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TRAPPING ELECTRONS OVER SURFACE OF ^{4}HE

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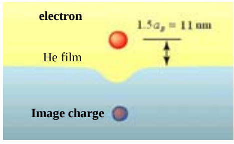
A step towards Qubit with electrons on helium

Qubit outlooks



- electrons on helium are attracted by image charge and present an hydrogen like spectrum for perpendicular states
- first excited state can be populate with a 125 Ghz microwave (5.8 K). ground and first excited state of one electron can be used for a qubit.
- coulomb interactions are not screened: Coulomb interaction can coupled qubit. Typical length between qubit: the Wigner crystal lattice.

- liquid helium: no impurities
- Electrons float quite far away from the surface: interaction with surface vibration is relatively small.
- decoherence time is expected to be long enough ~10 µs
- Rabi frequency ~0.1 GHz, so the clock of this qubit is ~10 ns
- 10000 operations could be realized before decoherence.

(superconducting qubit~500 ns, 5000 operations)

first requirement: to trap and to control individual localized electron

- **Quantum computing Using Electrons Floating on Liquid Helium**
  M.I. Dykman and P.M. PLatzman
  Fortschr. Phys. **48** (2000) 1095
- **Could we Quantum Compute with Electrons on Helium?**
  M.J. Lea, P.G. Frayne and Yu. Mukharsky
  Fortschr. Phys. **48** (2000) 1109

Trapping a single electron

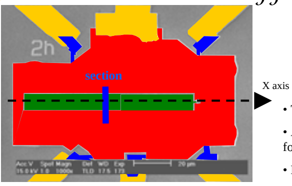
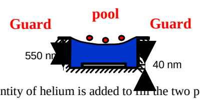
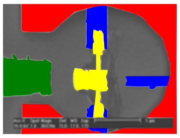


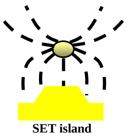
Figure 1

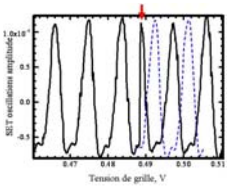


- The exact quantity of helium is added to fill the two pools and the ring.
- A 550 nm film is created above the two pools whereas a Van Der Waals film is formed above the guard.
- Electrons are created by a corona discharge.
- Only electrons above pools and ring are mobile.

Inside the ring: a SET

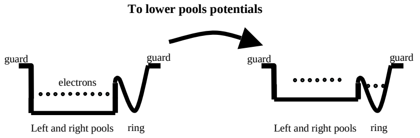


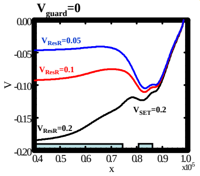




- Electrons are detected in the ring using an SET
- They induce on the SET island an extra charge δq.
- This extra charge change the phase of the coulomb blockade oscillations
- Fitting the oscillations give their phase

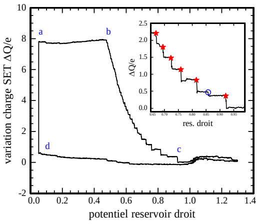
Discharge curves



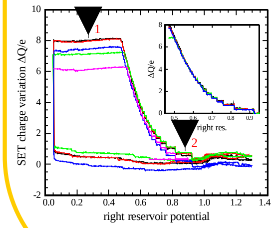


Potential profile along x axis *(fig.1)*

- We push electrons in the trap created by the SET in decreasing Right pool potential and then sweep it to more positive potentials



- **a-** the ring is full of electrons.
- **b-** electrons start to leave the ring.
  one electron leaves the ring at each stair.
  the number of electrons is constant between two steps.
  It's difficult to see clear jumps at the beginning of the curve because of the SET noise.
- **c-** the ring is empty, charge is more or less constant
  no electrons enter in the ring, fluctuations are due to fluctuators in the substrate .
- **d-** electrons enter in the ring, a new cycle can begin.



last jumps are around ~0.4 e, value which is reproduced by simulations

- good stability of the last electron jump.
- We first charge the ring (position **1**)
- We go directly to position **2**
- One and only one electron remains in the trap: can be check in sweeping or pulsing the right pool.

See also Royal Holloway College results: Appl. Phys. Lett. *8***6**, 153106 (2005).

We are now able to trap one single electron above an helium film

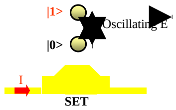
Discussion and conclusion

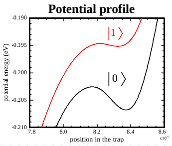
- First step to Qubits with electrons on helium has been achieved, one electron can be trapped and controled.
- No plateau has been seen. Measure a short relaxation time t<0.4 µs.
- vibration states in the trap could explain those observations.
- *electron temperature versus I_{ds} current through the SET*

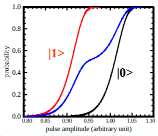
limit explanation to the first two vibration levels
current induce transition between ground state and first excited state. They check $N_0\Gamma_u=N_1\Gamma_d$

- effective temperature define as $N_0/N_1=\exp(-h\nu/k_BTe)$
- Γ_u is due to SET excitation, $\Gamma_d=\Gamma_u+\Gamma_{env}$ is SET excitation+ interaction with environnement
- Γ_{env} = 5 µs^{-1} whereas direct measurement gives < 0.4 µs but depends on the knowledge of the exact geometry. Estimate can be 10 times smaller.
- Next step is to excite the electron with a monochromatic microwave and measure its relaxation time.

Extraction curves



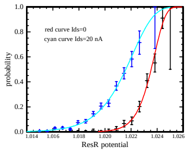




- Current through the SET creates an oscillating electric field which induce transitions between ground and first excited state: time required to mix states τ ~ 15 µs, thermalisation time ~ 10 µs
- Barrier height depends on the electron state: then extraction curve depends on the electrons state (red and black curves). We should observe an average of previous curves. (blue curve).

Experiment

- We pulse right pool potential and measure the probability of escape during the pulse.
- Pulse length ~0.2 µs is estimated to be short enough compare to relaxation time (10 µs).
- We can do this for different heating (i.e. different values of the current through the SET).
- Can also study probability of escape with the cell temperature.



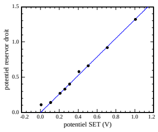
When increasing current, curves shift to the left and width increase.
Can be seen as an increased of the temperature of the electron (continuous energy levels and/or fast relaxation time).
For a thermally activated process, probability of escape is given by:

p(V)=1-exp(-$\omega_0\tau$/2p exp(-$E_b(V)/k_BT_e$)

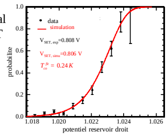
ω_0 trap frequency
$E_b(V)$ barrier
T_e electron temperature

Both barrier $E_b(V)$ and trap frequency ω_0 are estimated from potential profile simulations

Accuracy of this procedure



Plot Reservoir right potential of the last jump versus SET potential.
Blue curve: expected value from simulation.
Exactly the same slope
No fitting parameters

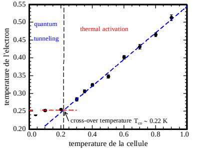


Without heating current and at low cell temperature:
Escape via quantum tunneling

Can calculate the escape with the knowledge of the potential profile
No fitting parameters

Looks as if barrier is well known from the simulations

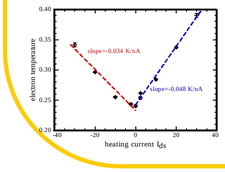
Temperature of the electron versus temperature of the cell



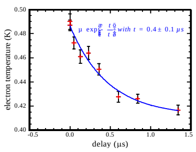
When temperature is low, escape occurs via quantum tunneling
When temperature increase, escape becomes thermally activated

Cross-over temperature (when quantum tunneling rate=thermal rate) is a property of the trap geometry.
Good agreement between experiment T_{co}=0.22 K and simulation T_{co}^{fit}=0.24 K
slope (~0.37) is reproducible but should be 1.
don't have any explanations.

Temperature of the electron versus current though the SET



Electron temperature increase linearly with SET current.



Relaxation time measurement

1- Heat the electron with large current (50 nA).
2- wait for a while (delay)
3- apply pulse.
4- fit the escape curve to find the temperature
5- relaxation time shorter than 0.4 µs.