Royal Holloway
University of London

EPSRC

Progress towards an electronic array on liquid helium

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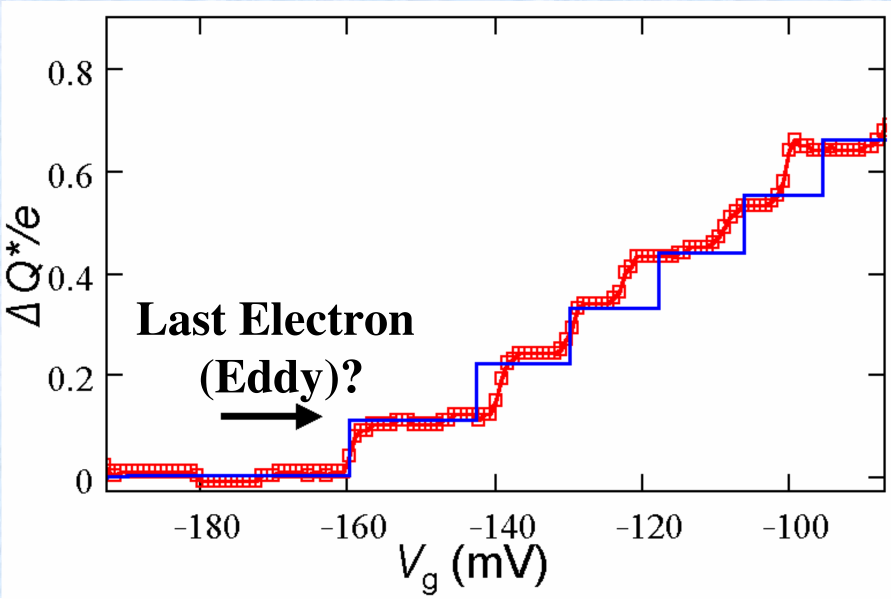
Saclay: Dr. Yury Mukharsky
Emmanuel Rousseau

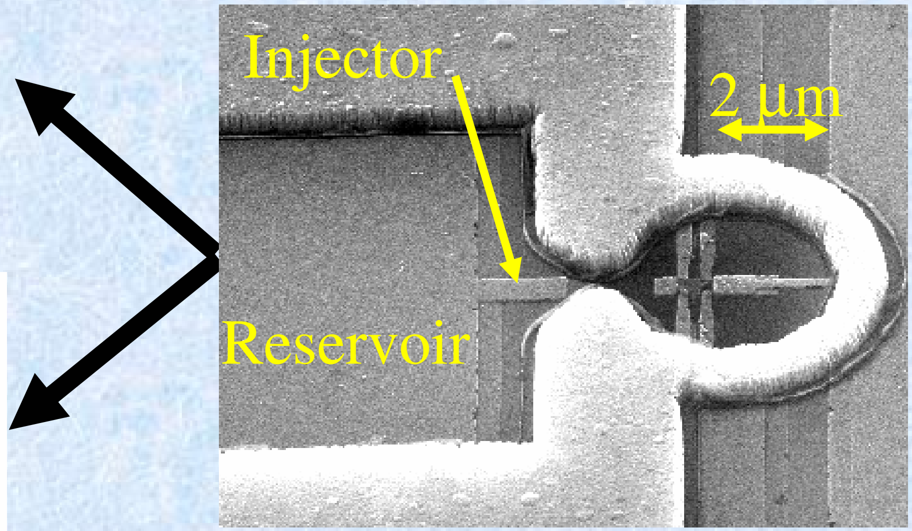
Michigan State: Prof. Mark Dykman

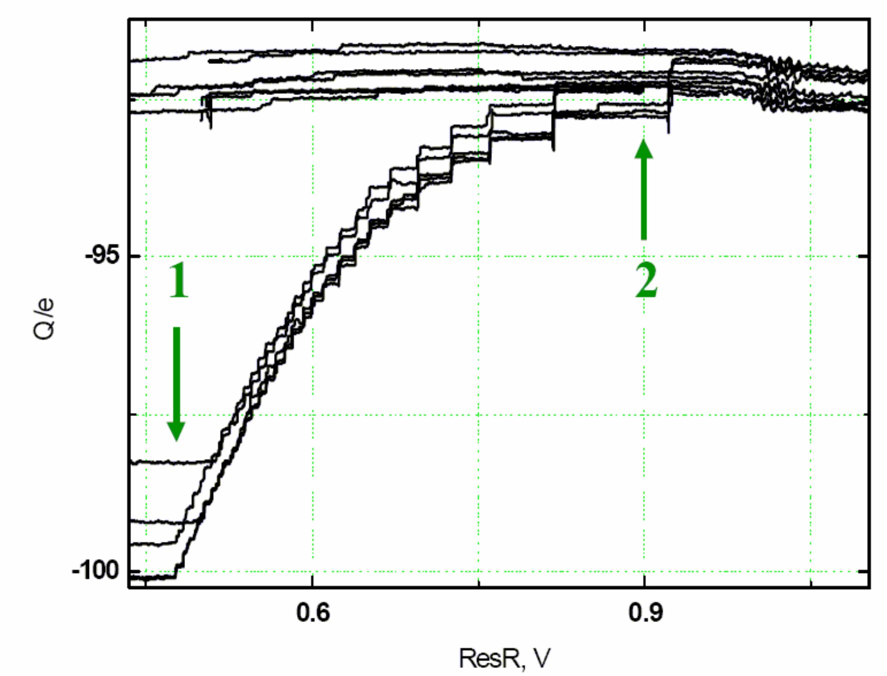
Beginnings: Single Electron Control



Royal Holloway

G. Papageorgiou, P. Glasson ***et al***
APL **86**, 153106 (2005)

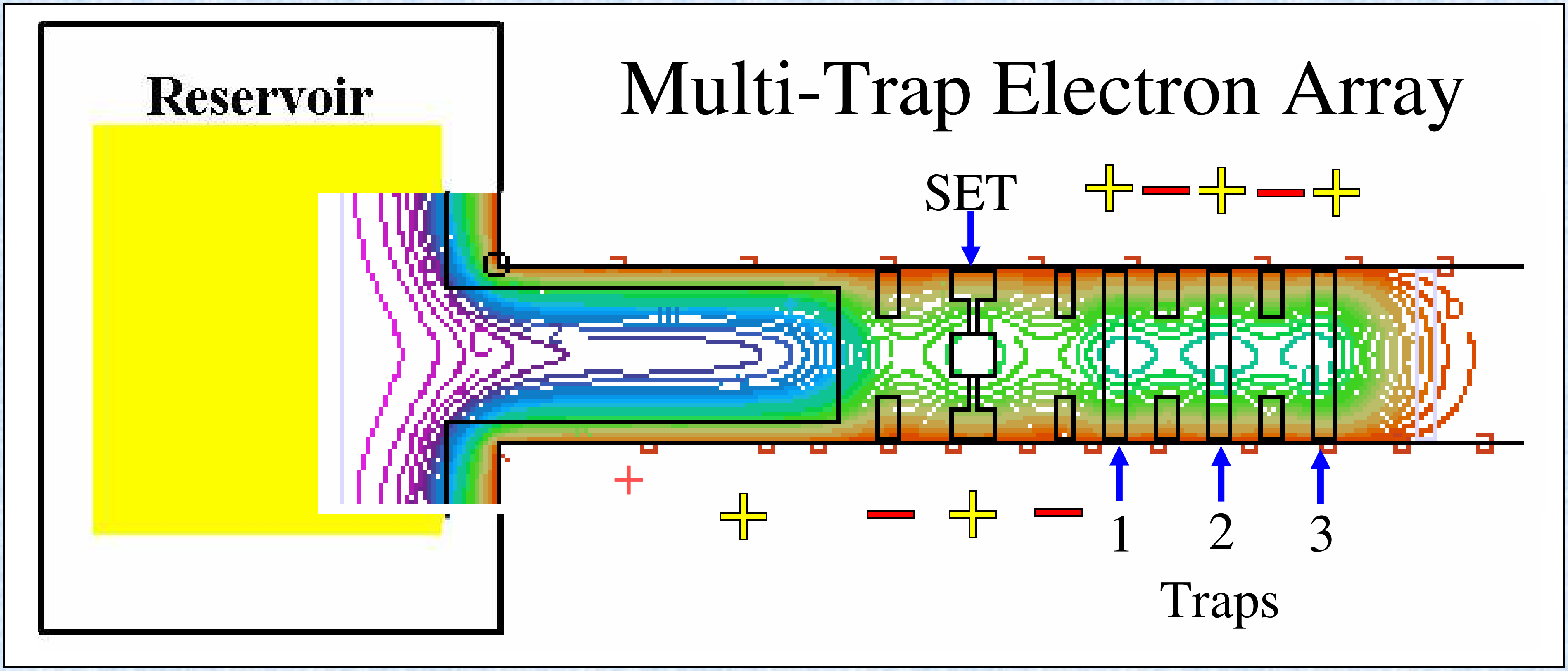




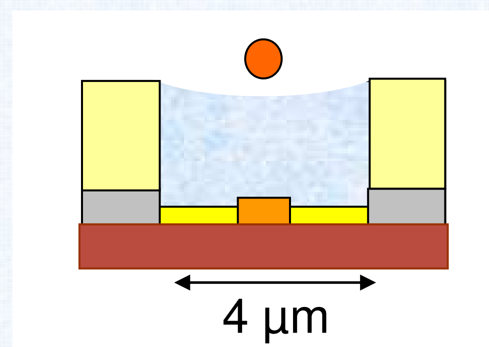
Courtesy of Dr. Yury Mukharsky and Emmanuel Rousseau at CEA at Saclay, France

Aims of New Device

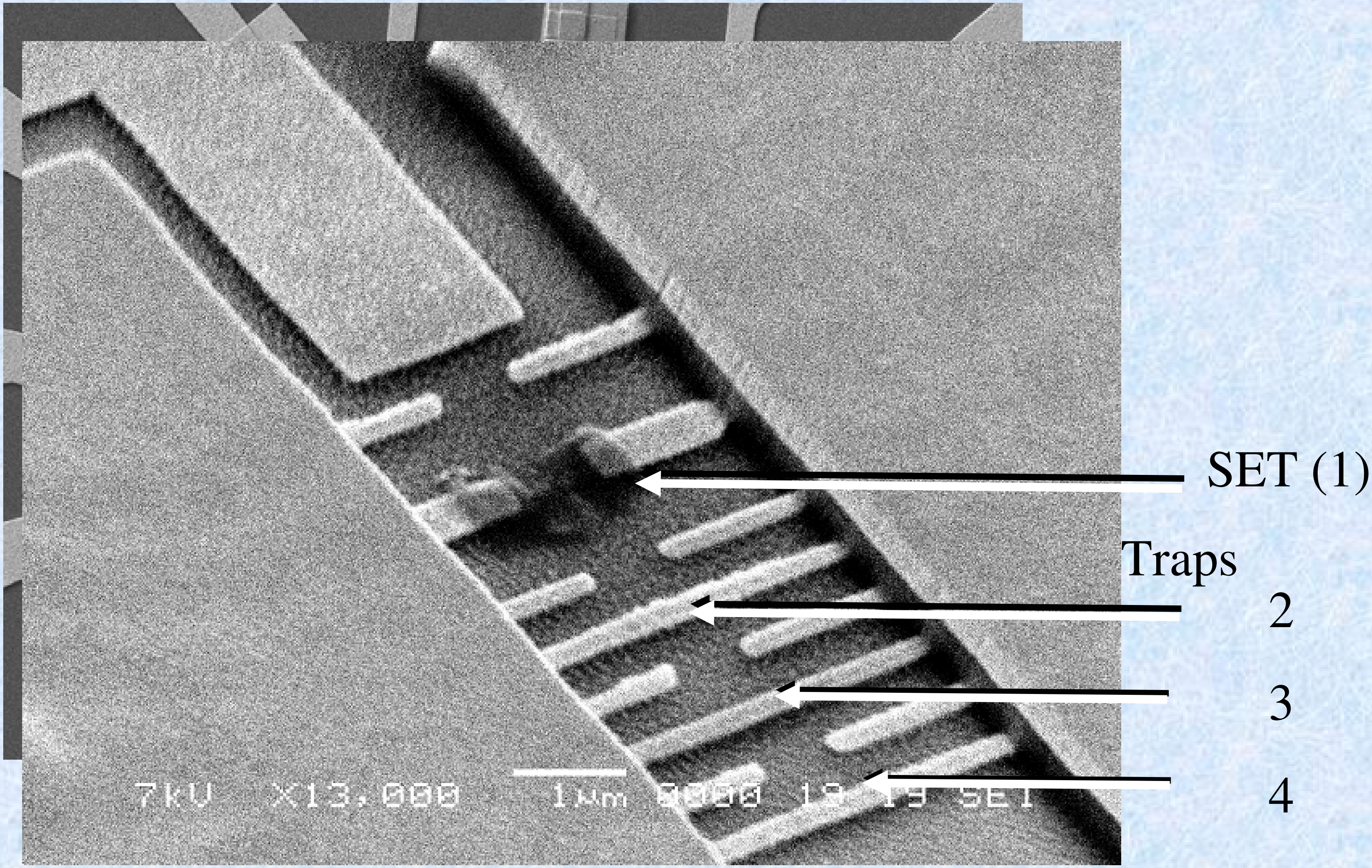
- Single electron manipulation and detection
- Array of electron traps
- Trap-to-trap control and manipulation
- Stark shift tuning (Individual trap)
- Collect electrons in an electron reservoir
- Apply microwaves ~ 200 GHz



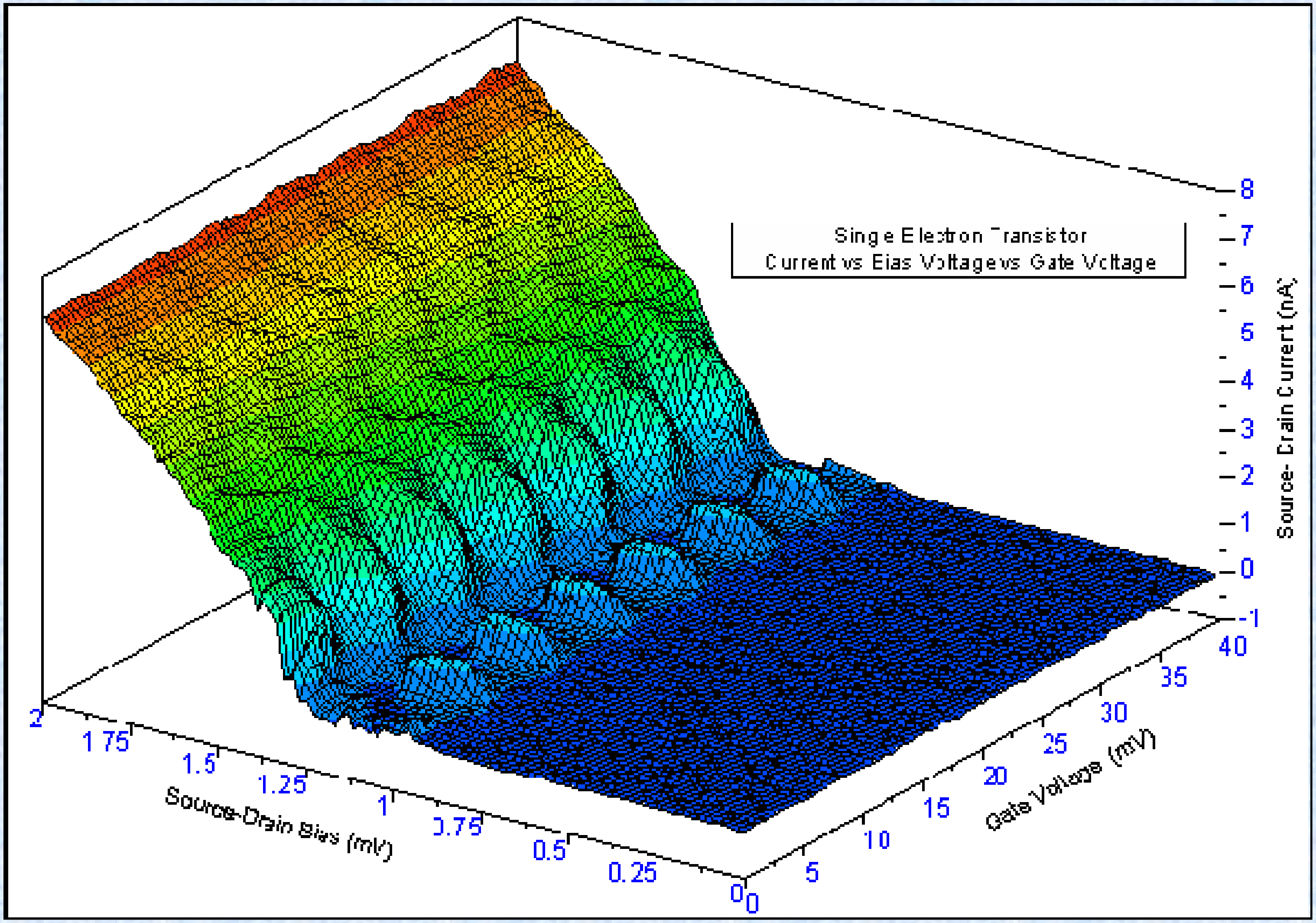
- Electron storage
- SET as an electron detector
- Multi-trap sample
- Single trap Stark shift tuneable



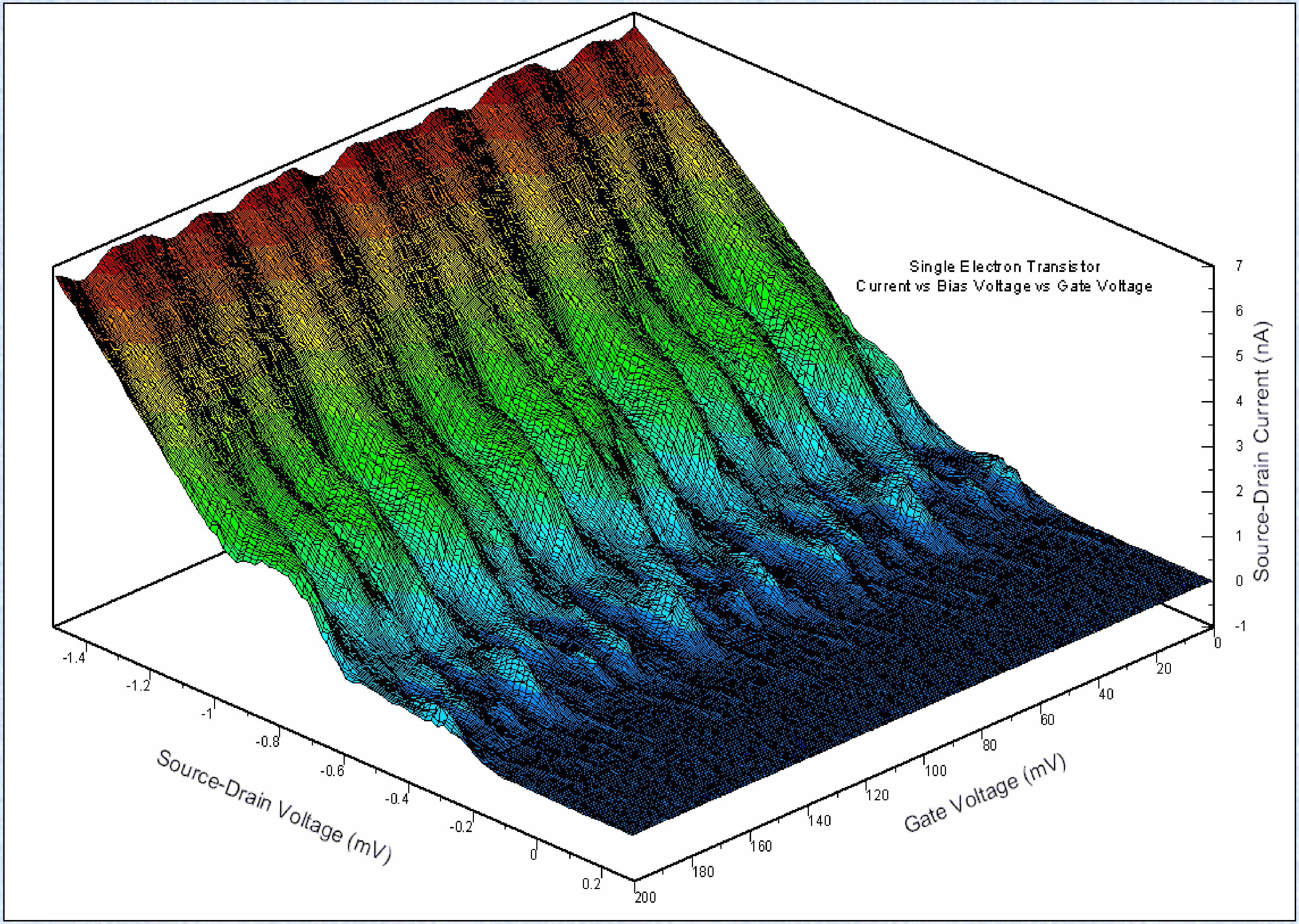
New Fabricated Device



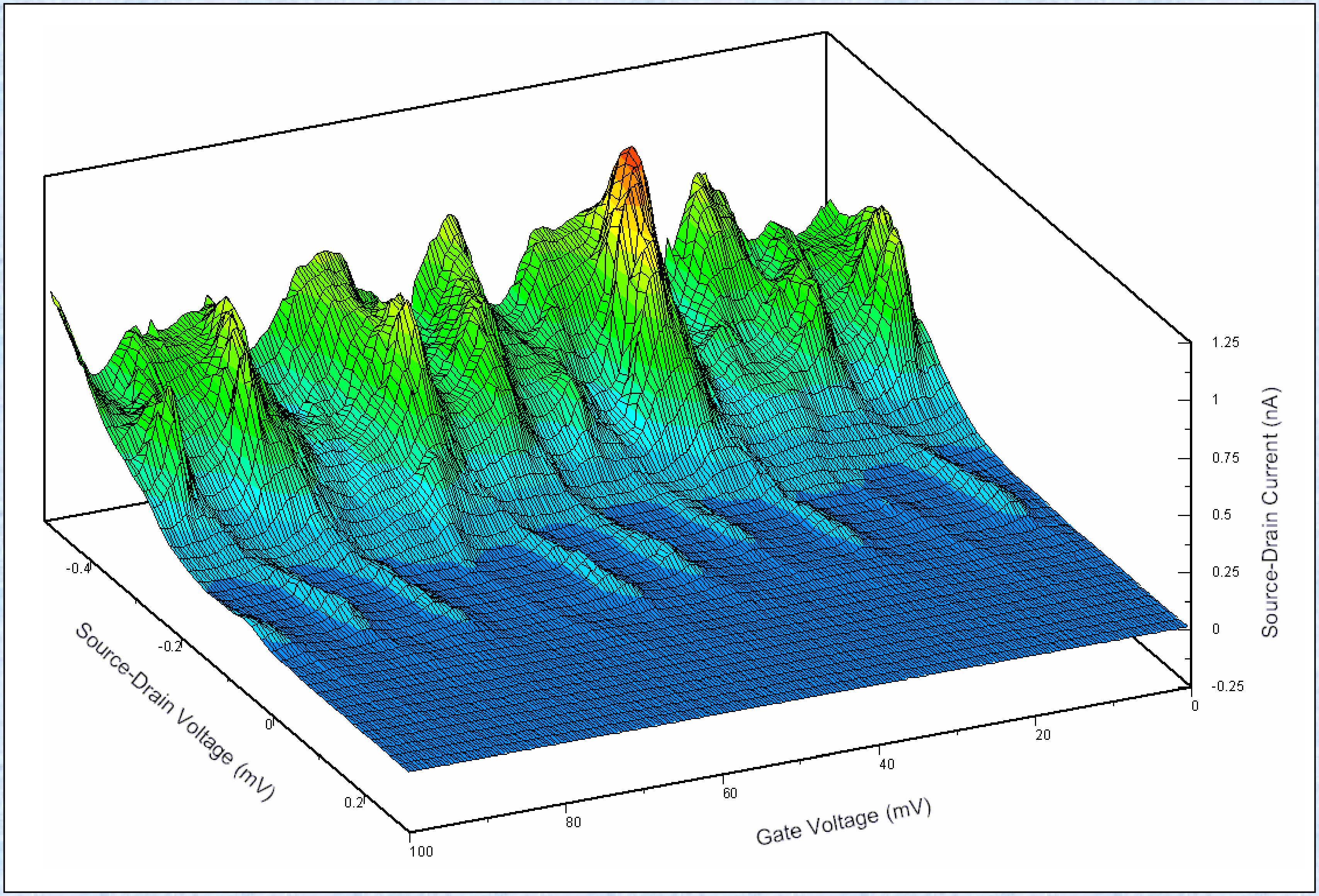
SET *I-V* Curve


Singe Electron Transistor
Current vs Bias Voltage vs Gate Voltage
Source-Drain Current (nA)
8
7
6
5
4
3
2
1
0
-1
Source-Drain Bias (mV)
2
1.75
1.5
1.25
1
0.75
0.5
0.25
0
Gate Voltage (mV)
0
5
10
15
20
25
30
35
40

Device SET *I-V* Curve



Coulomb Blockade Oscillations (CBO)



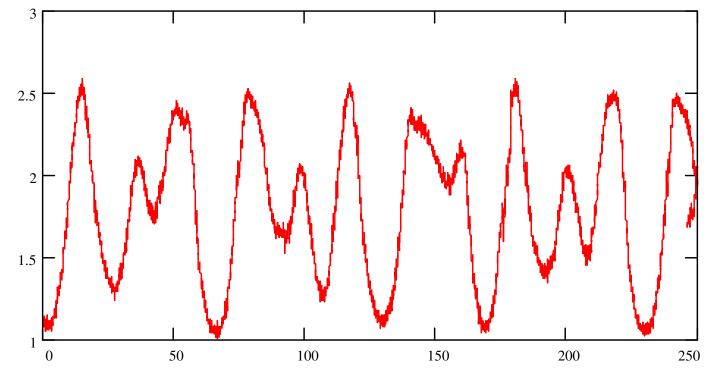
Double-Island ?

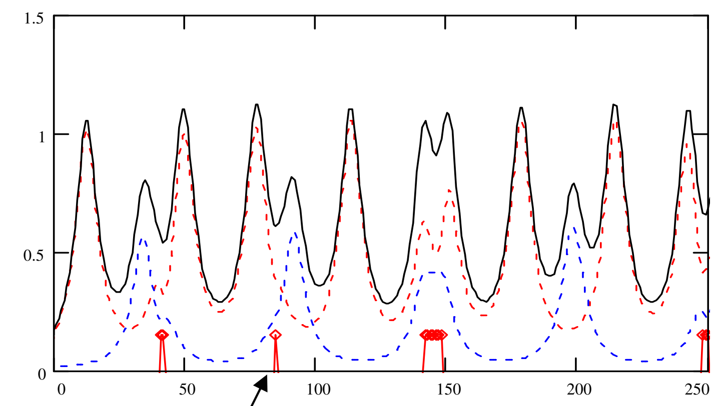
Unusual current peaks with V_g modulation are observed!

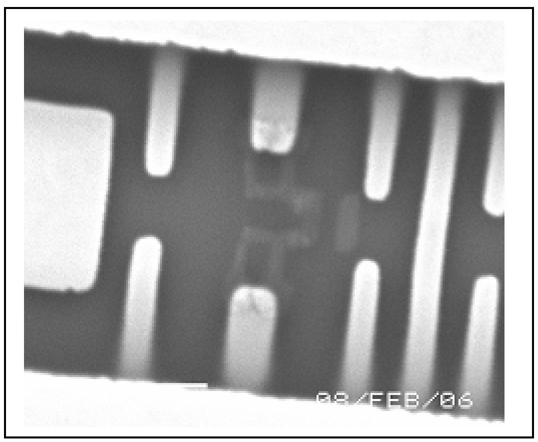
Current peak positions are predicted by assuming 2 SET islands capacitively coupled.

Structure reproduced by Lorentzian fit about each peak position.

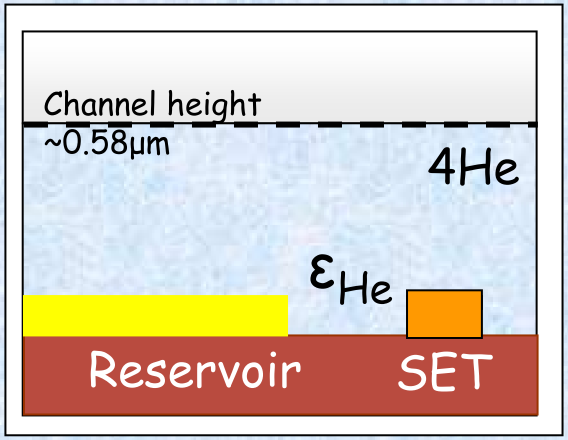
However, SET is still charge sensitive!



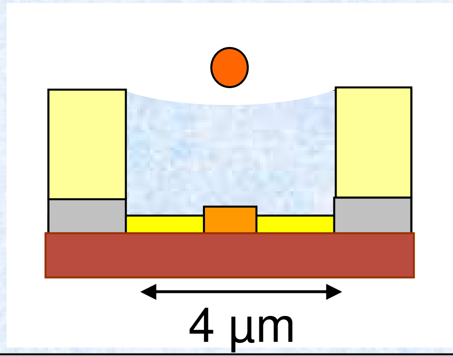


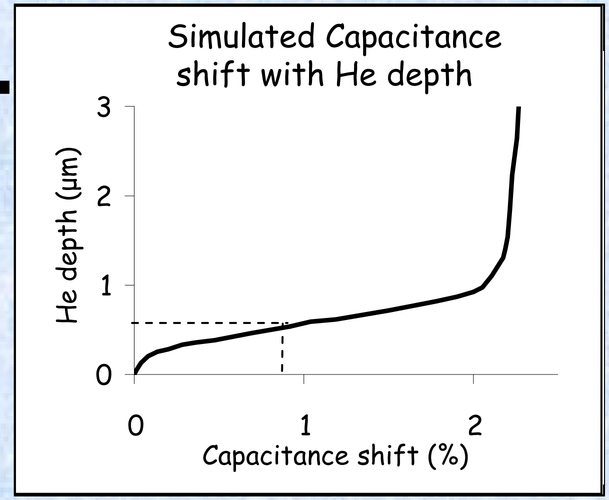


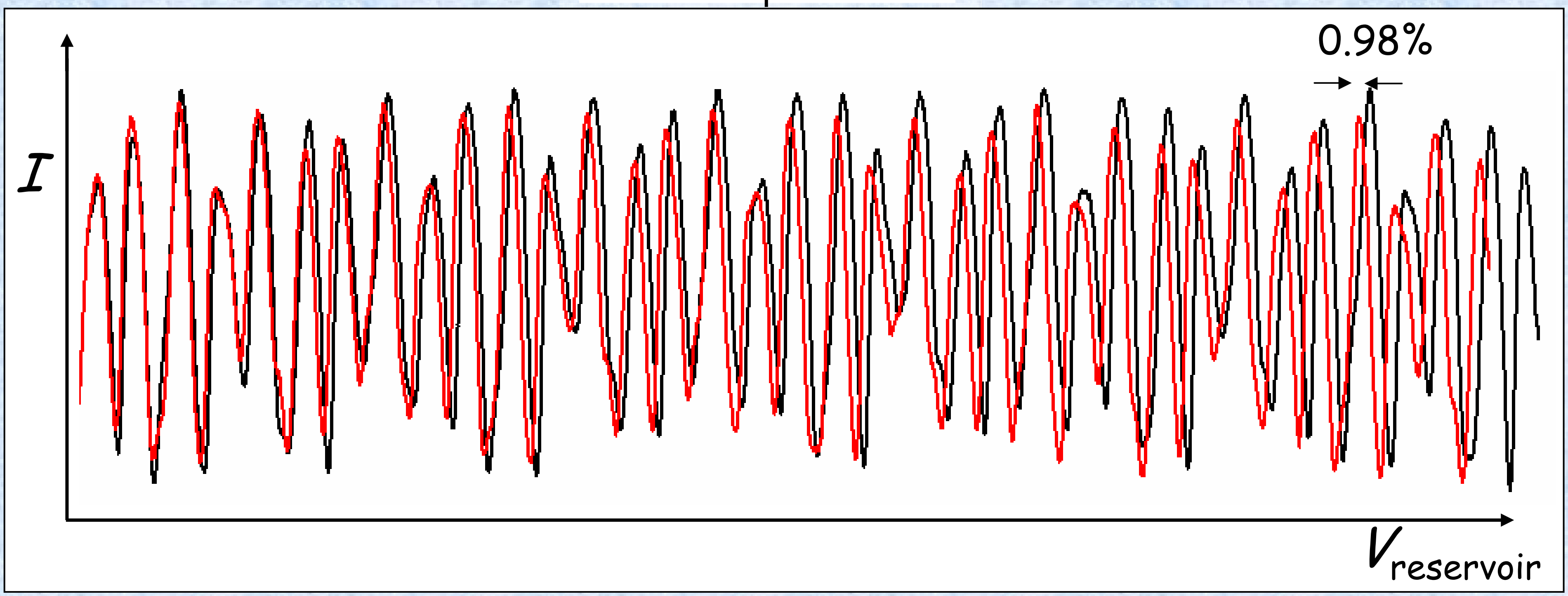
Phase Shift Due to Adding Helium



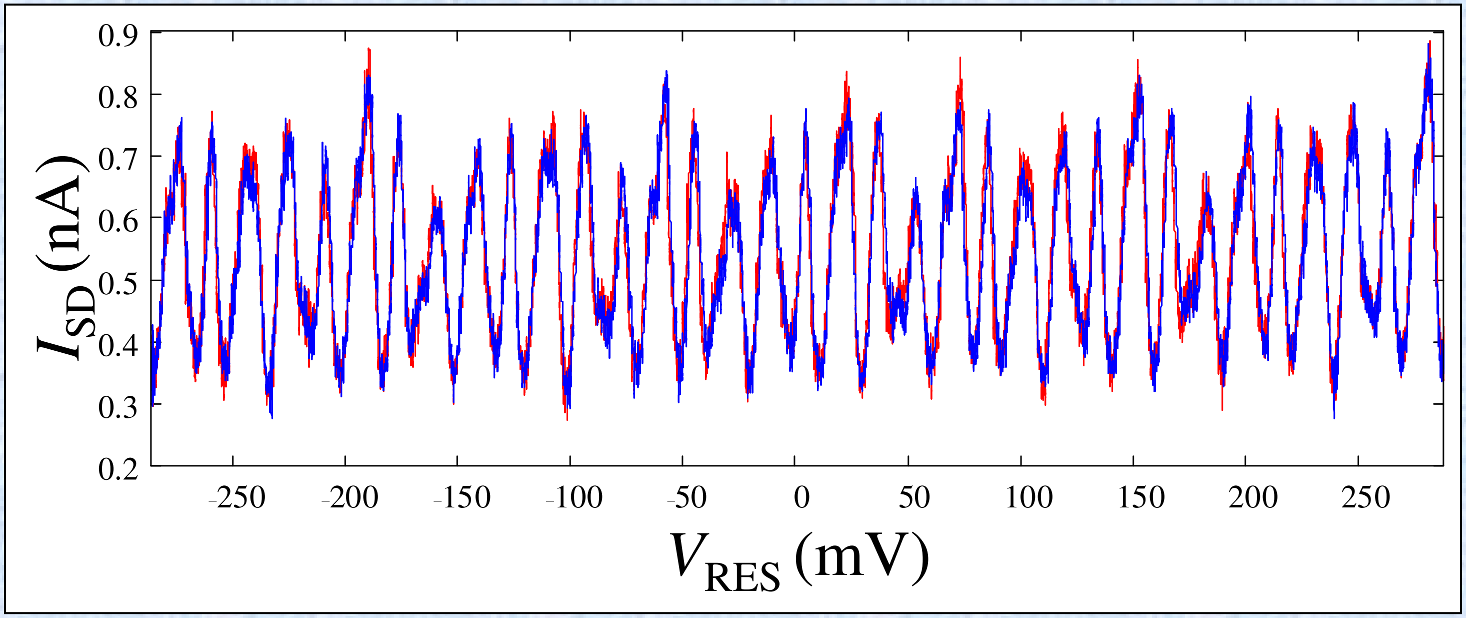
d_{He} = 0.58µm predicts a 0.92% change in period.





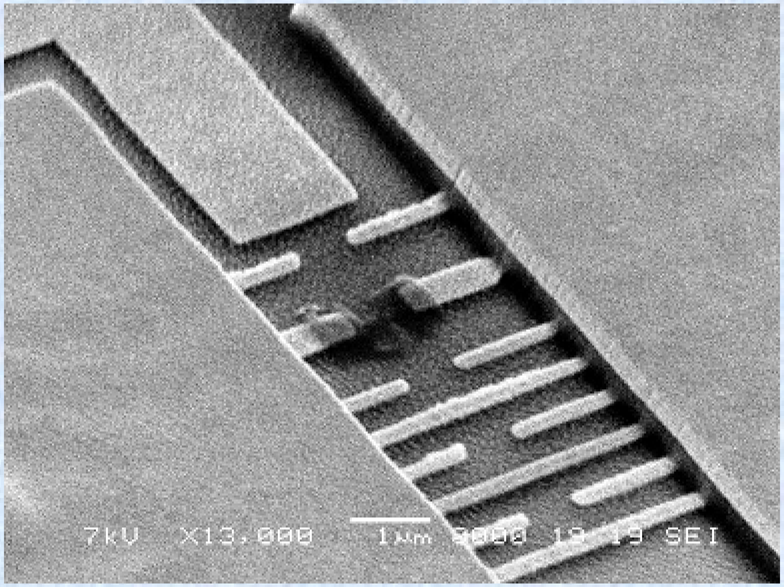


Phase Stability Before Adding Electrons

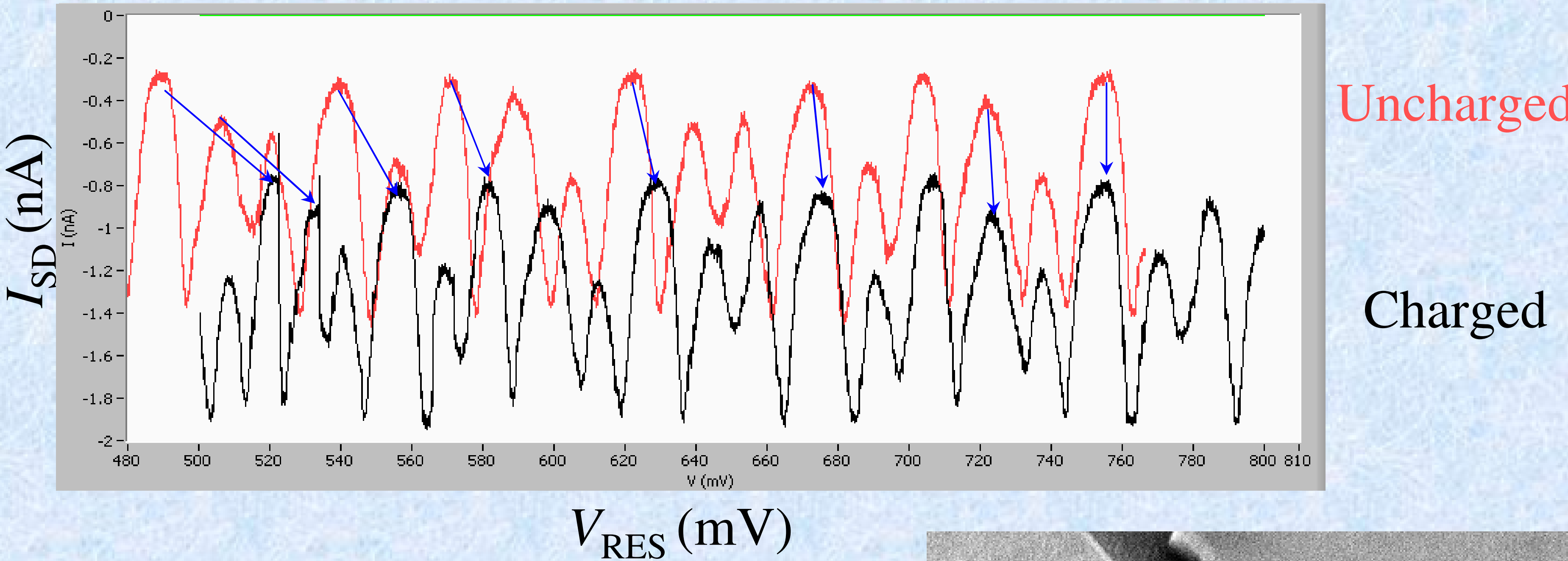


- Before charging:

Stable phase over 600 mV range

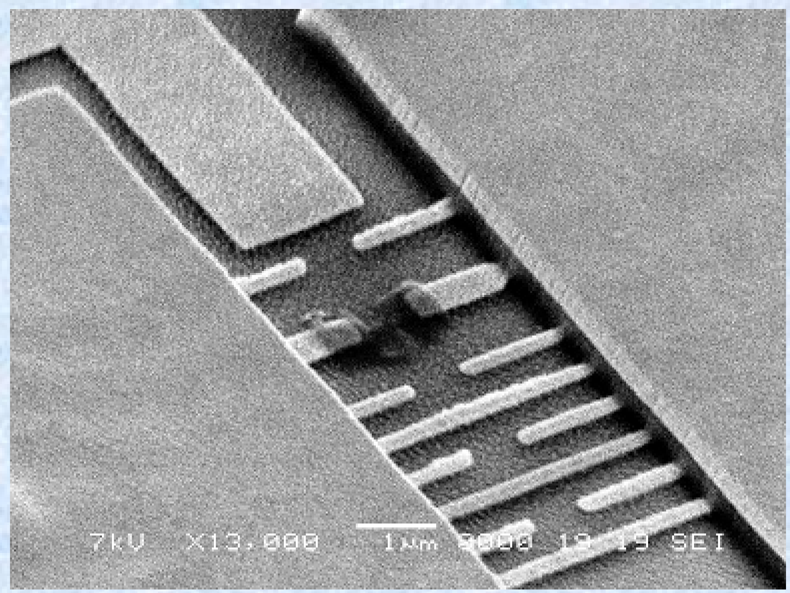


Charged: Phase changes

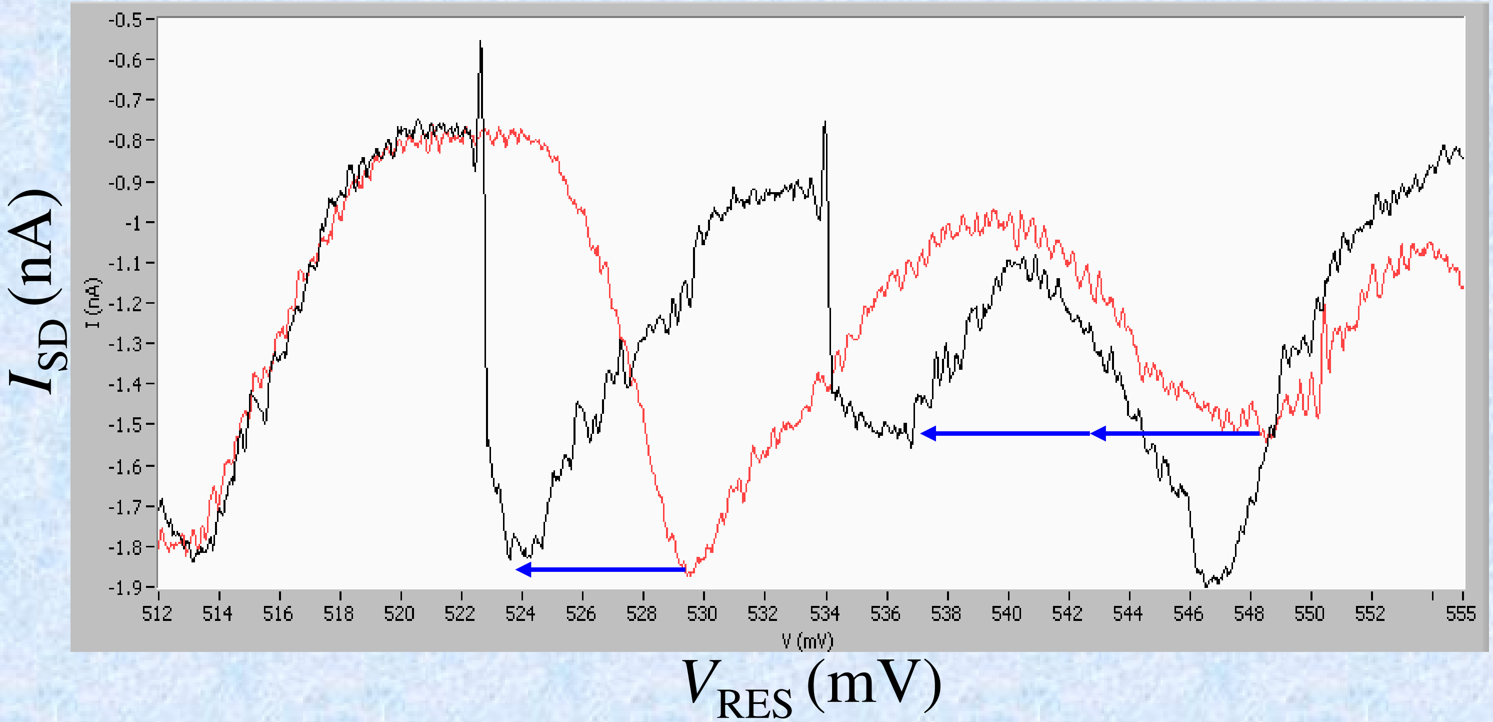


After Charging:

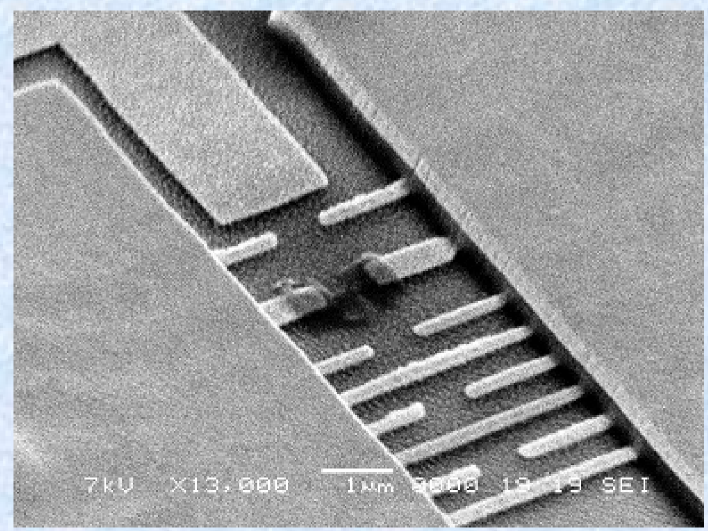
- Decrease in period
- Changes in phase observed



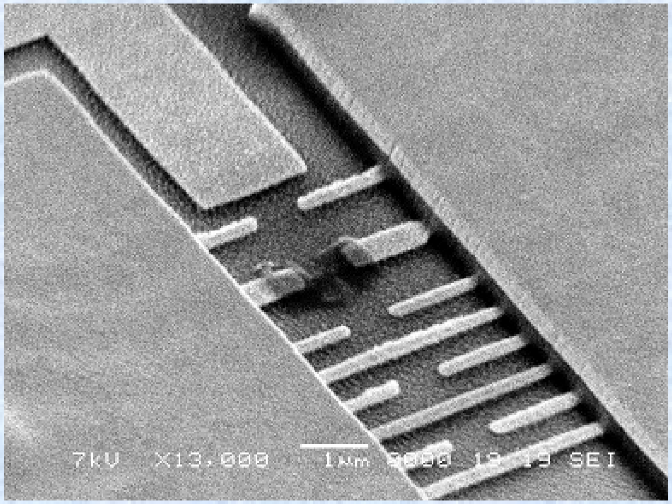
Phase Shifts in Jumps

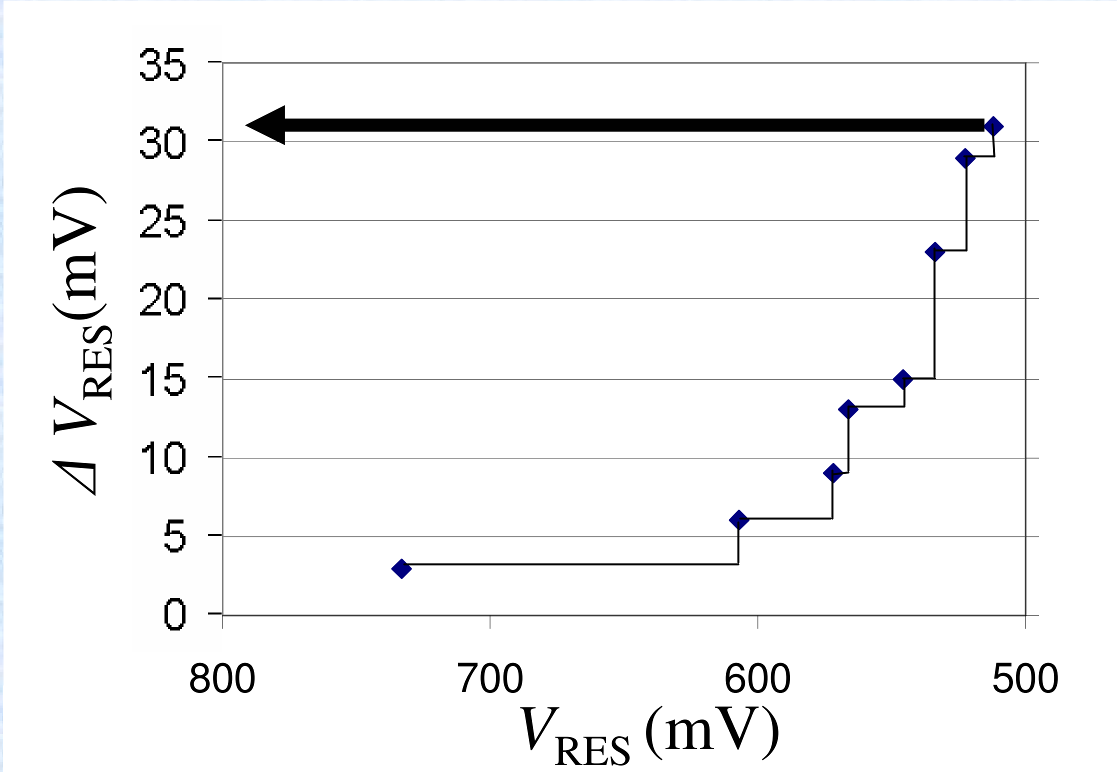


- Phase change accrues in discreet jumps
- Jumps in ‘Trap Charging’ direction



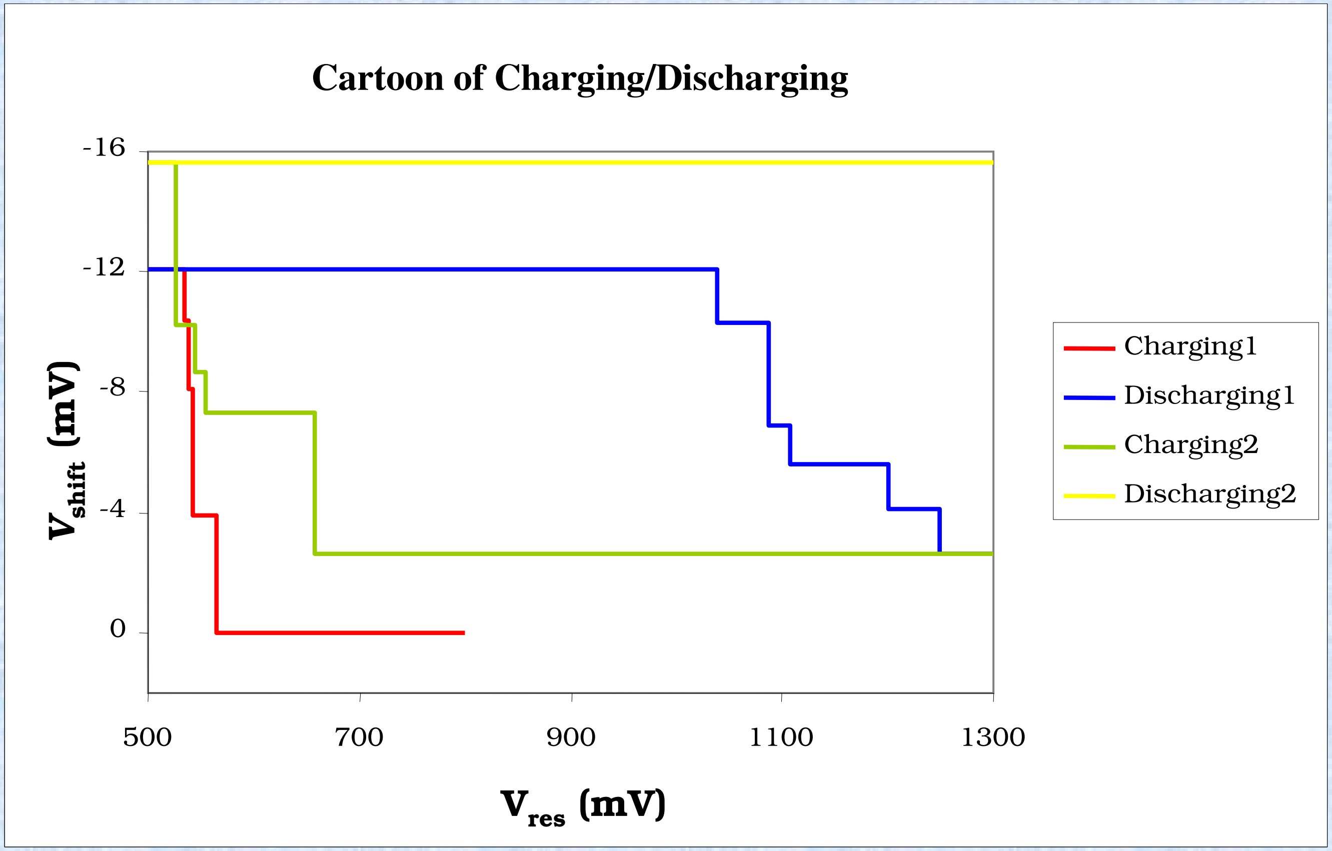
Movement of charge with $V_{reservoir}$

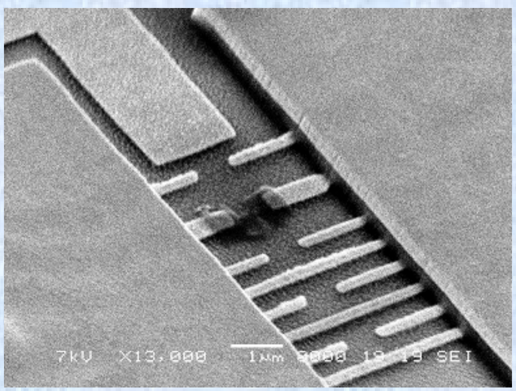




- Charge movement detected.
- Charge increase in jumps.
- Well charging direction

Counting Charge Jumps





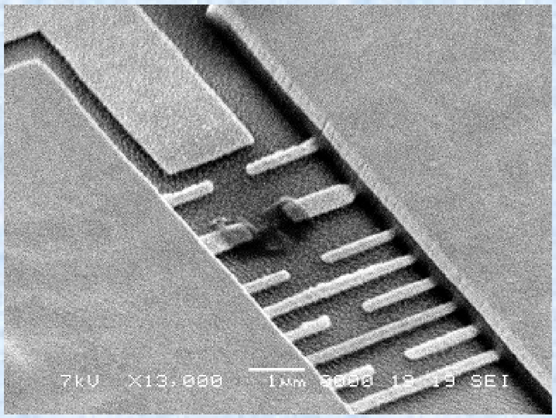
- Can follow hysteretic charge/discharge loop with reservoir electrode sweep
- However charge movement quickly ceases!

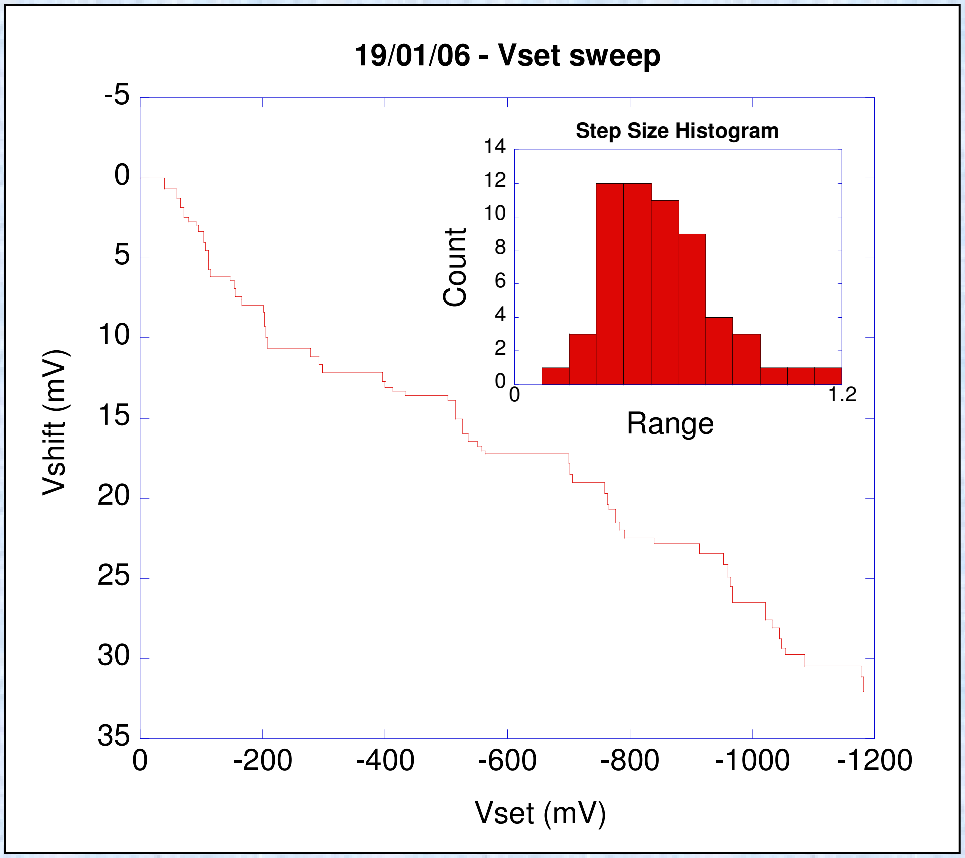
Problem – we cannot discharge the trap above SET!

With all electrodes held at constant potential we can sweep the SET potential negative with respect to the well

Observe many discharging events even at highly negative voltage

Strong indication that our well is too deep…





Conclusions about Multi-Trap Sample I

- Charge stable before firing.
- SET is sensitive to charge movement.
- Trap area can be charged.
- Inability to discharge well indicates sample problems

Fabrication, Problems & Muti-Trap II

David Rees

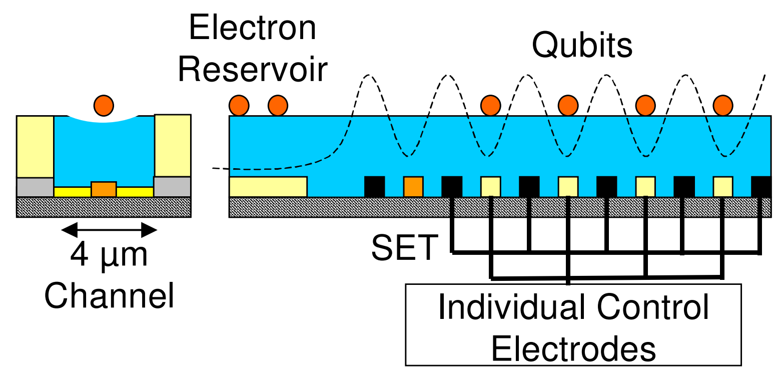
Fabrication - Linear trap array design

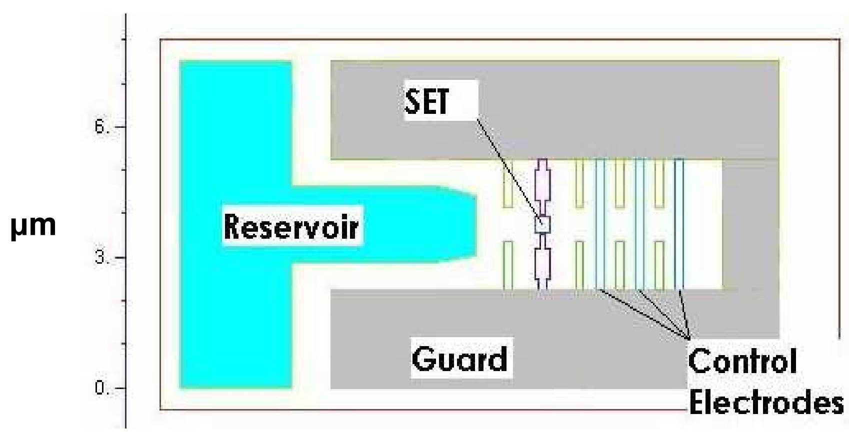
Require linear array of potential wells:

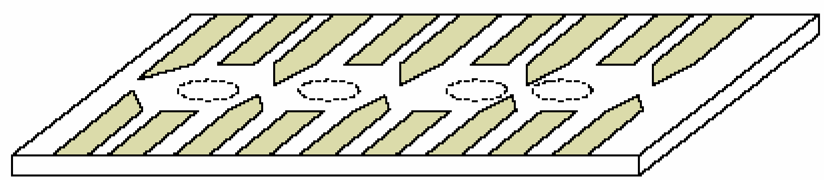
Ideally… $V_{well} \sim 3$ mV

$d \leq 1.5$ μm

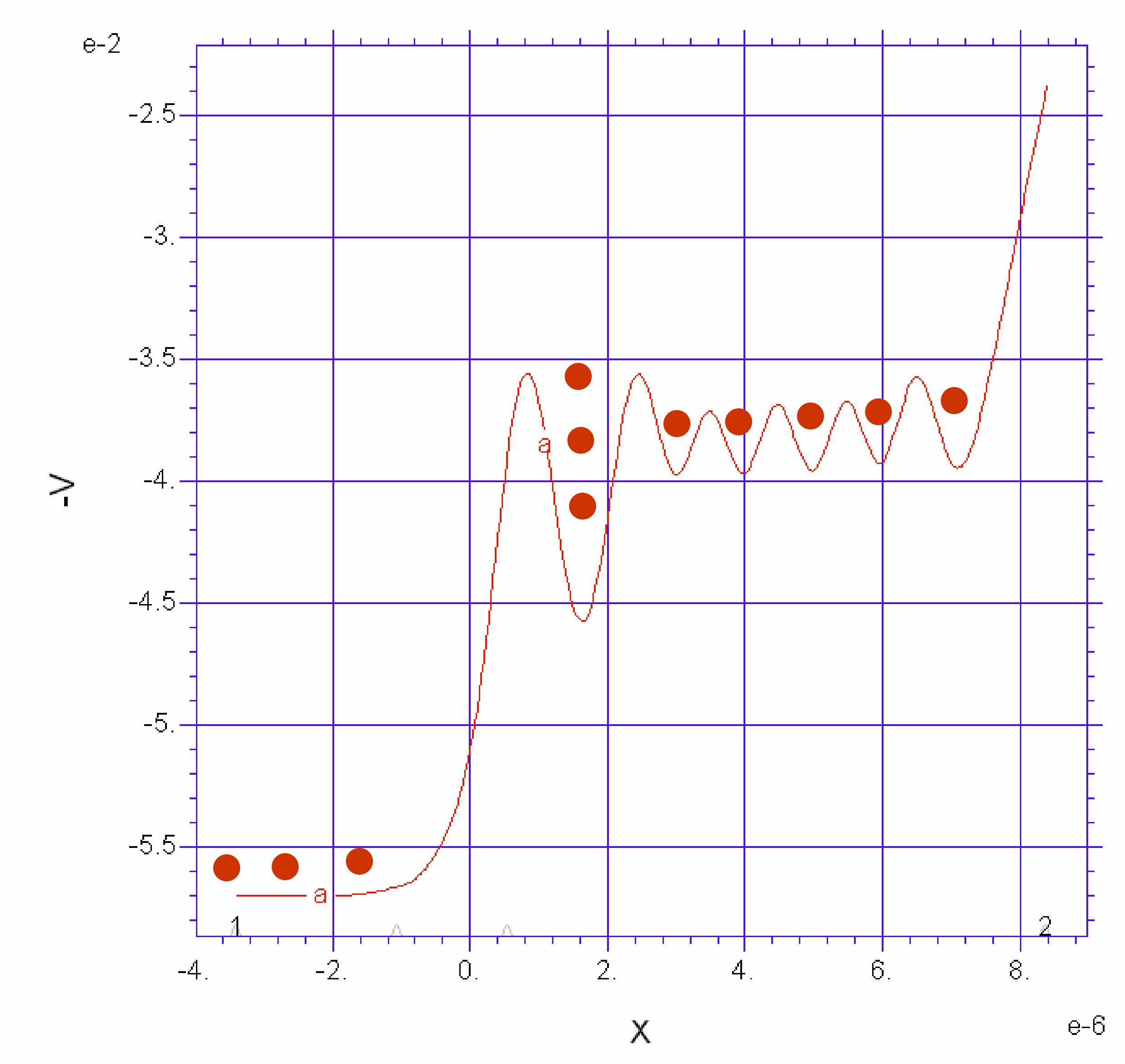
$h \sim 0.5$ μm







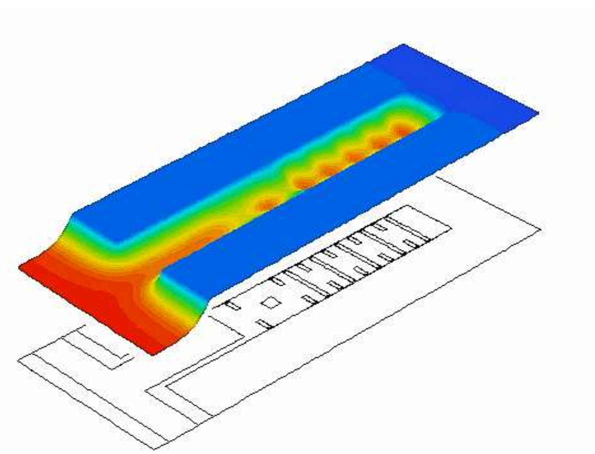
DiVincenzo and Loss (PRA 57, 120 (1998))

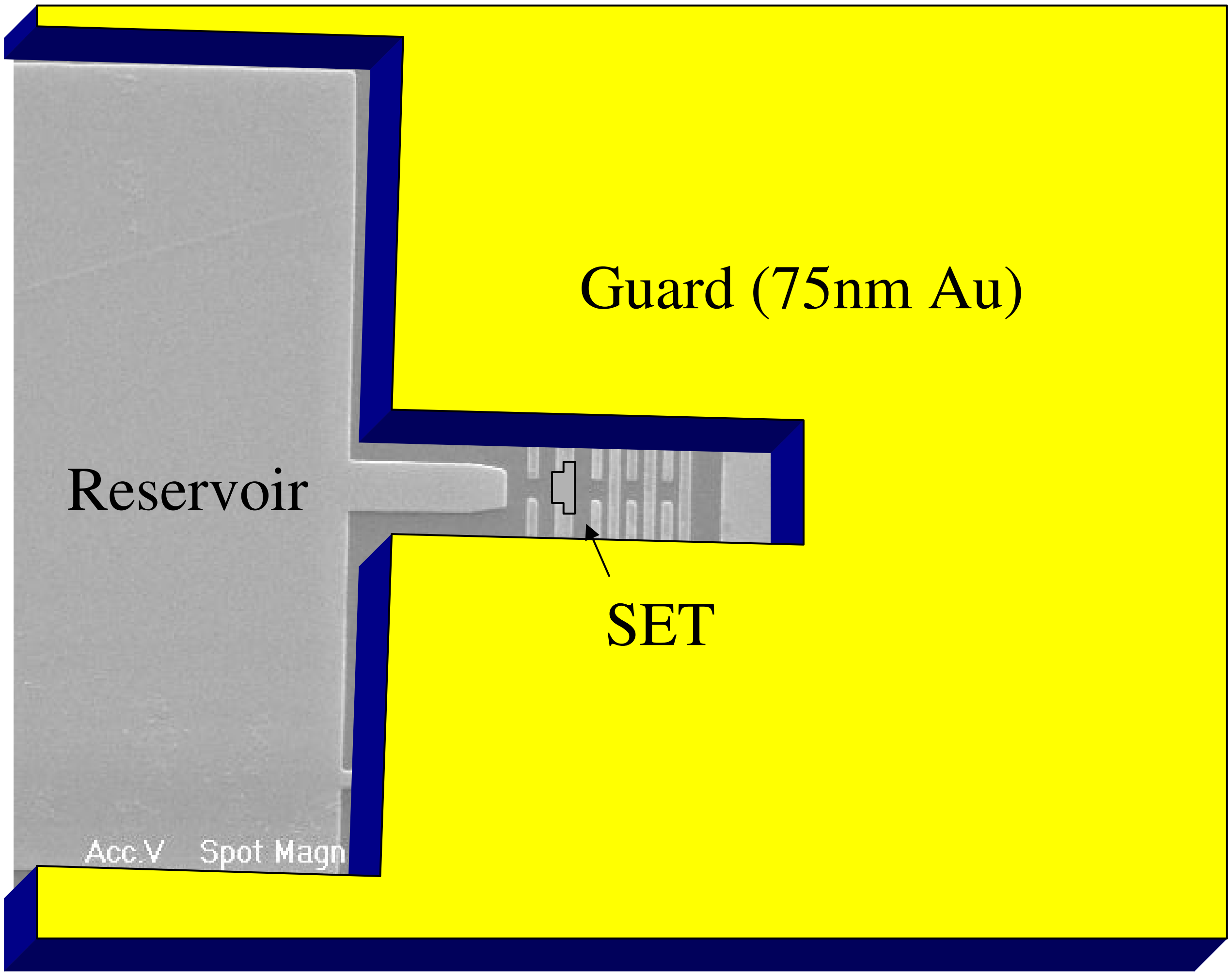


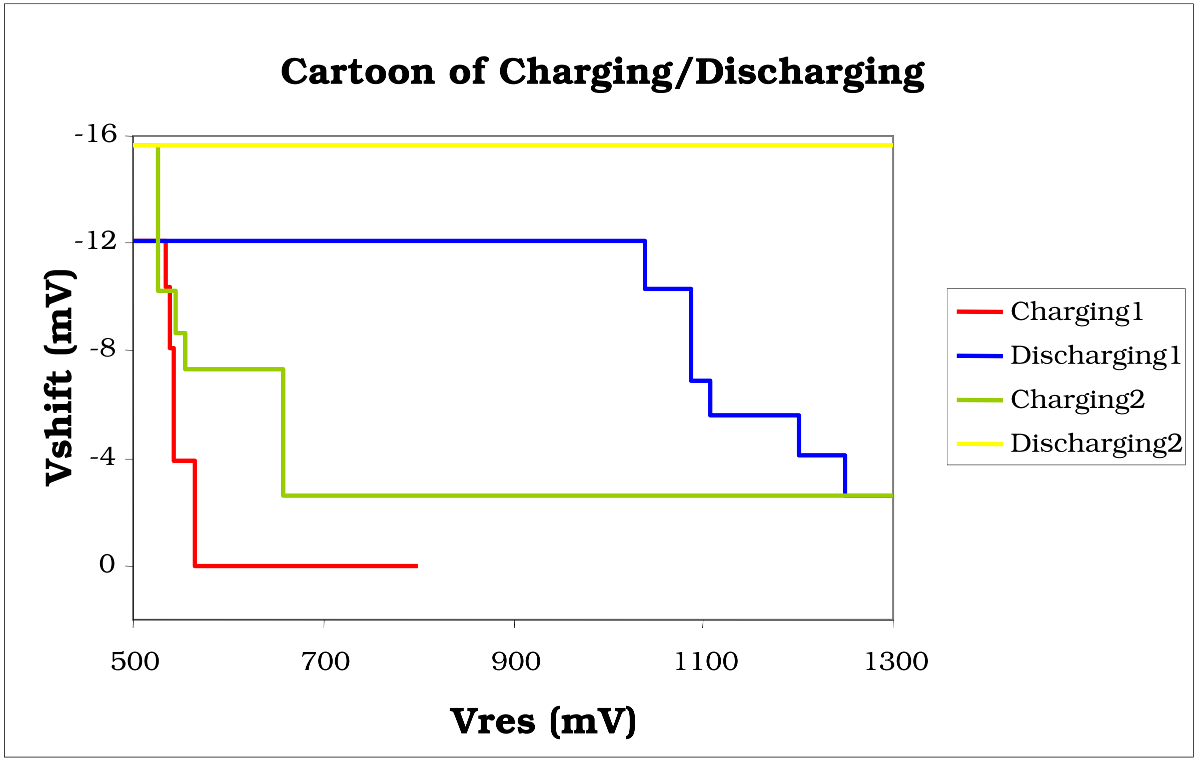
d = 1.4 µm

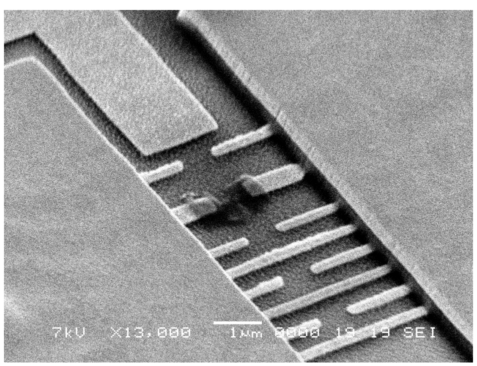
V_{well} ≈ 3mV

f_0 = 21.3 GHz



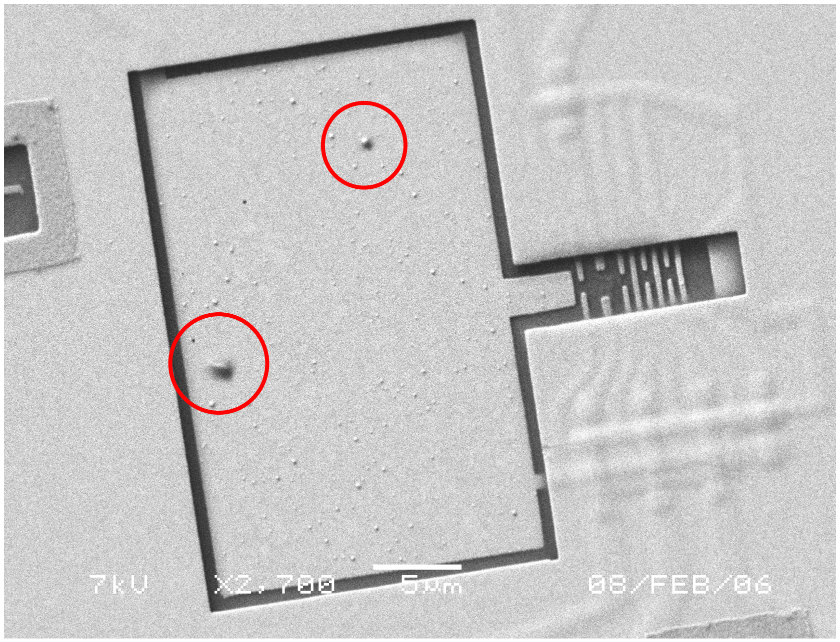

Guard (75nm Au)
Reservoir
SET
Acc.V Spot Magn

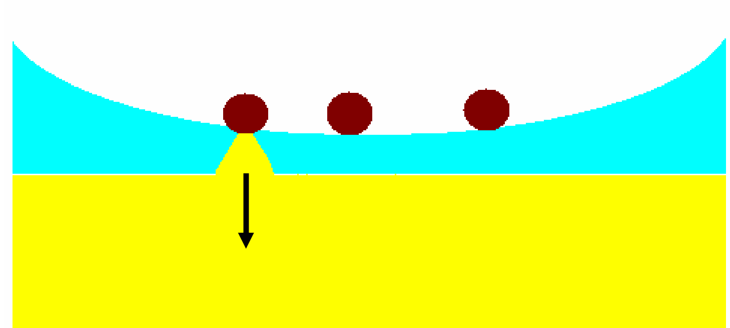




Can follow hysteretic charge/discharge loop with reservoir electrode sweep

However charge movement quickly ceases!





Electrons may drain through spikes in reservoir electrode

OR

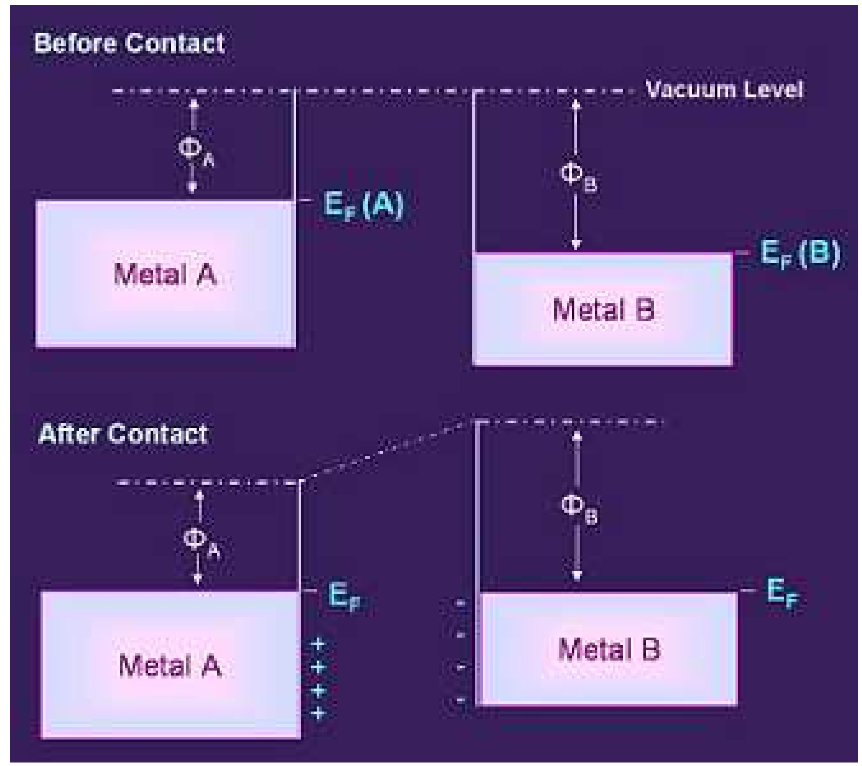
Bending of He film under electrostatic pressure may cause short

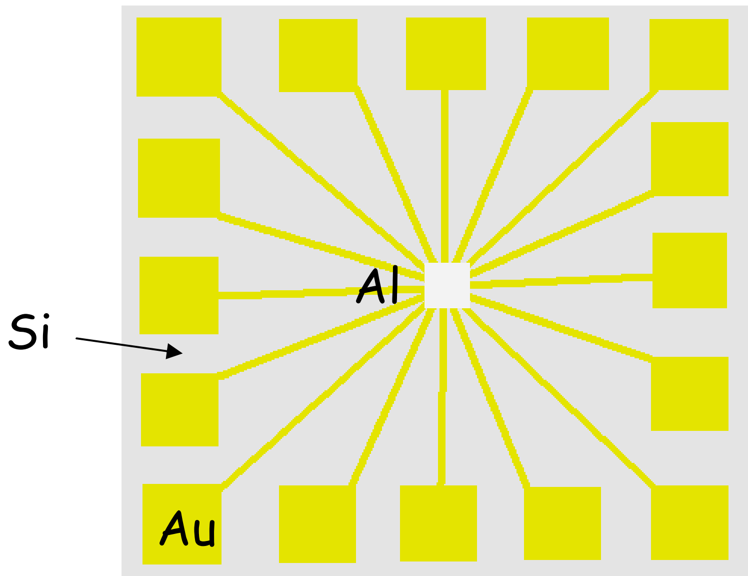
An electrostatic potential (contact potential) develops when two materials of different work functions φ are brought into contact:

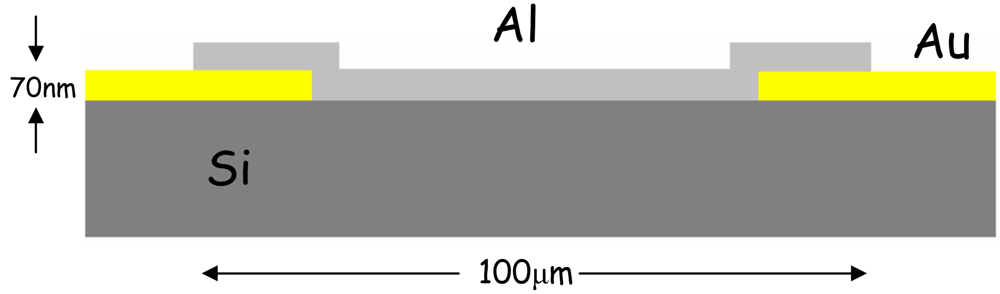
$$V_{cp} = -(\varphi_B - \varphi_A)/e$$

$\varphi_{Au} \approx 5.1eV$, $\varphi_{Al} \approx 4.1eV$

For Al/Au: $V_{cp} \approx 1V$ (!)



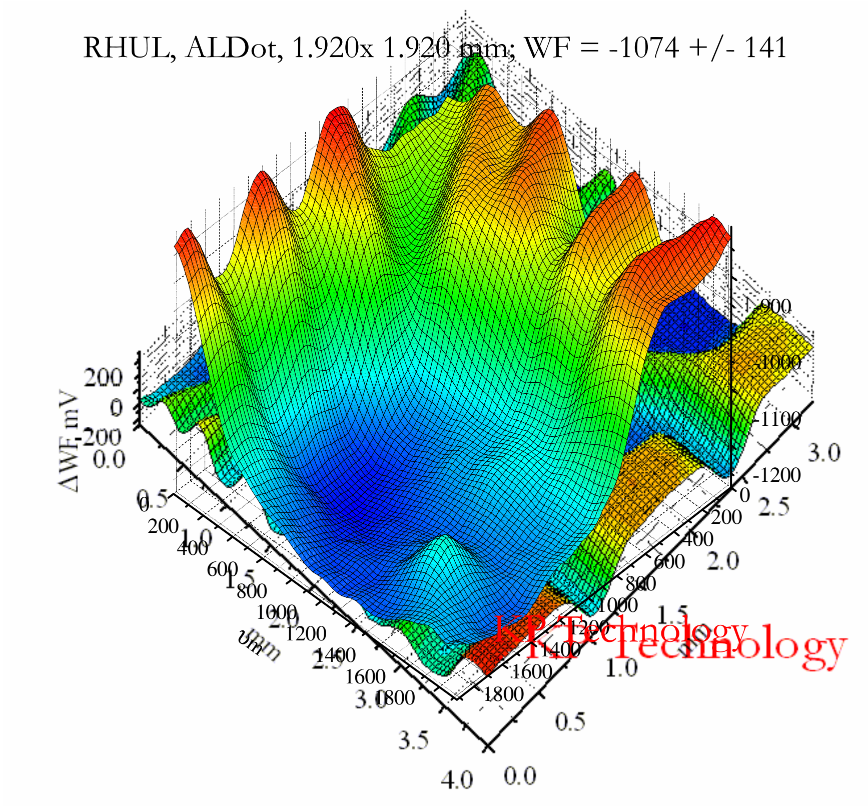




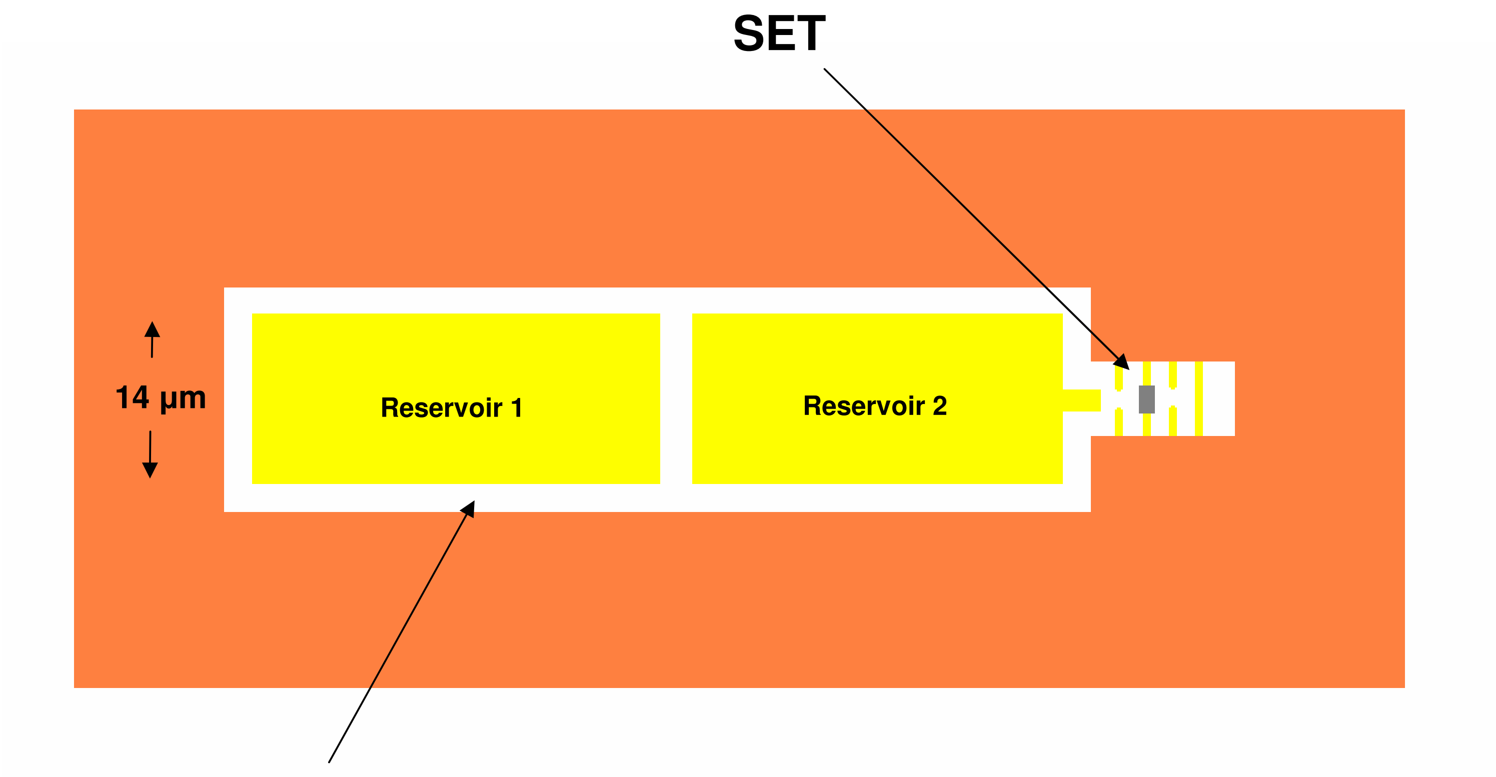
φ of Al/Au sample measured by KP Technology (Prof. Iain Baikie) via scanning electrostatic probe technique:

$V_{cp,measured}$ = 1074 ± 141 mV

$\varphi_{Ag} \approx 4.7eV$
$\varphi_{Nb} \approx 4.3eV$



We have modified our sample design – fabrication is currently underway firstly in Au and ultimately in Nb!



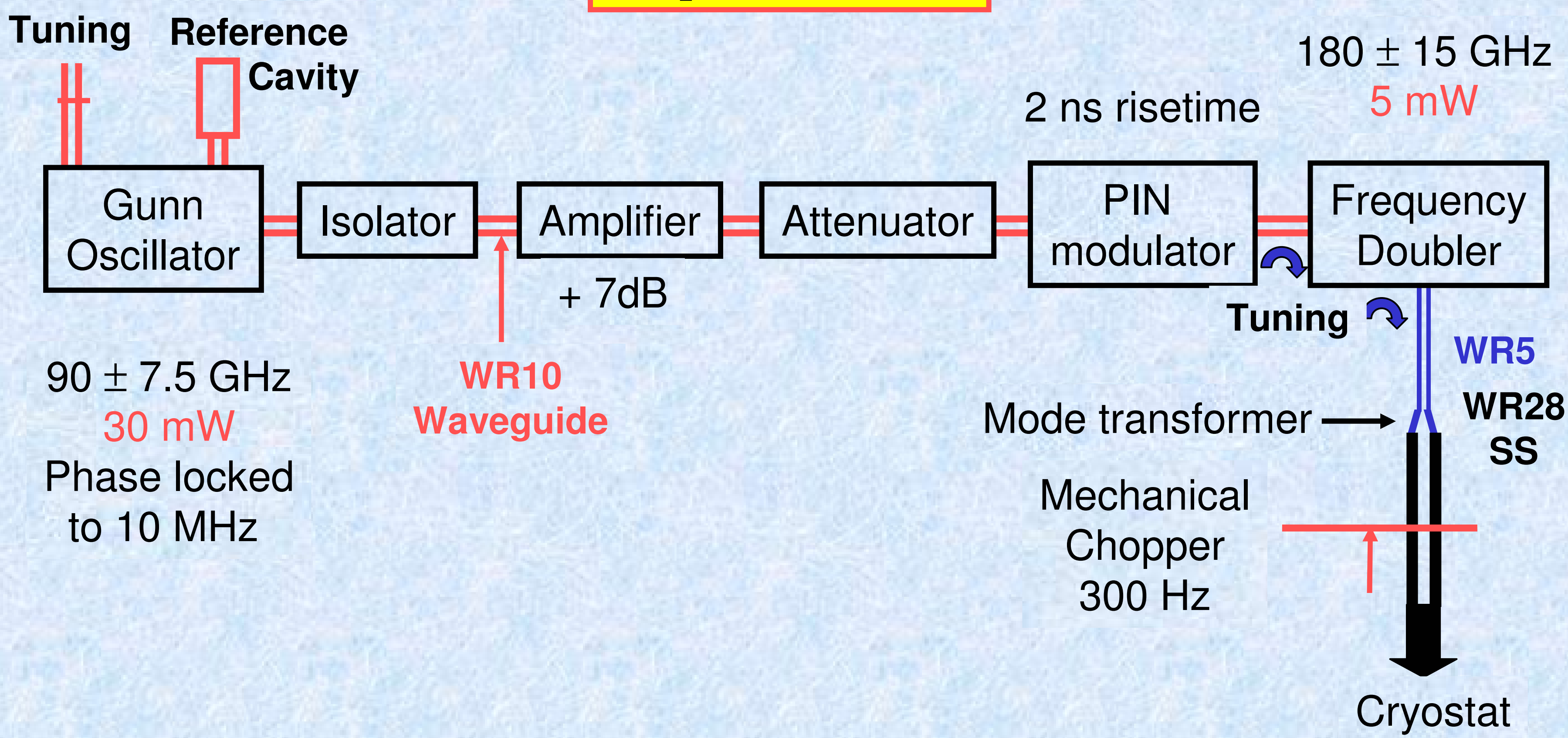
Split reservoir to observe change in C_{RES1}

The Microwave System and Cell

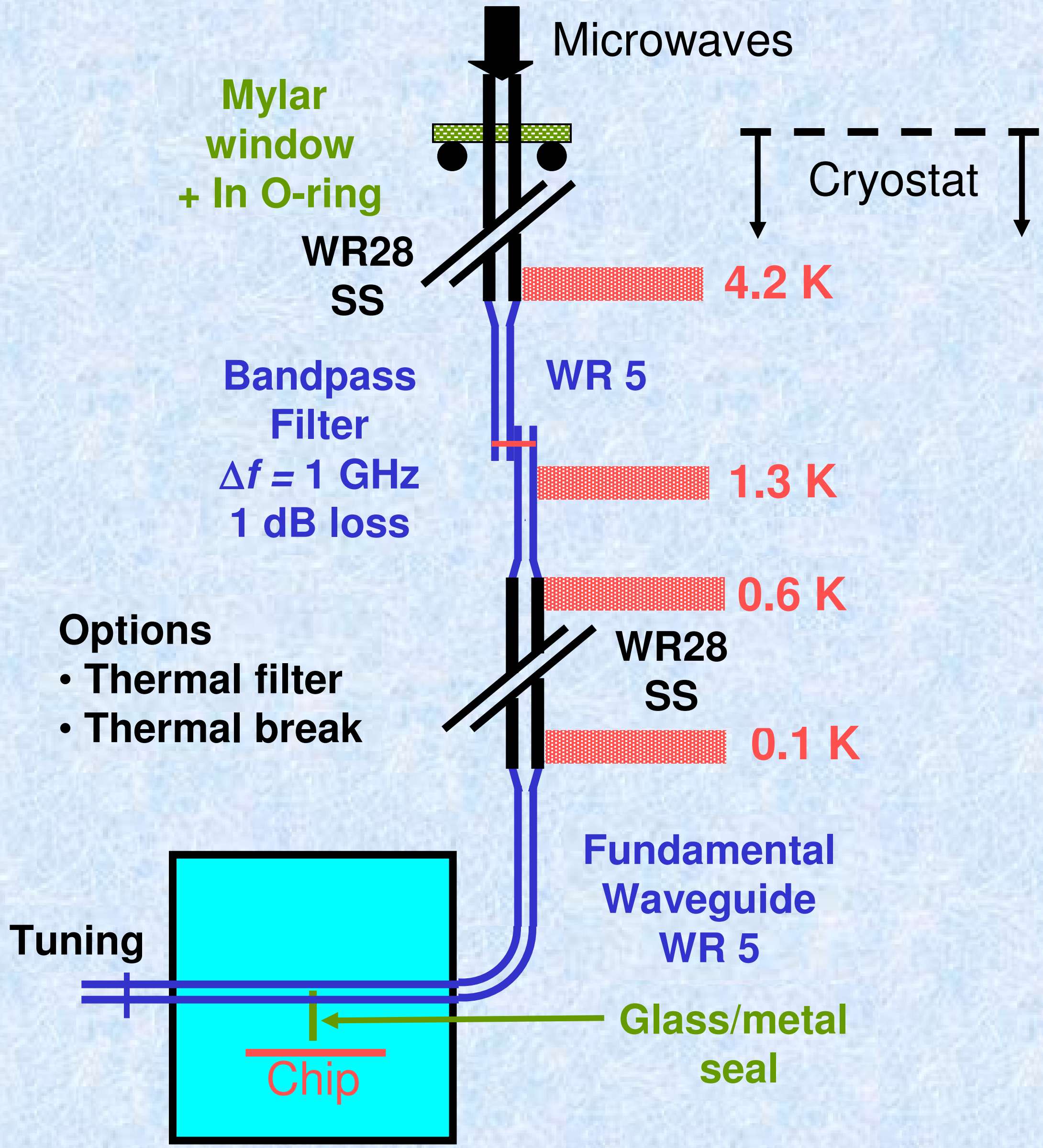
Prof. Mike Lea

Peter Frayne
Royal Holloway
University of London

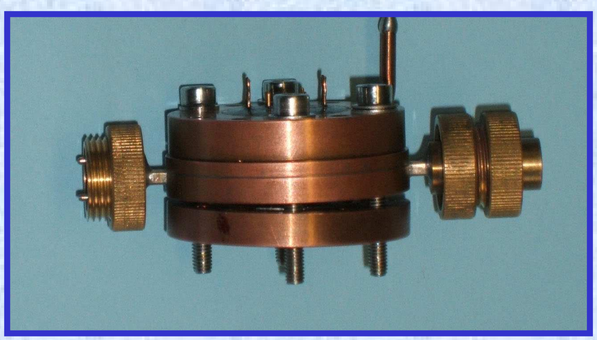
Rydberg
resonance
190 GHz
E_z = 10.7 kV/m



Peter Frayne
Royal Holloway
University of London



Cell

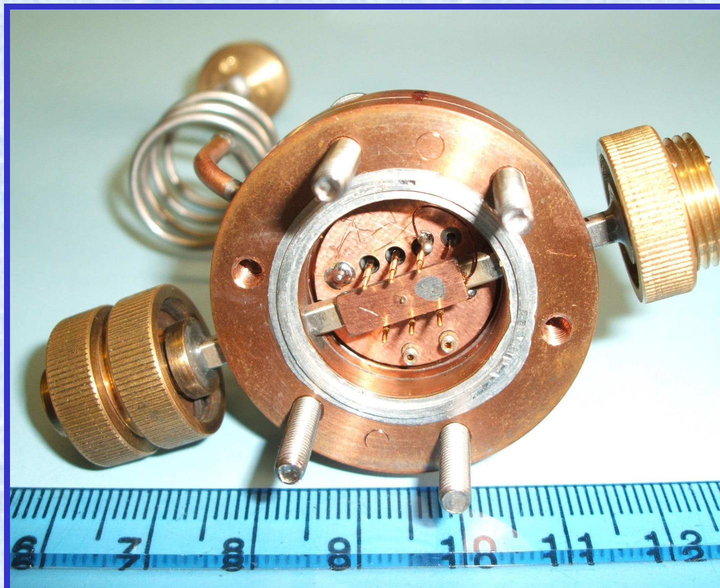


Microwave Components and Cell

Thermal break in fundamental mode waveguide - two back-to-back waveguide tapers (WR-05 to WR-28) with needle point mountings

Band-pass filter (WR-05) for removing thermal radiation complete with coupling horns to overmoded waveguide (WR-28)

Fundemental mode 'Swan-Neck' coupling piece for microwave cell



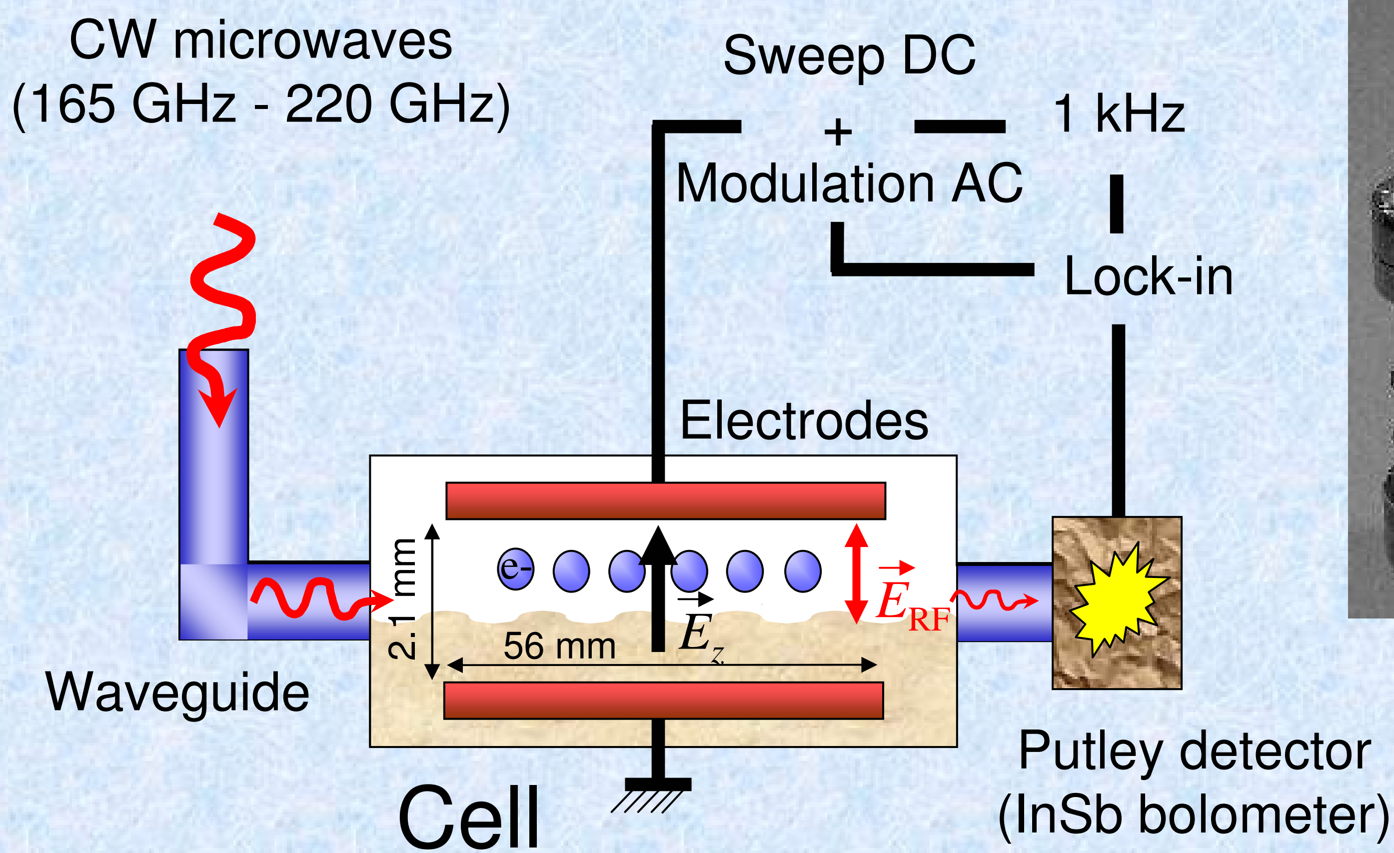
Upper microwave cell showing waveguide and coupling pin

Low Microwave Power

- Stark tuning resonance $f_{12}(E_z)$
- Linewidth $\gamma(T)$
- Temperature dependent resonance $f_{12}(T)$

High Microwave Power

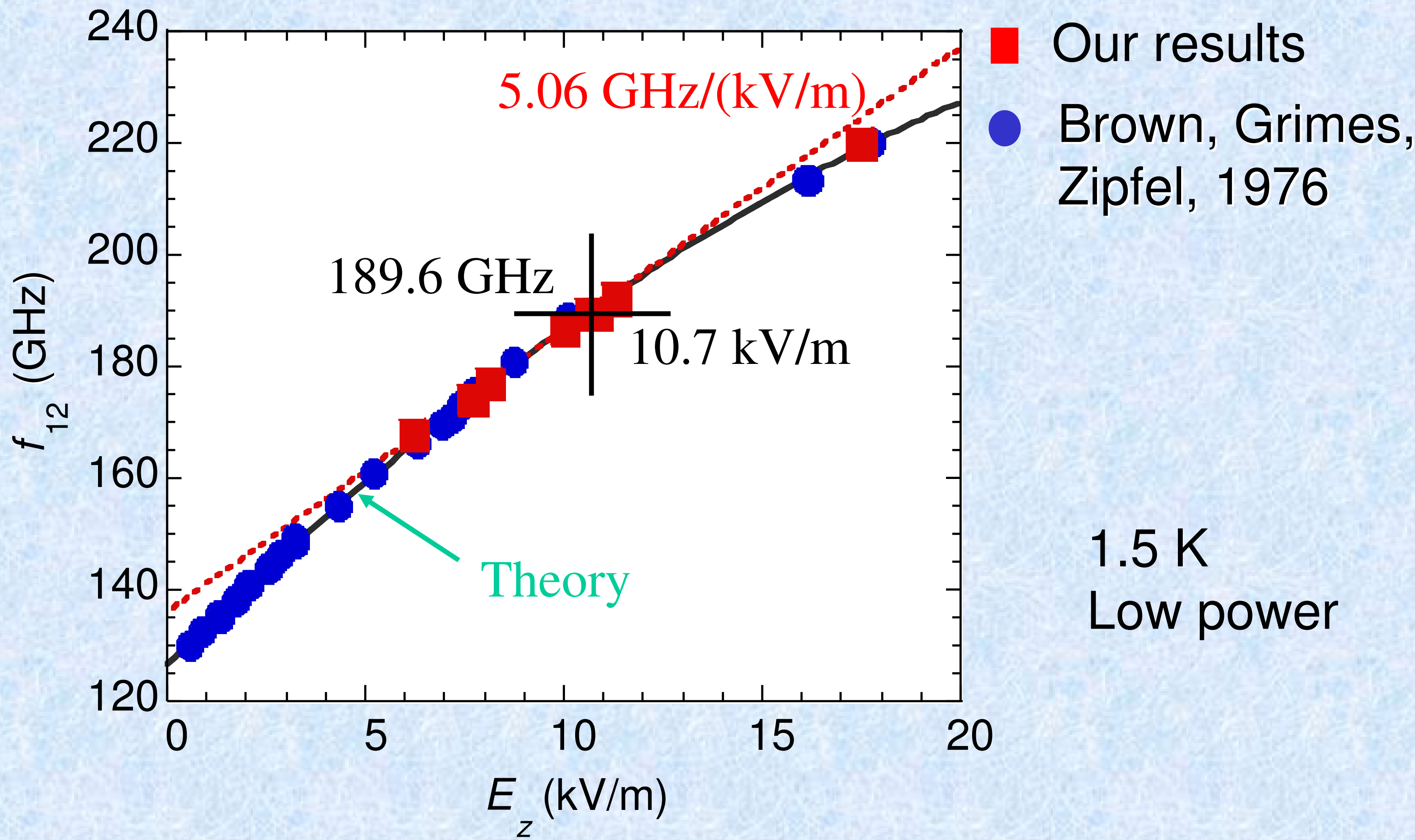
- Absorption saturation
- Power broadening
- Absorption hysteresis


CW microwaves
(165 GHz - 220 GHz)
Sweep DC
+
Modulation AC
1 kHz
Lock-in
Electrodes
e-
2.1 mm
56 mm
$\vec{E}_z$
$\vec{E}_{RF}$
Waveguide
Cell
Putley detector
(InSb bolometer)

Cell

Ground state to first excited Rydberg state

Resonant frequency f_{12} increases with E_Z



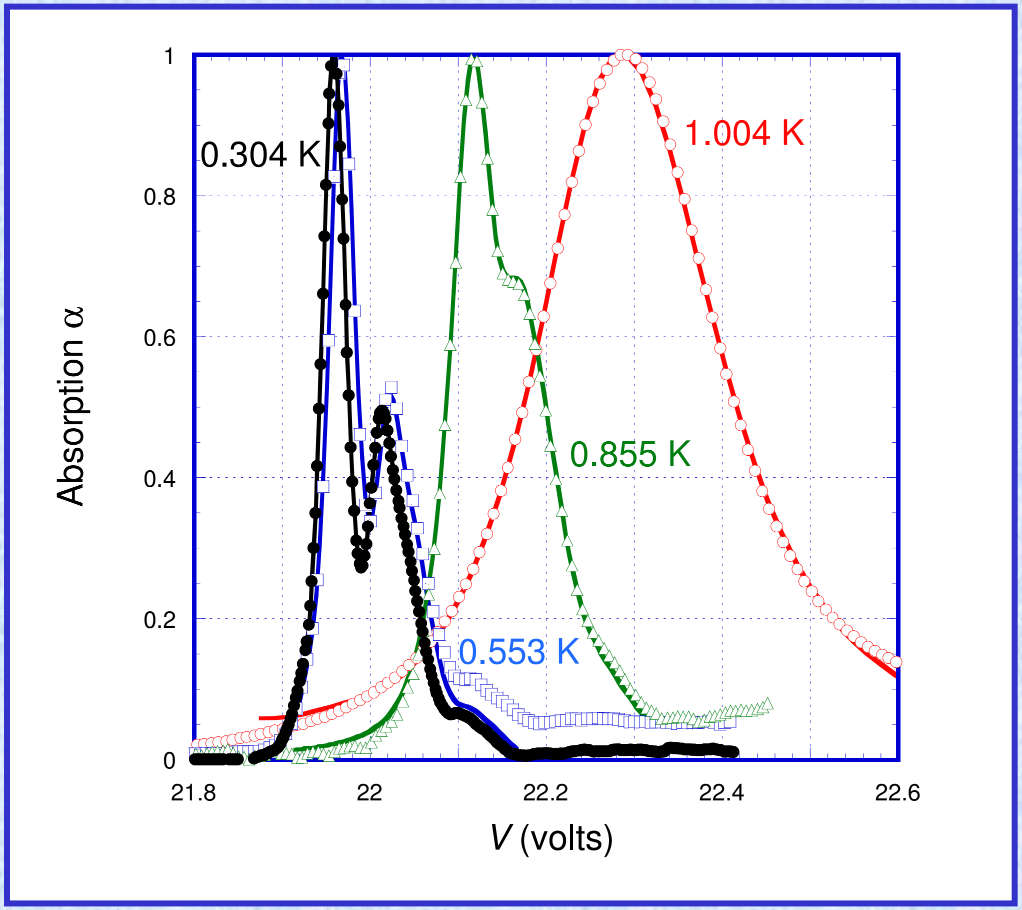
1.5 K
Low power

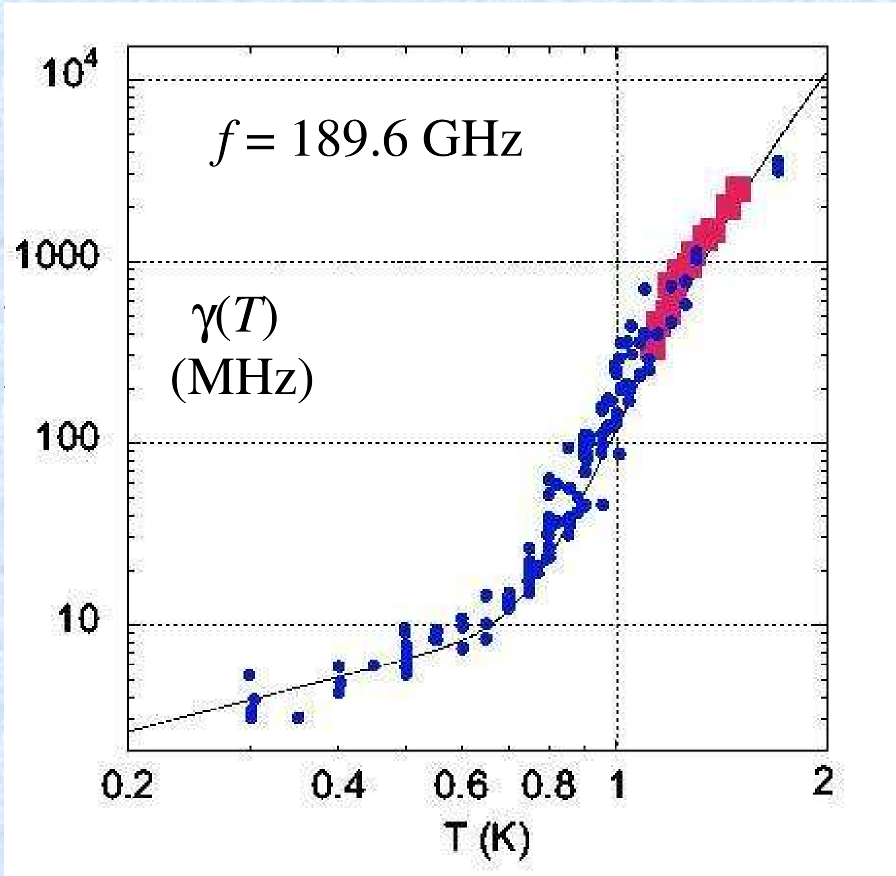
Low temperatures:
Inhomogenous broadening

Medium temperatures:
Inhomogenous broadening
convoluted with a Lorentzian

High temperatures:
Lorentzian broadening

Resonance frequency *decreases*
as the temperature *increases*





E.Collin *et al.* PRL **89**, 245301 (2002)

- Grimes *et al.* (1976)

Theory: Ando (1976)

$$\gamma = AT + BN_{gas}$$

Ripplon Gas atom

Scattering

NB not the absolute linewidth

Inhomogeneous broadening

plus a contribution $\gamma(T)$

$\Delta f_{12}(T) = f_{12}(0) - f_{12}(T)$

$\approx$ 800 MHz at 1 K

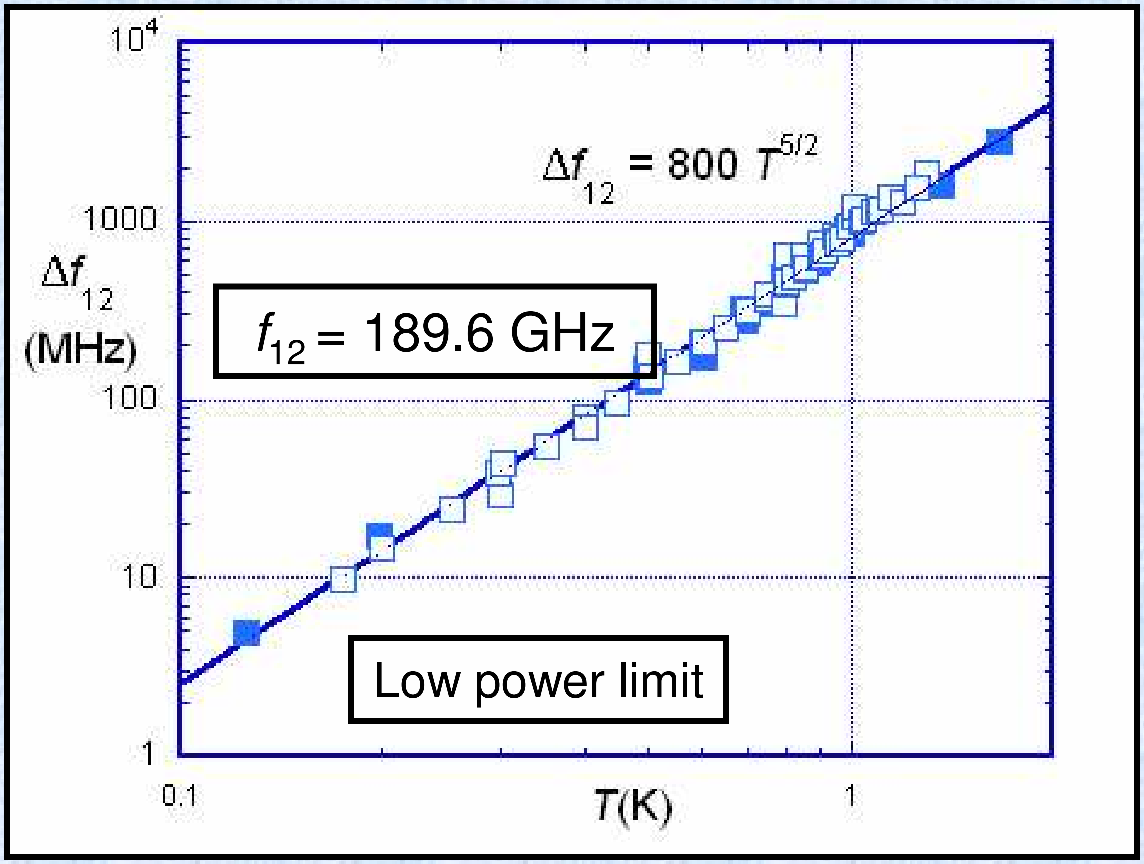
$\Delta f_{12}(T) \propto T^{5/2}$ or

$\propto T^{7/3}$

b

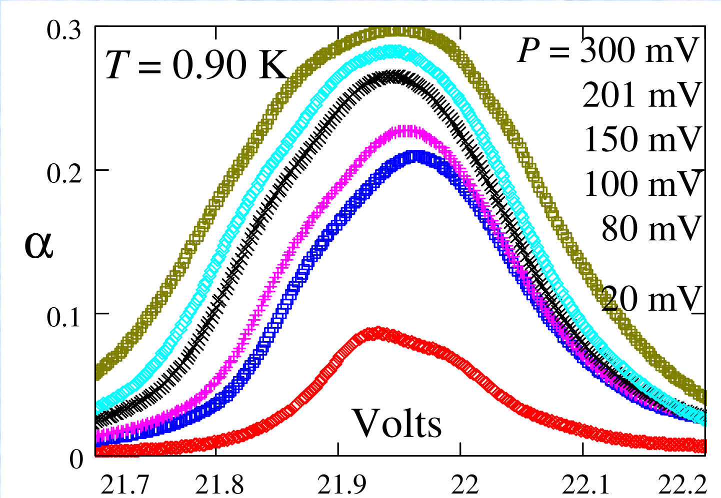
T-dependent surface profile and potential well

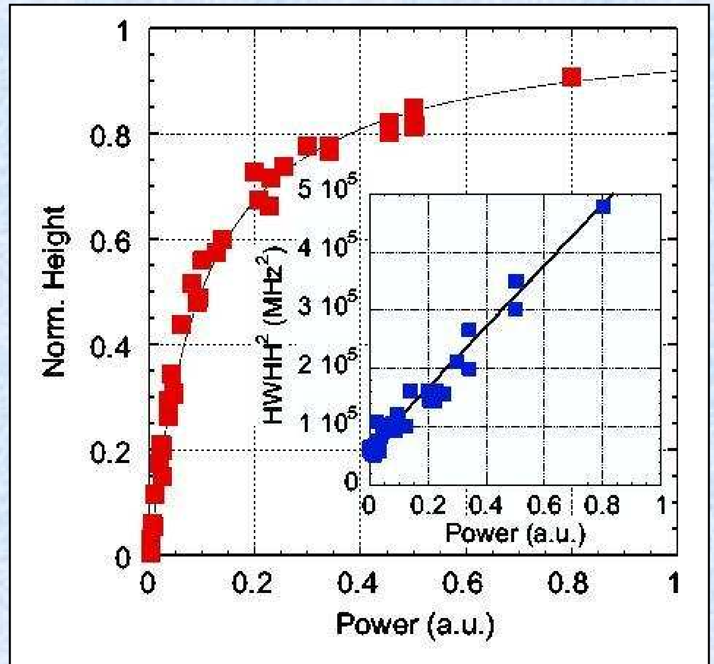
2-ripplon effects?

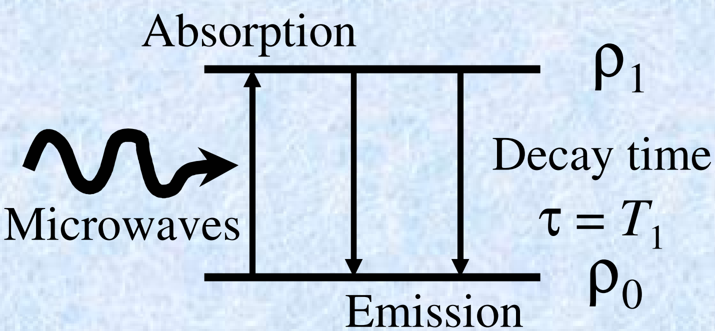


Electrons on Bulk Helium

Absorption Saturation + Power Broadening







2-level system?

Rabi frequency Ω

$\Omega^2 \propto$ Power

$$\alpha = \frac{0.5N\gamma\Omega^2}{\delta^2 + \gamma^2 + \gamma\tau\Omega^2}$$

$$\gamma_P^2 = \gamma^2 + \gamma\tau\Omega^2$$

BUT:
Heating?
Higher sub-bands?
Bleaching?

Vertical transitions:

Microwave absorption 1 → 2

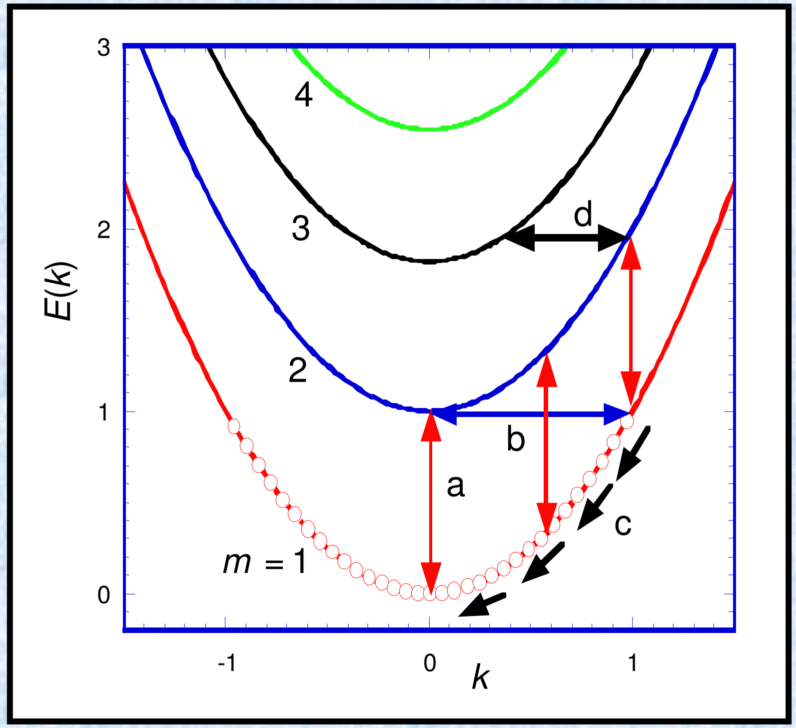
Energy relaxation τ_E: $N \rightarrow 2 \rightarrow 1$
(2-ripplon)

Horizontal transitions:

Momentum scattering τ_k: $N \leftrightarrow 2 \leftrightarrow 1$
(1-ripplon + gas atom)

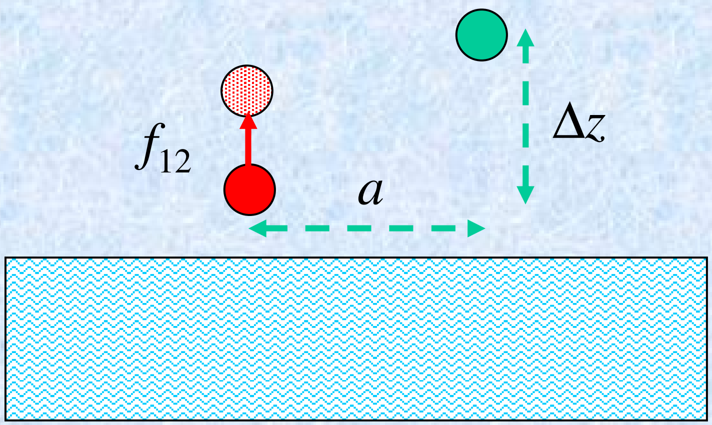
Thermal equilibrium

Electron-electron scattering τ_{ee}



$\tau_{ee} << \tau_k << \tau_E$

Microwave energy → Very hot electrons → Excited sub-bands
→ Bleaching + Population saturation
→ Power broadening + Absorption saturation

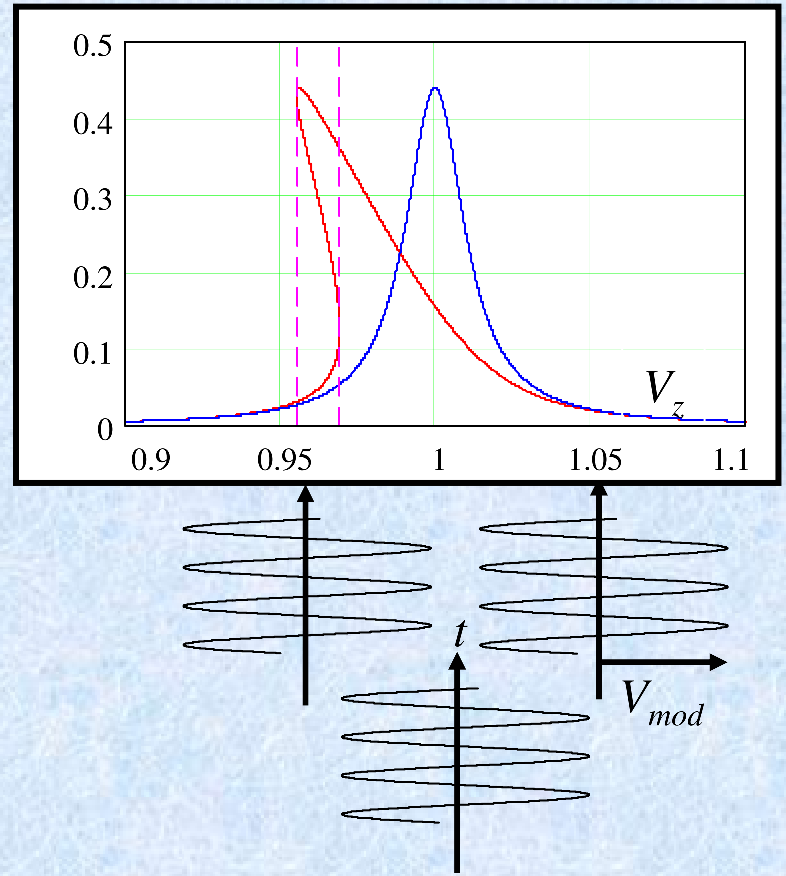


$$\Delta f_{12} = \frac{e^2\, \Delta z^2}{h\, 4\pi\varepsilon_0 a^3}$$

Resonance frequency shifts with

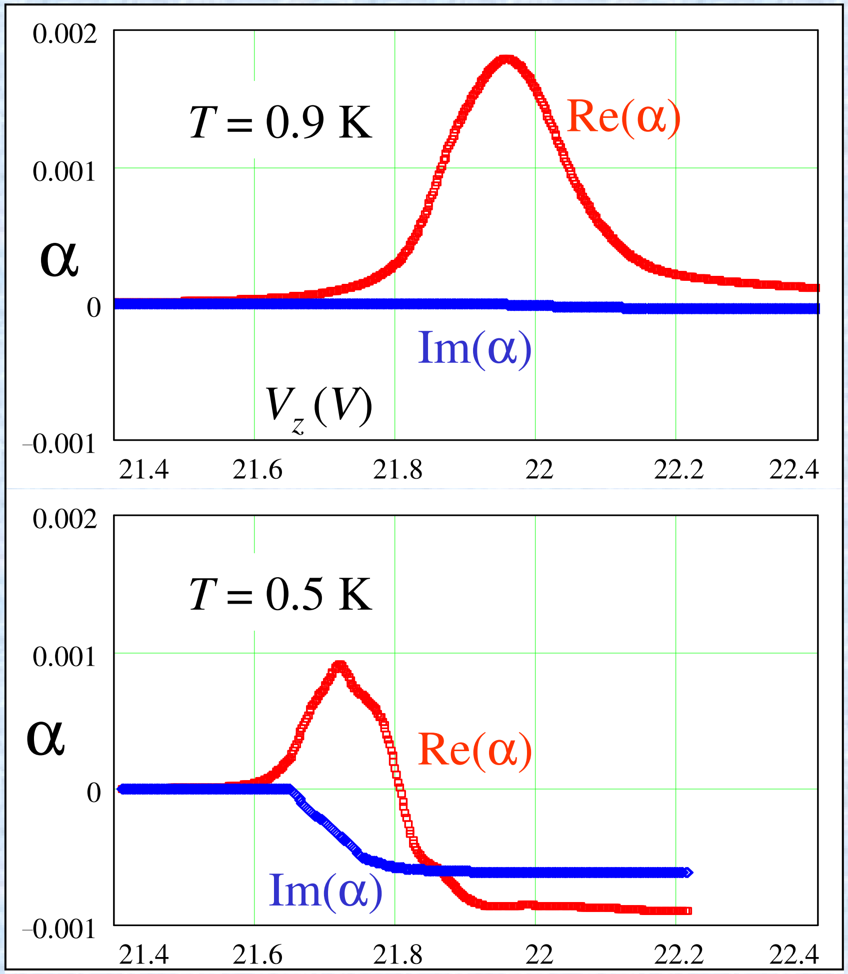
- Electron density
- Power absorbed
  (excited state population)

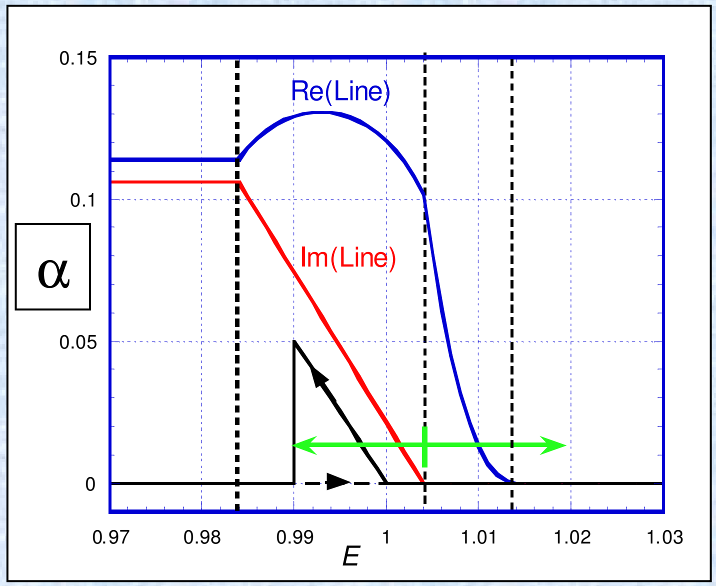
$\Delta f_{12} \approx 34$ MHz
$n = 10^{11}$ m^{-2}
2-level saturation



Finite a.c. voltage modulation

Hysteresis ≡ Complex Lineshape





Low Microwave Power

- Stark tuning resonance $f_{12}(E_z)$
- Linewidth $\gamma(T)$
- Temperature dependent resonance $f_{12}(T)$

High Microwave Power

- Absorption saturation
- Power broadening
- Absorption hysteresis

Future Setup
RF Set

Dr. Vladimir Antonov