Detection of spin, location and occupation number for single impurity (Arsenic donor), using silicon quantum dot.

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M. Hofheinz et al. Cond-mat 0504325

Motivations:

CMOS industry produces nowadays the smallest artificial structures (CMOS FET with gate length of 3 nm have been reported)

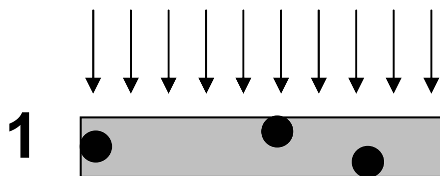
➔Use this technology to build ultimate Silicon SET (in particular using the expertize in dopant implantation processes)

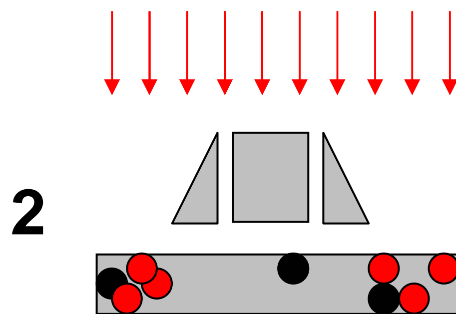
➔Fabrication of SET compatible with CMOS for hybrid applications (SET and FET are very similar devices at this scale)

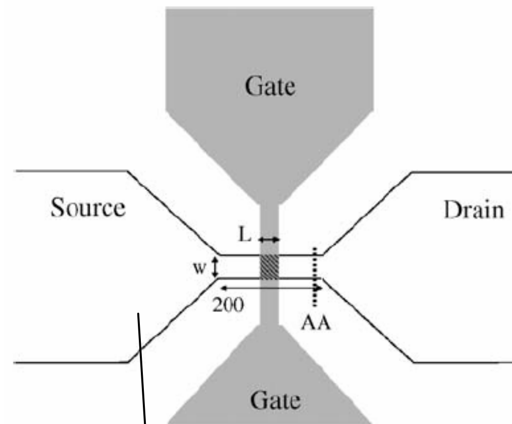
➔(hopefully) a reduced offset charge dynamics (as compared to others SET (metallic, 3-5, CN ….)

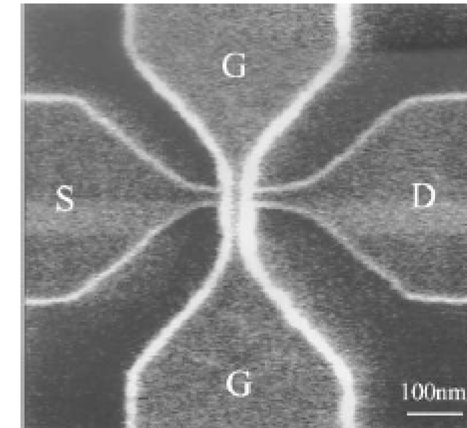
SET made with standard silicon microelectronics platform

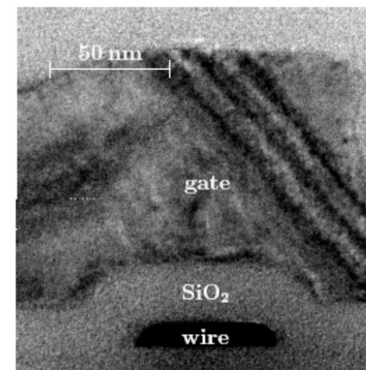
Two steps implantation:

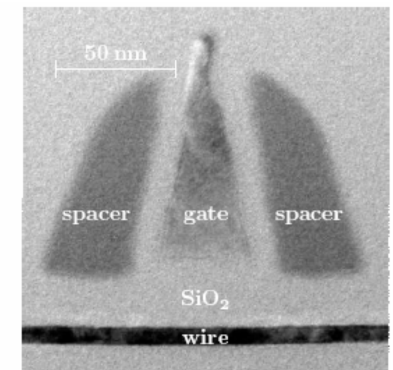










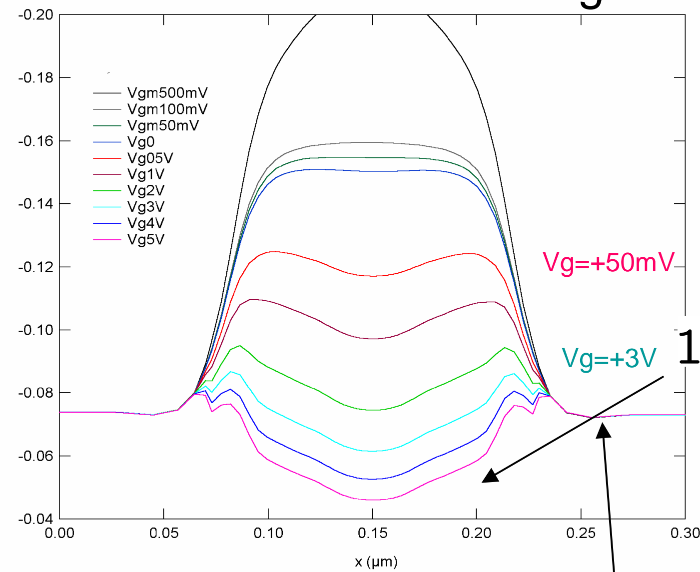


Silicon-On-Insulator thin film

Coulomb island induced by a positive gate voltage
S-D Barriers are the low-doped access regions below the spacers

M. Boehm et al. Phys. Rev. B 71, 033305, 2005.

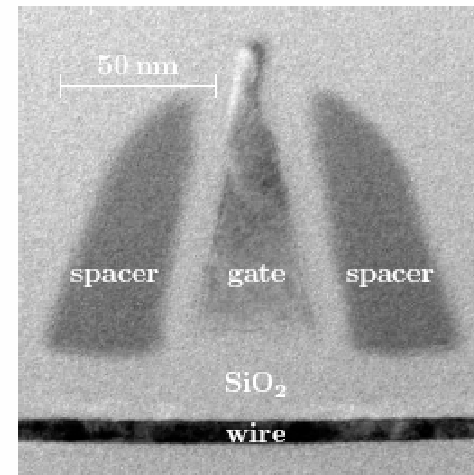
Conduction band edge

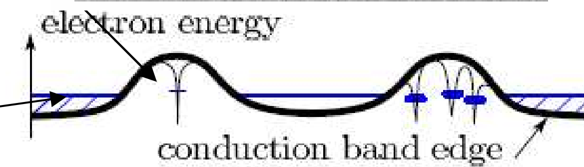


Vg=+50mV

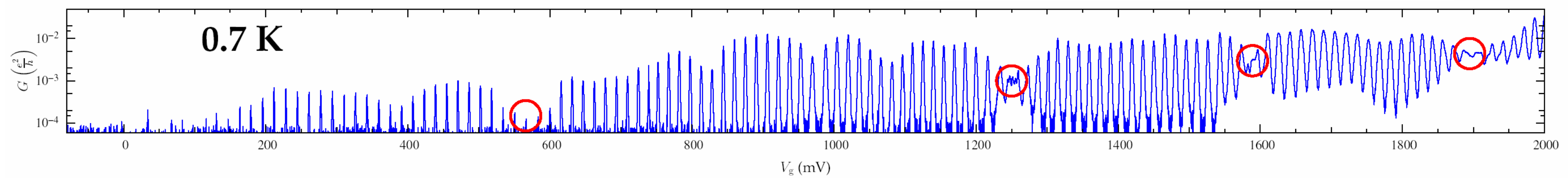
Vg=+3V

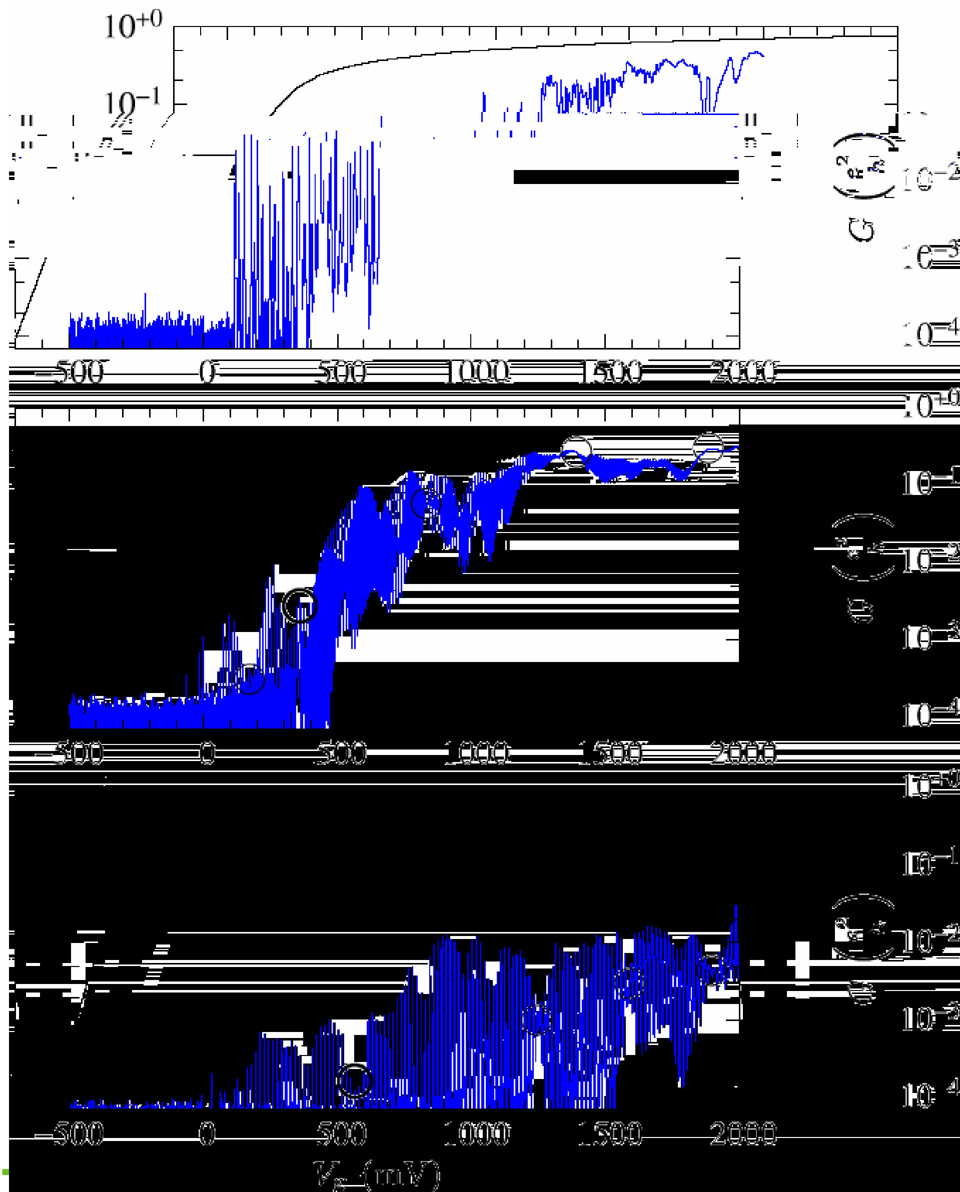
$1 \quad 10^{18} cm^{-3} As$





$5 \quad 10^{19} cm^{-3} As$





DOPING LEVEL IN ACCESS REGIONS:

$5\ \ 10^{19} cm^{-3} As$

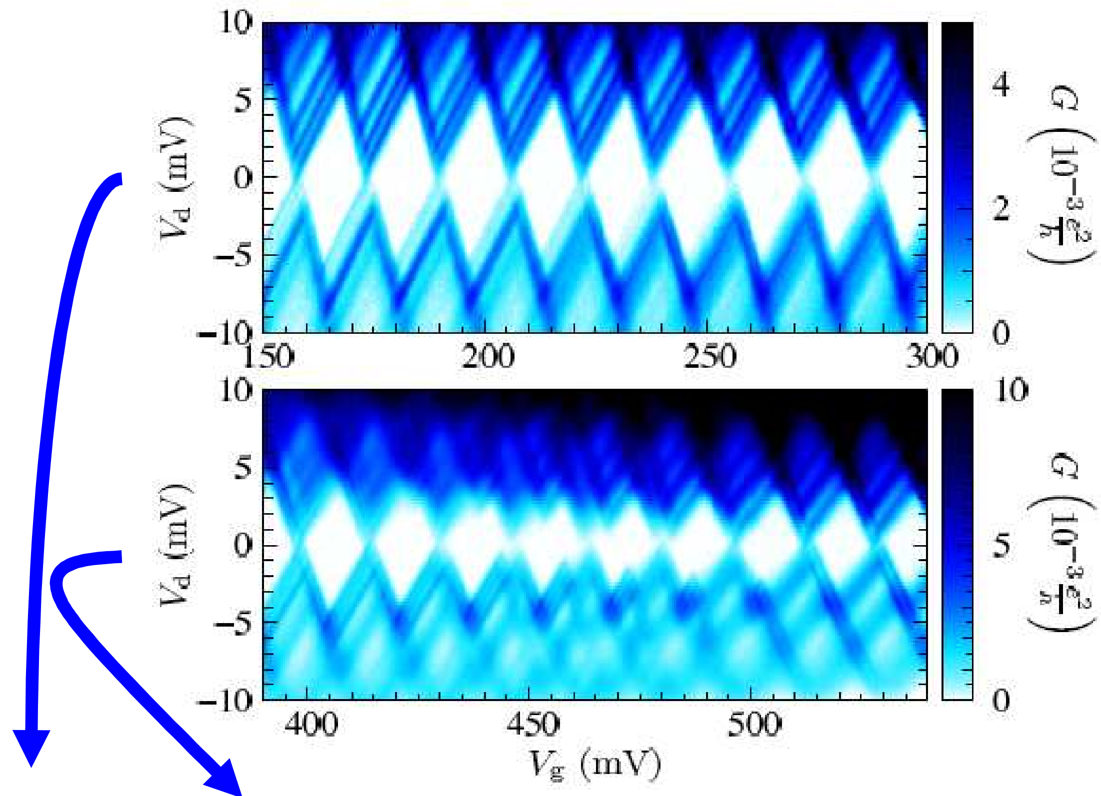
10 nm gate oxide thickness

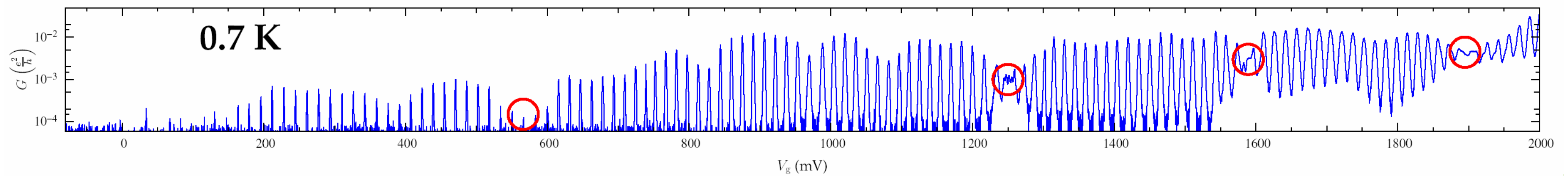
$1\ \ 10^{18} cm^{-3} As$

NB: we expect to see 15 donors in our span in Vg at this concentration

24 nm gate oxide thickness

Anomalies in Coulomb diamonds

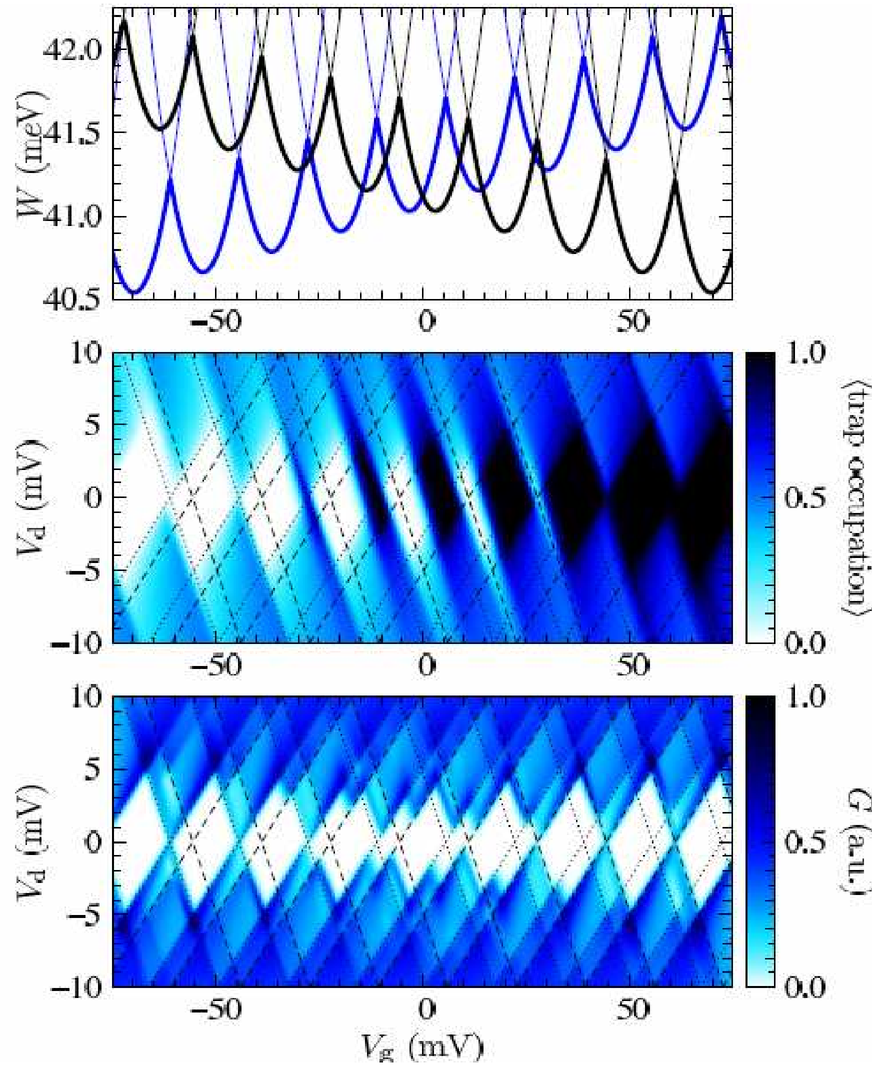


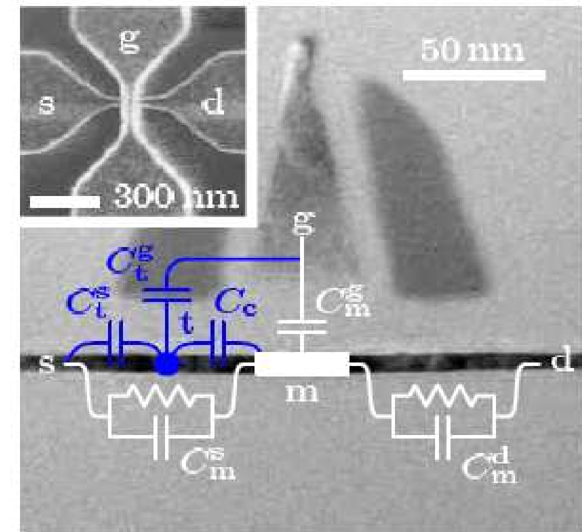


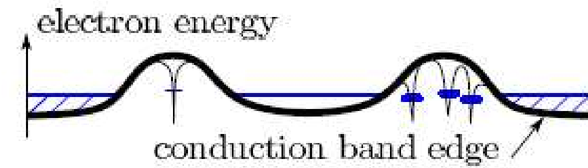
Simulation (electrostatic +master equation)

mean occupation number of the impurity

conductance

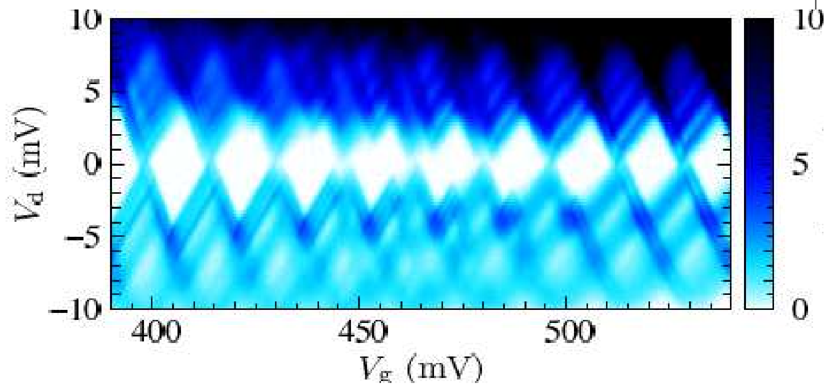




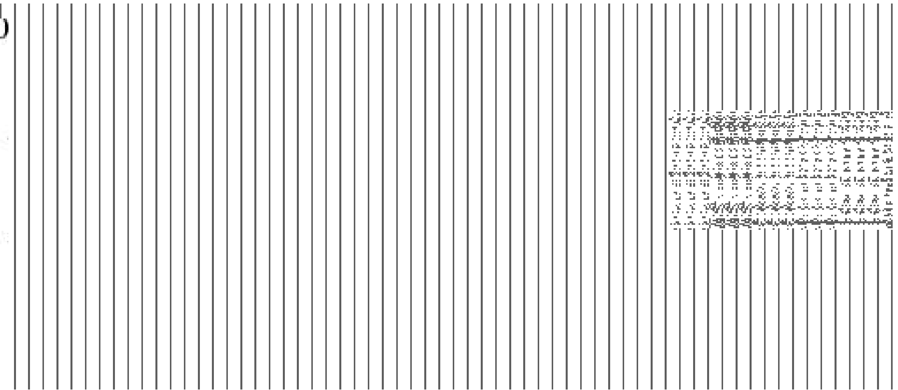


(T=1K)

experiment



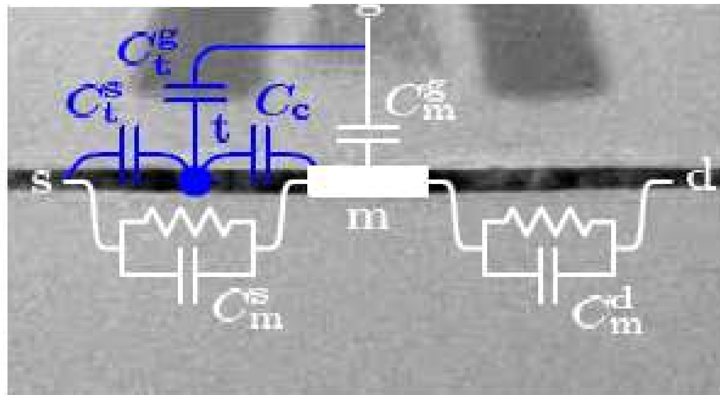
simulation



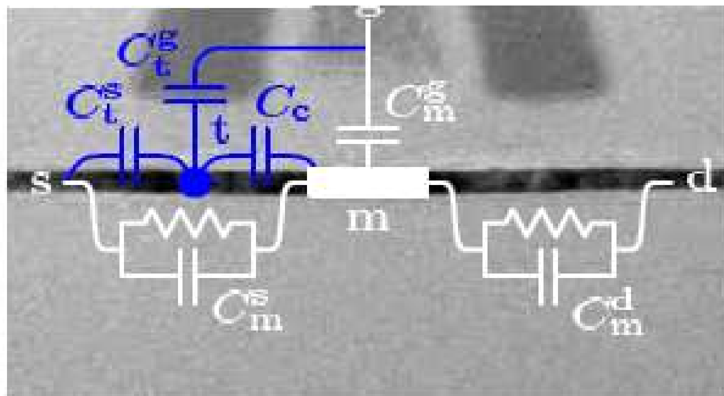
Two effective parameters:

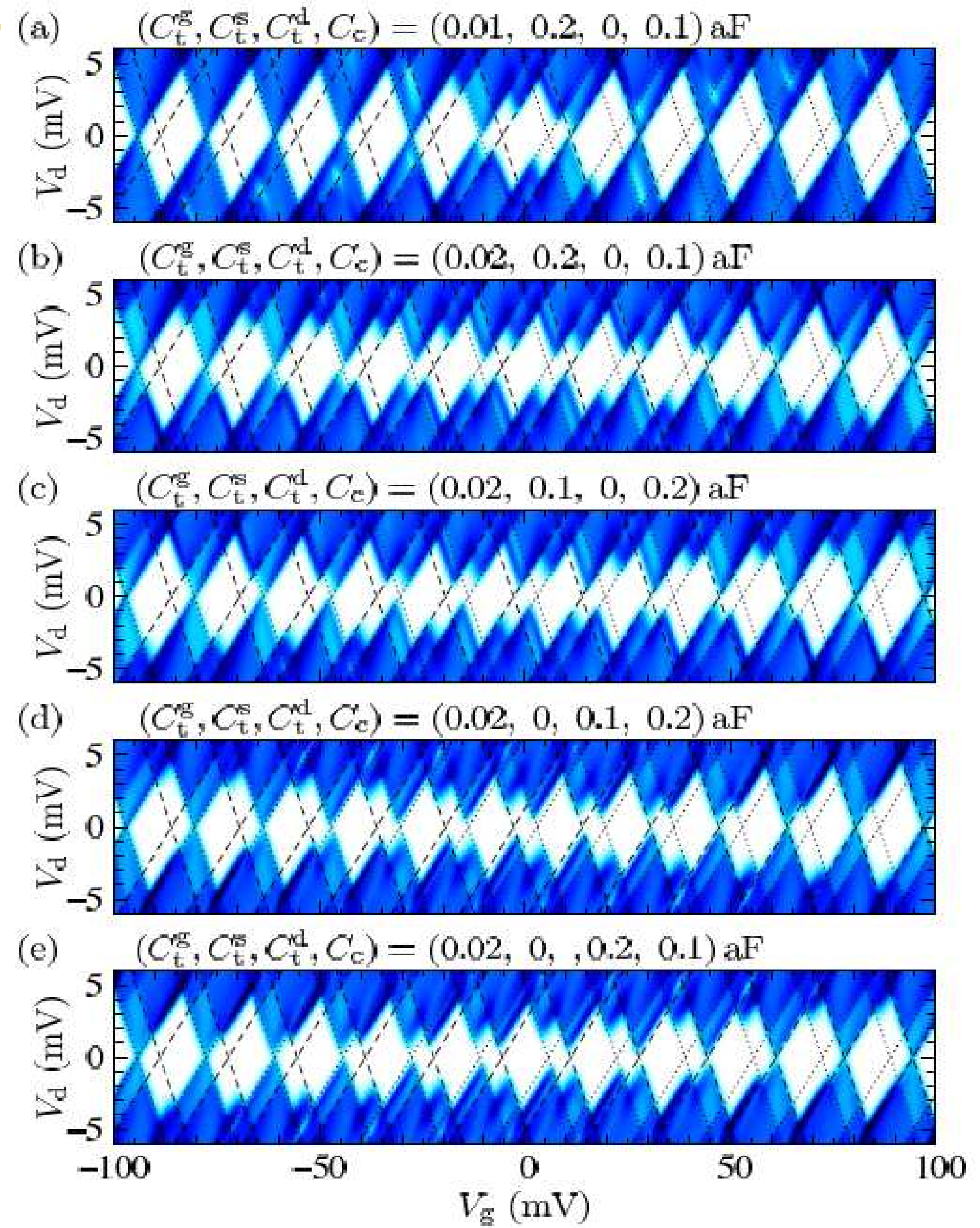
$$\alpha_t = \frac{C_t^g}{C_t + C_c} \text{ and } \beta_t = \frac{C_c}{C_t + C_c}$$

Main dot: C^g_m = 60 e/V,
$C^d_m = C^s_m$ = 70 e/V
Trap: C^g_t = 0.045 e/V , C^s_t = 2 e/V ,
C^d_t = 0,



Capacitance matrix permits to evaluate
the position of the donor



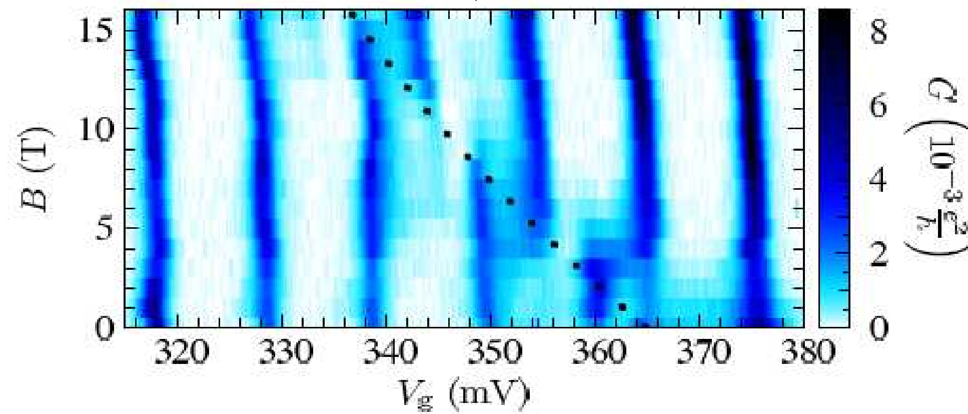


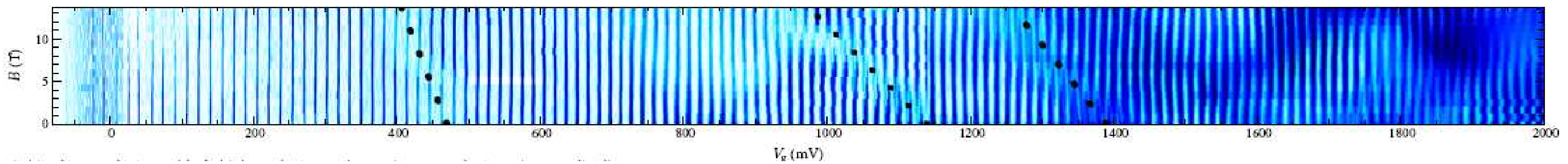
spin of the impurity

Zeeman shift (without parameter)

$$\Delta S_z = +1/2$$

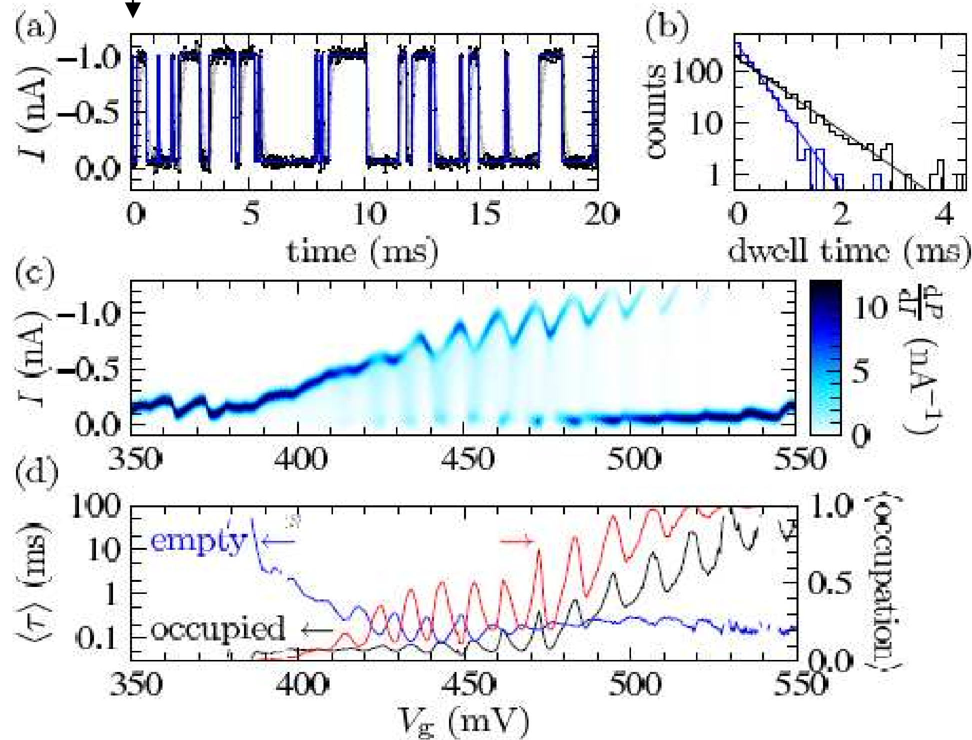
(g=2)

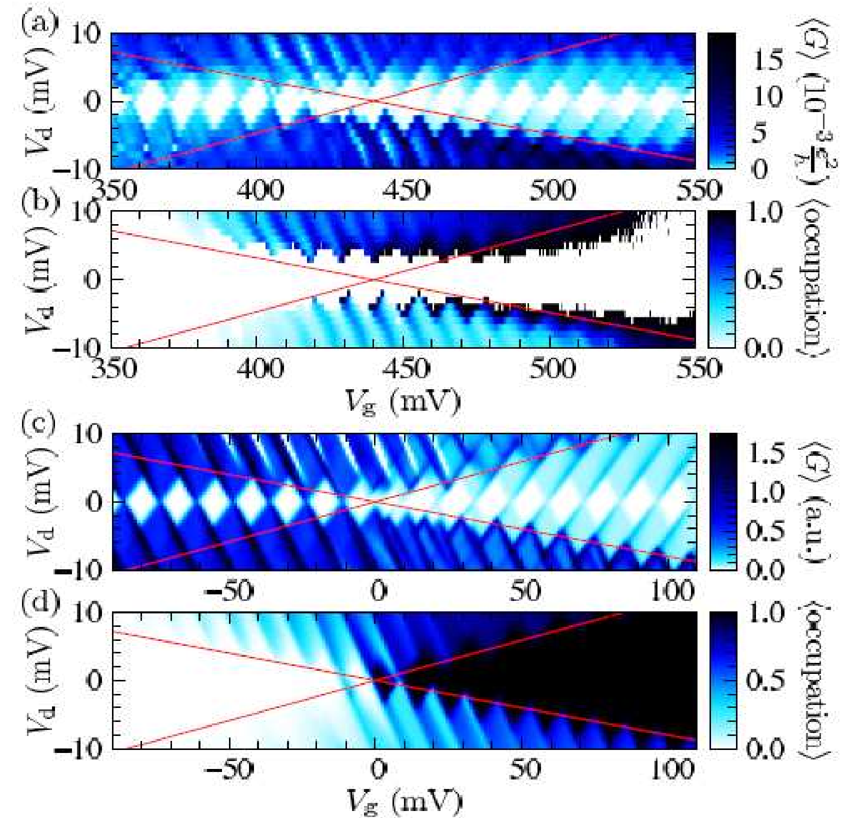




Different slopes correspond to different lever arm parameter (different capacitances)

time resolved occupation number of the impurity





Coulomb diamonds for conductance and for counting switching events

Conclusions:

•Single arsenic donor states have been characterized by Coulomb blockade using a silicon quantum dot as an electrometer.

•Charge stability is excellent in our silicon devices.

•Source and drain capacitances have been quantitatively related to the increase of dielectric constant with energy in the doped access regions (not shown today)