Electron counting spectroscopy of CdSe nanocrystals using Nanotube Transistors

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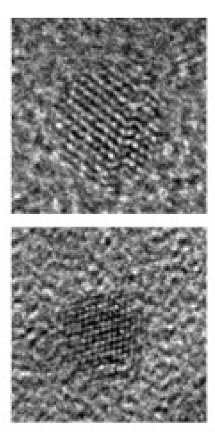
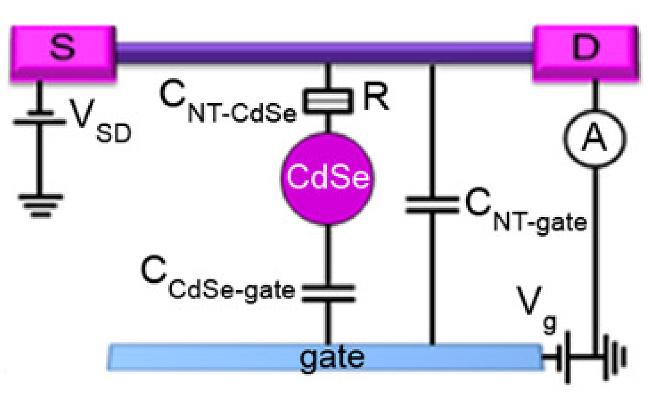
Single electron detection has been used to probe the electronic properties of semiconducting CdSe quantum dots. The detection scheme is based on an original approach where the investigated particle is attached to only one electrode, a carbon nanotube (CNT) [1].
The conductance of the nanotube is measured as a function of a gate voltage (V_g), which allows the detection of individual electrons transferred onto the particle. We noticed no electron transfer for certain range of V_g which is attributed to the energy gap of the CdSe particle. Our study shows that this single-electron detection enables the study of the separation in energy between the electronic discrete levels of the semiconducting particle. Finally, this technique allows the study of chaotic behavior of the energy levels in the CdSe particle.

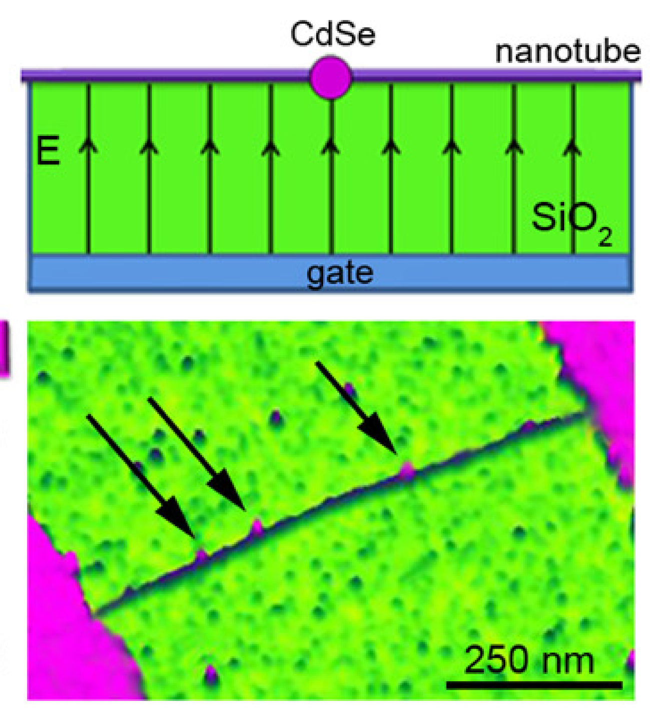
Principles

Geometry

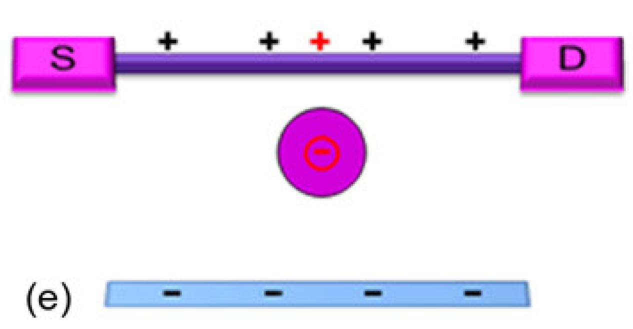
Only one electrode - a carbon nanotube



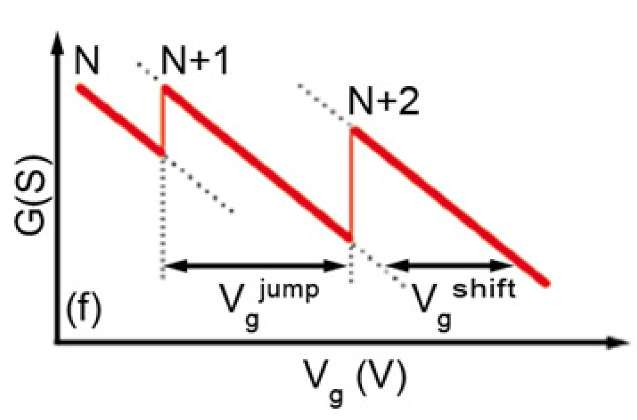




Detection scheme



The nanotube has two roles:
- electron reservoir
- it detects the transfer of single electrons onto the CdSe particle



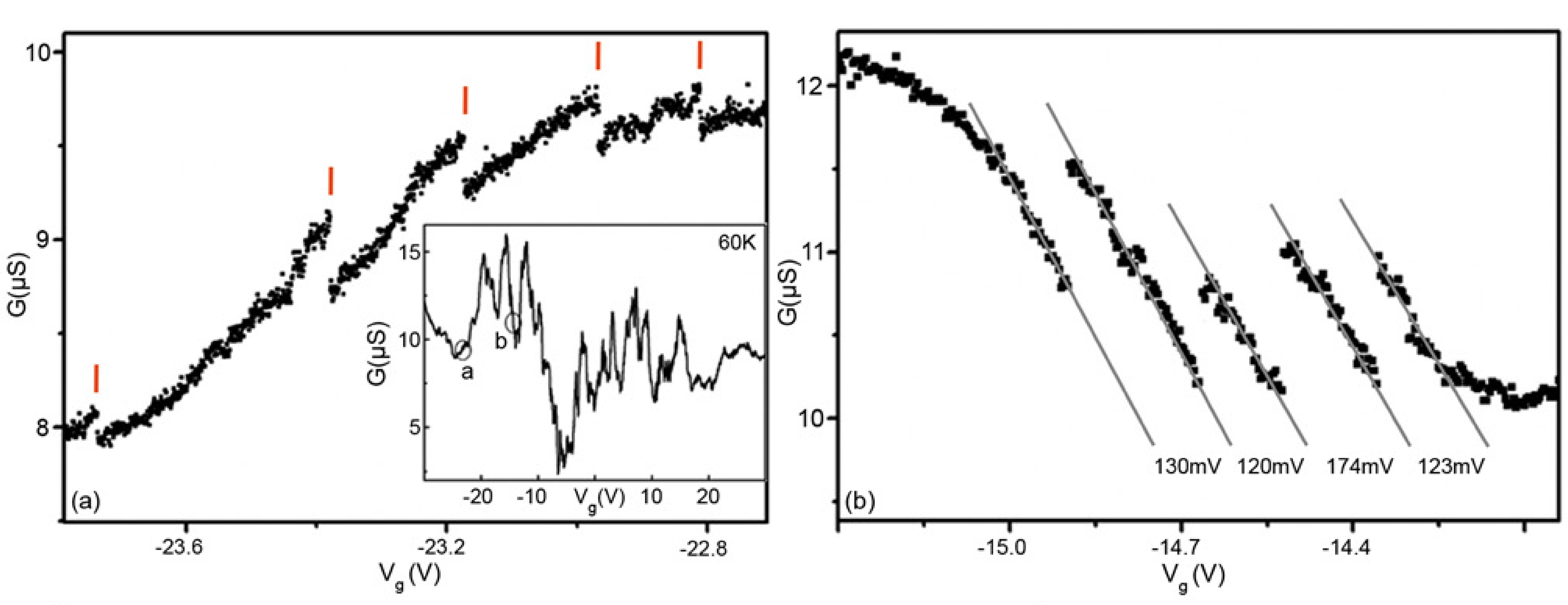
One electron transfer corresponds to the shift of the tube conductance .

$$\Rightarrow V_g^{shift} \sim E_C + \Delta E$$

charging energy — level spacing energy

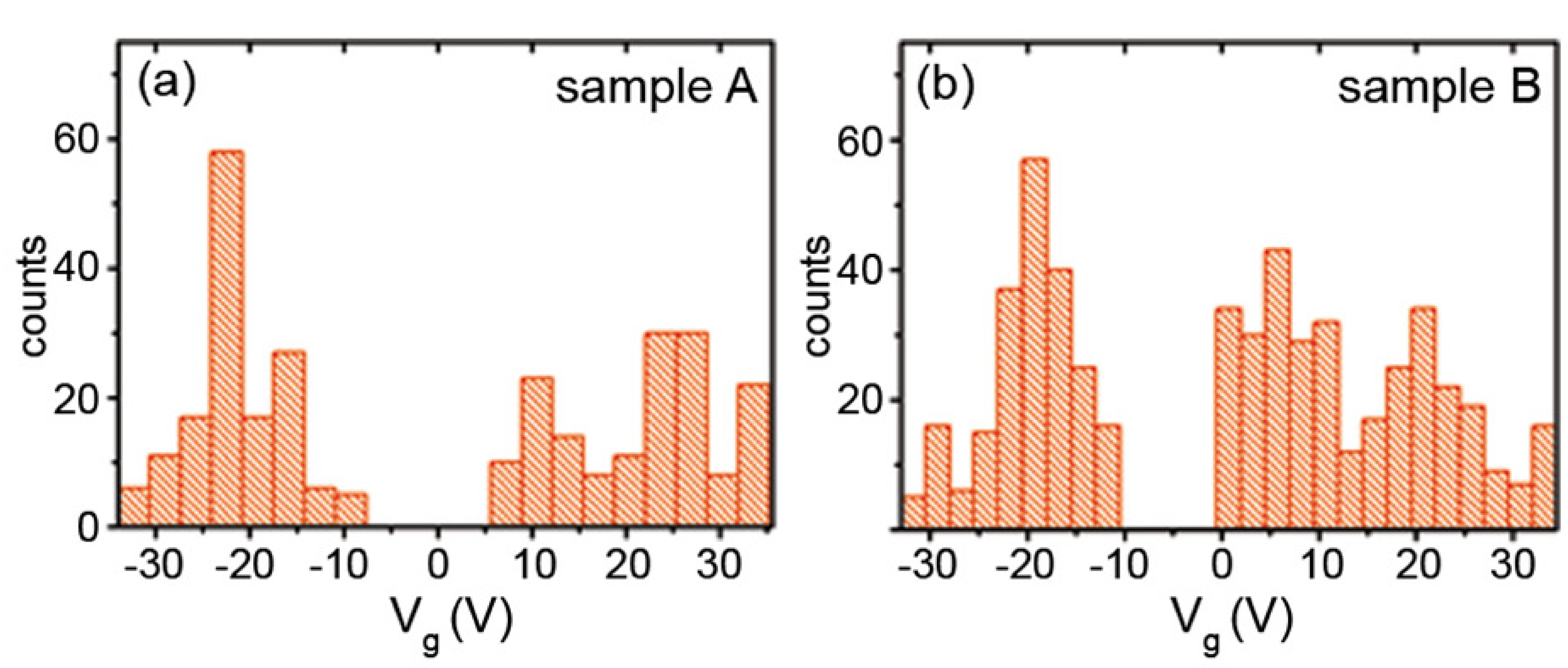
Experiments

Counting electrons – shifts in the tube conductance



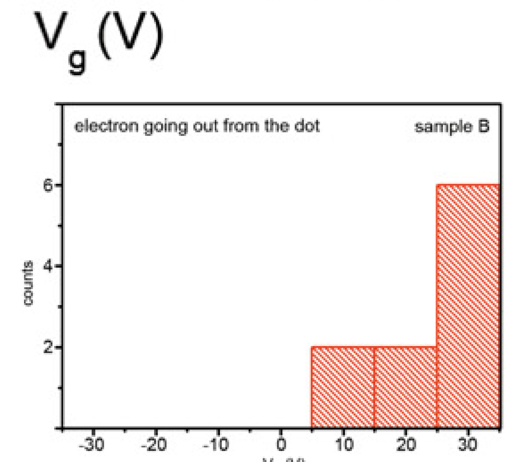
Shifts not equal → fluctuactions of the addition energy

Electron counts vs gate voltage



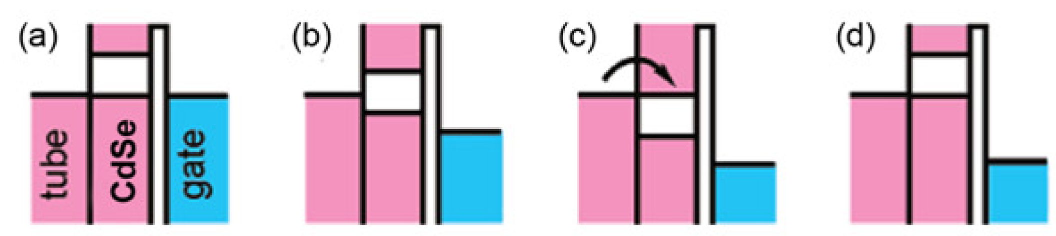
The gate voltage gap → energy gap of the dot

We can put ~200 electrons (!) onto the 5 nm CdSe dot



Energy levels distribution

Principles



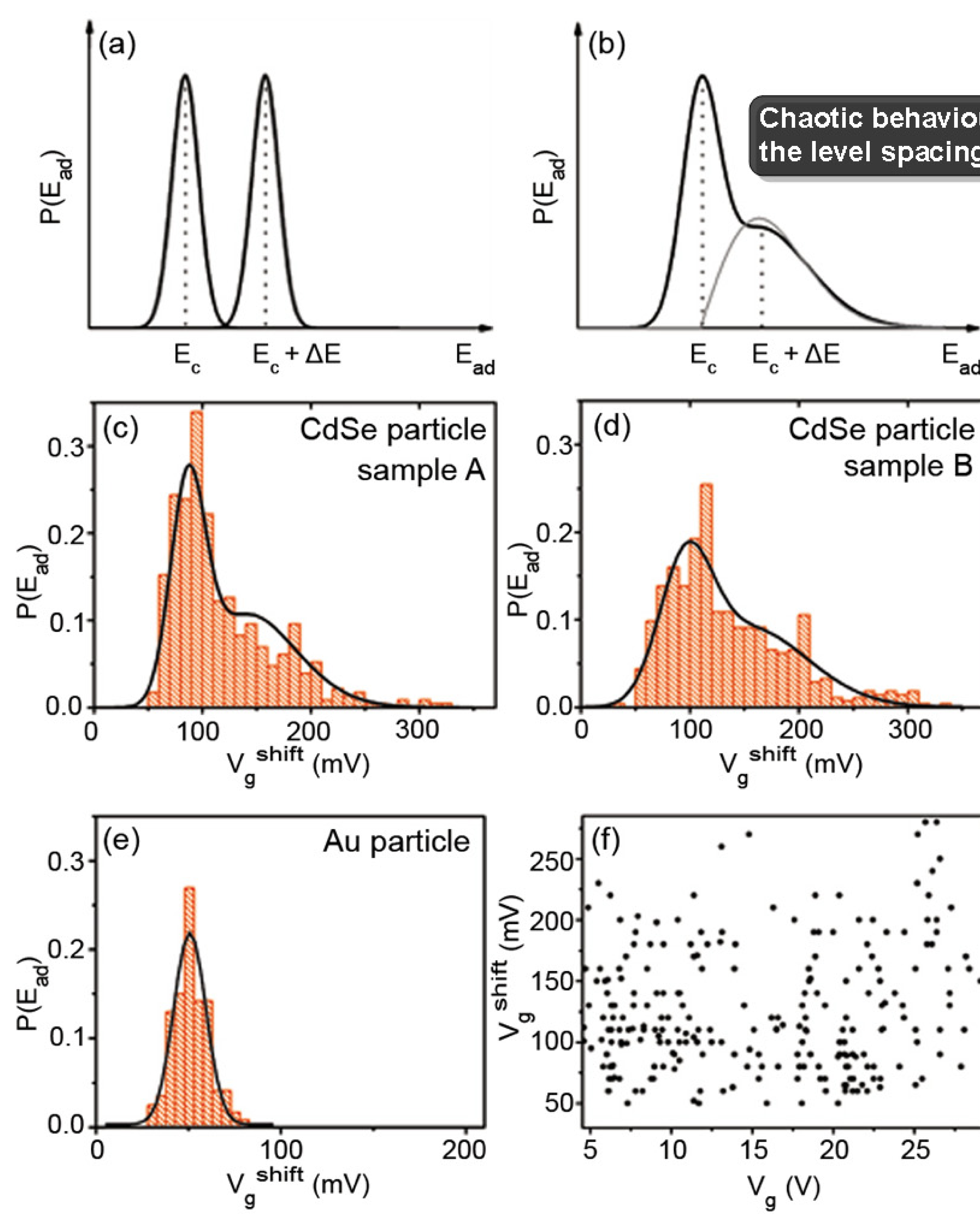
$$V_g^{shift} = \alpha \underbrace{(E_C + \Delta E)}_{E_{ad}}$$

Addition energy related with the gate voltage

Constant Interaction model

$$E_{ad}^{i} = \begin{cases} E_C & i = even \\ E_C + \Delta E & i = odd \end{cases}$$

Distribution of the energy levels in the dot



Bimodal distribution of addition energy → chaotic behavior

Experimental evidence of the fluctuation of level spacing energy

Sample A	Sample B
$E_c \approx 23{,}2\ mV$	$E_c \approx 19{,}2\ mV$
$\Delta E \approx 18{,}3\ mV$	$\Delta E \approx 15\ mV$

[1] A. Gruneis, M. J. Esplandiu, D. Garcia-Sanchez and A. Bachtold, *Nano Letters* **7** 3766 (2007).