especially thermopower

Basic concept

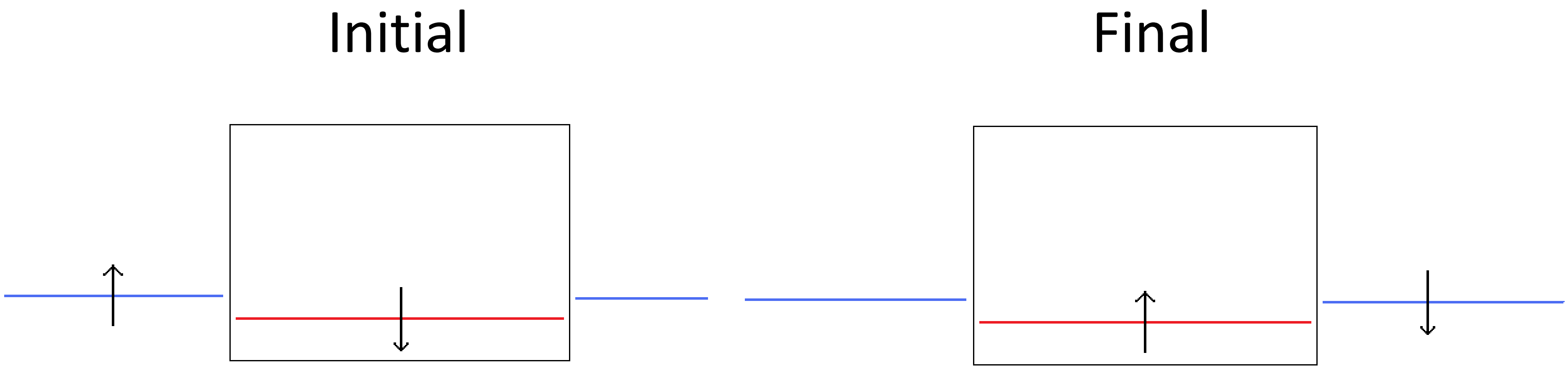
- Kondo effect leads to enhanced thermoelectric coefficients
- One dot n-type, other dot p-type thermoelectric device
- External heat gradient leads to a total current

Scheme



Kondo effect in quantum dots

- Lower conductivity in bulk materials
- Quantum tunneling with „spin flip“ leads to non-vanishing thermoelectric coefficients in quantum dots



Model Hamiltonian

- Anderson impurity

$$\hat{H} = \sum_{i\in\{u,d\}} \left(\varepsilon_i \cdot \hat{n}_i + U_i \cdot \hat{n}_{i,\uparrow} \hat{n}_{i,\downarrow} \right) + U' \cdot \hat{n}_u \hat{n}_d$$

$$+ \sum_{R_i,k,\sigma} \varepsilon_k \cdot \hat{c}^+_{R_i,k,\sigma} \hat{c}_{R_i,k,\sigma}$$

$$+ \sum_{R_i,k,\sigma} \left(V_{R_i} \cdot \hat{a}^+_{R_i,k,\sigma} \hat{c}_{R_i,k,\sigma} + h.c. \right)$$

Meir – Wingreen formula

$$G_i(T) = e^2 I_i^0(T)$$

$$S_i(T) = -\frac{1}{|e|T}\frac{I_i^1(T)}{I_i^0(T)}$$

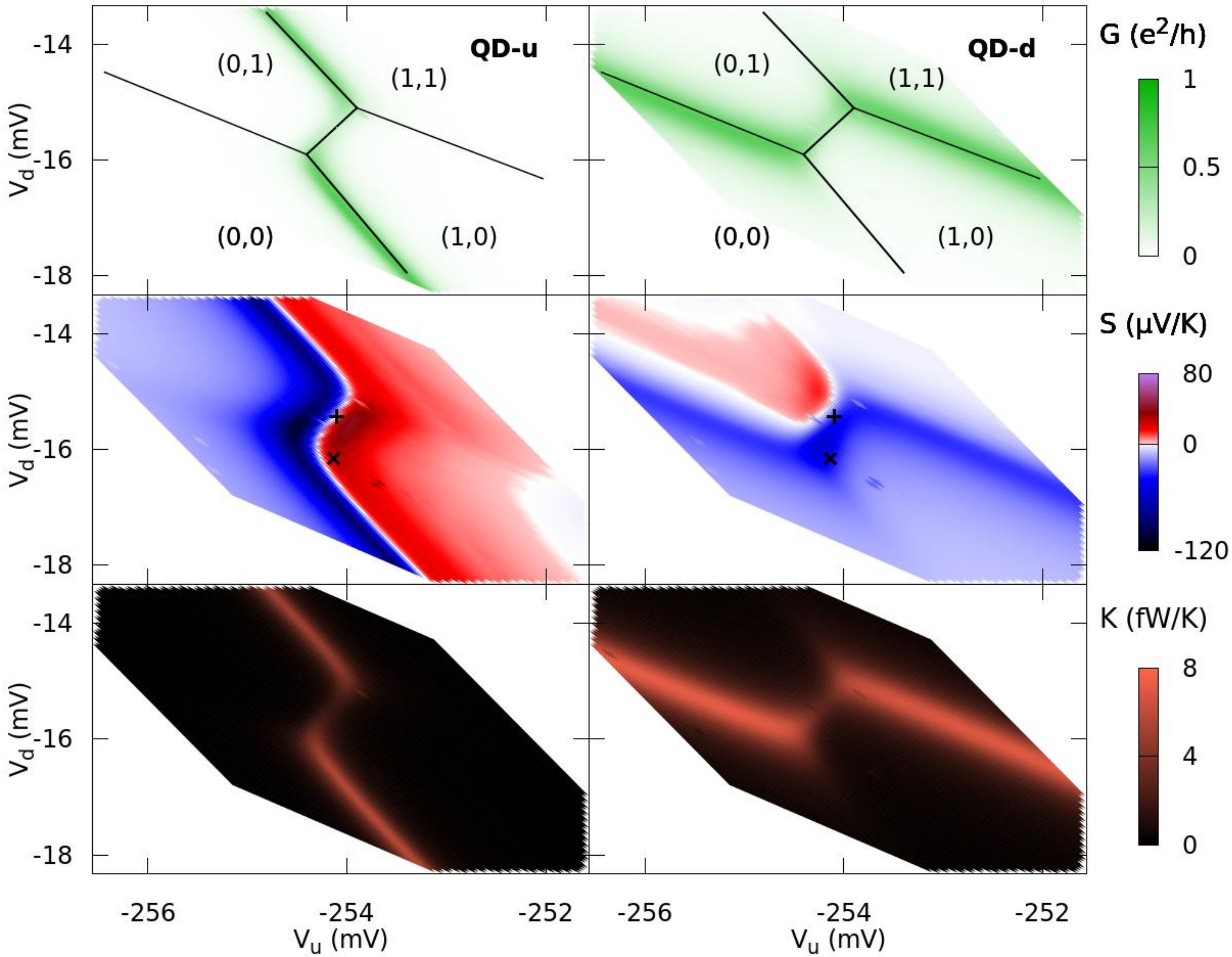
$$K_i^e(T) = \frac{1}{T}\left[I_i^2(T) - \frac{I_i^1(T)^2}{I_i^0(T)}\right]$$

$$I_i^n = \frac{2}{h}\int d\omega\omega^n \cdot \mathrm{T}_i(\omega)\left(-\frac{\partial f(\omega)}{\partial\omega}\right) \qquad \mathrm{T}_i(\omega) = 2\pi\frac{\Gamma_{Li}\Gamma_{Ri}}{\Gamma_{Li}+\Gamma_{Ri}}A_i(\omega)$$

Calculations

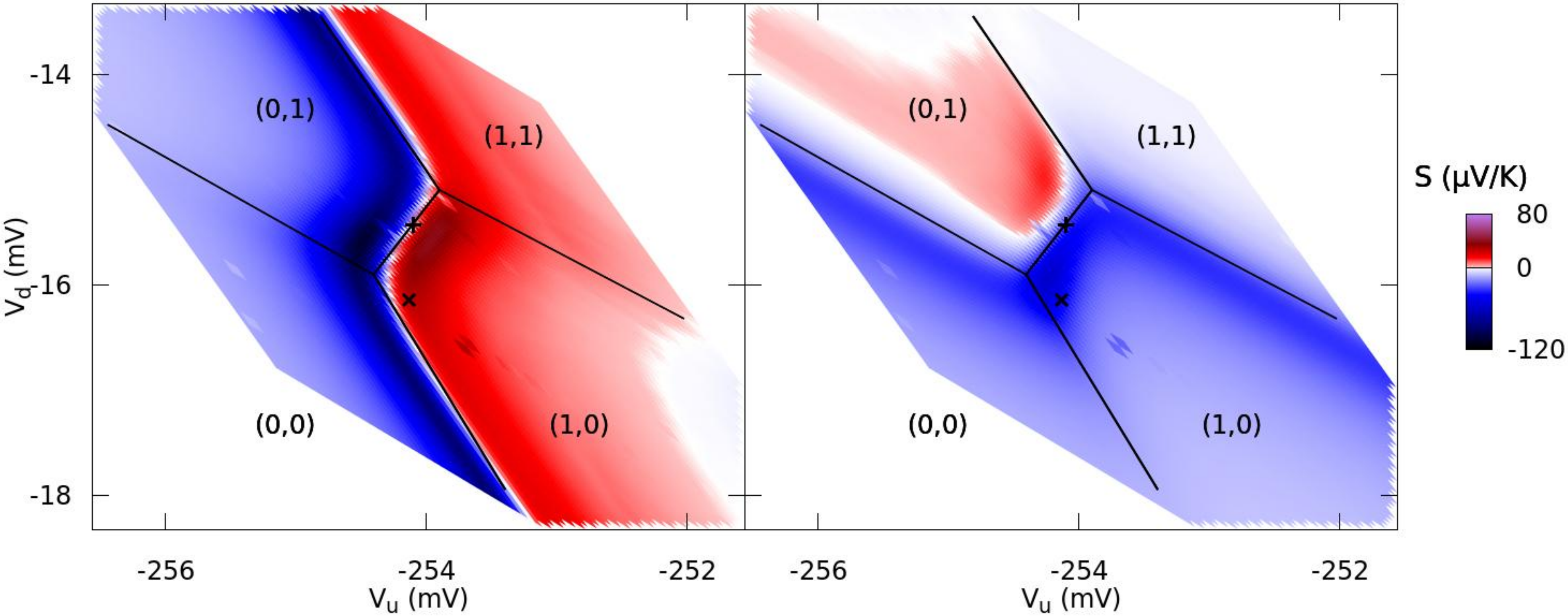
- Spectral functions via NRG
- Assymetric hybridization
- T=25mK
- Changing one gate voltage effects both quantum dots

Results

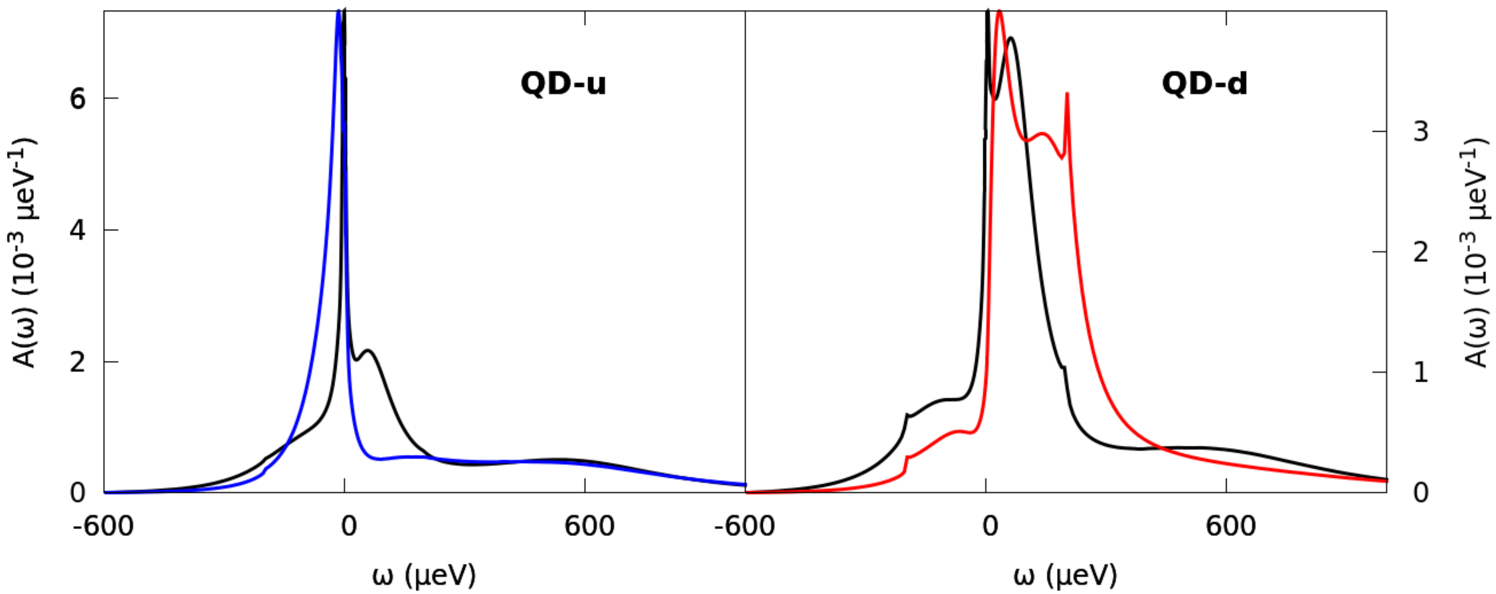


QD-u
QD-d
(0,1)
(1,1)
(0,0)
(1,0)
G (e²/h)
S (μV/K)
K (fW/K)
1
0.5
0
80
0
-120
8
4
0
-14
-16
-18
V_d (mV)
-256
-254
-252
V_u (mV)

Thermopower



Spectral functions



$$S_i(T) = -\frac{\pi^2 k_B}{3|e|} k_B T \frac{dA_i(\omega)/d\omega\big|_{\omega=0}}{A_i(0)}$$

Applications 1

- Energy scale μeV
- Temperatur scale mK
- Uninteresting except for Peltier cooling at very low temperatures
- Basic research

Applications 2

- Reducing size to nm => rescaling of energy and temperature scale
- Multiple connected quantum dots connected via a common back electrode
- Integration on computer chips for the cooling of waste heat and power generation

Problems & Outlook

- Small thermopower
- Figure of merit is not too high
- Calculated for specific parameters

Problems & Outlook

- Small thermopower
- Figure of merit is not too high
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- Calculate spectral functions for different parameter sets
- Go to lower temperatures

References

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