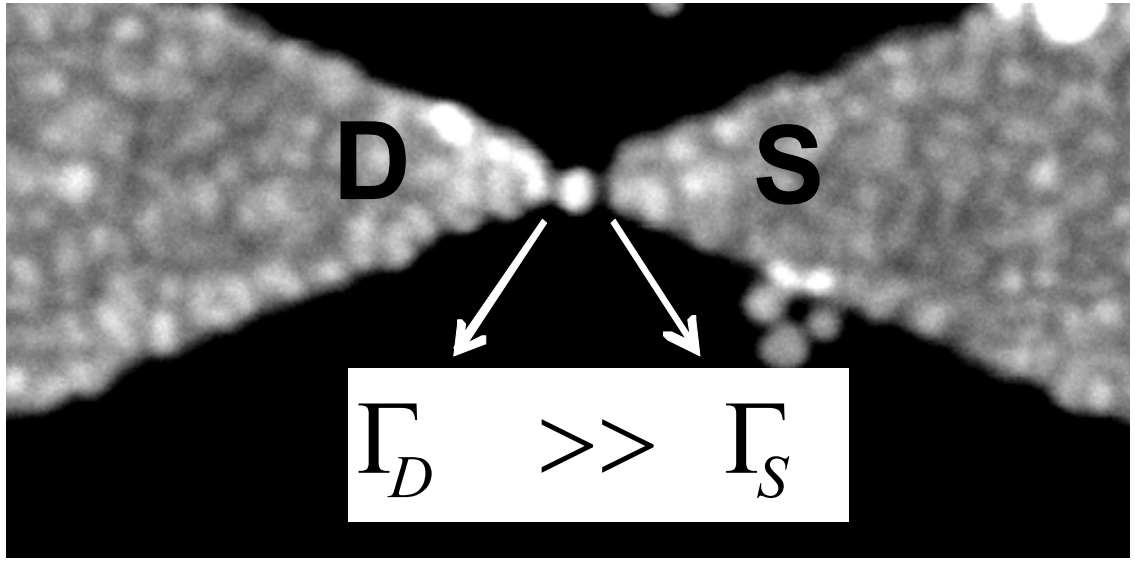
Coulomb blockade and electron interaction effects in strongly coupled metallic quantum dots

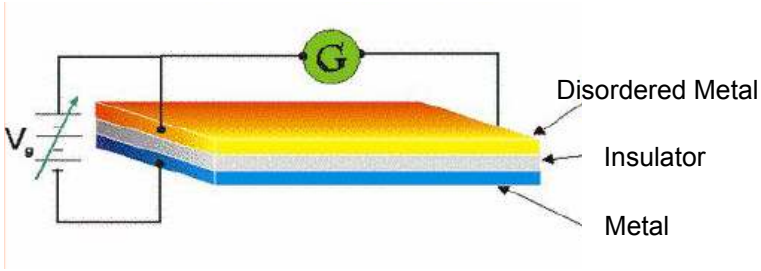
Liora Bitton and Aviad Frydman

Dima Gutman and Richard Berkovits

Bar Ilan University



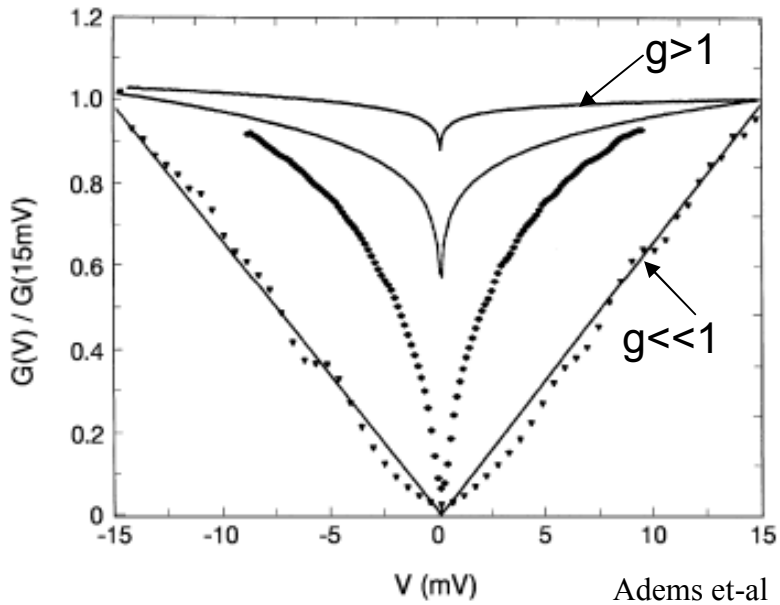
2D



VOLUME 84, NUMBER 7 PHYSICAL REVIEW LETTERS 14 FEBRUARY 2000

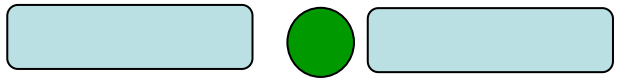
Coulomb Gap: How a Metal Film Becomes an Insulator

V. Yu. Butko,* J. F. DiTusa, and P. W. Adams
Department of Physics and Astronomy, Louisiana State University, Baton Rouge, Louisiana 70806
(Received 10 September 1999)

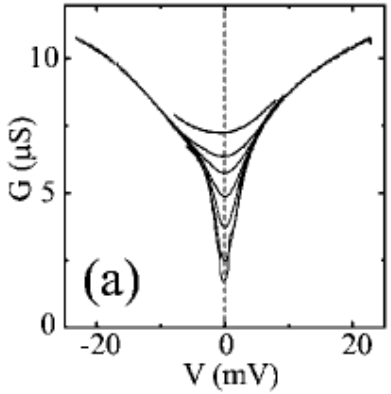


Adems et-al

0D

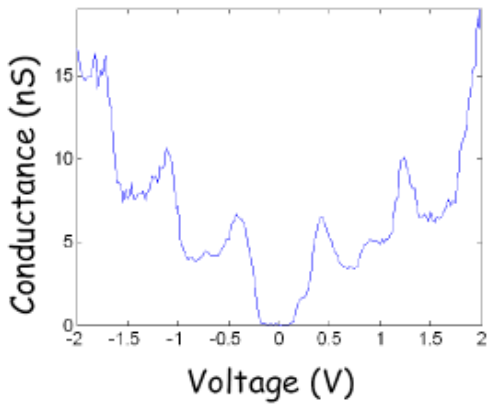


g~1, ZBA



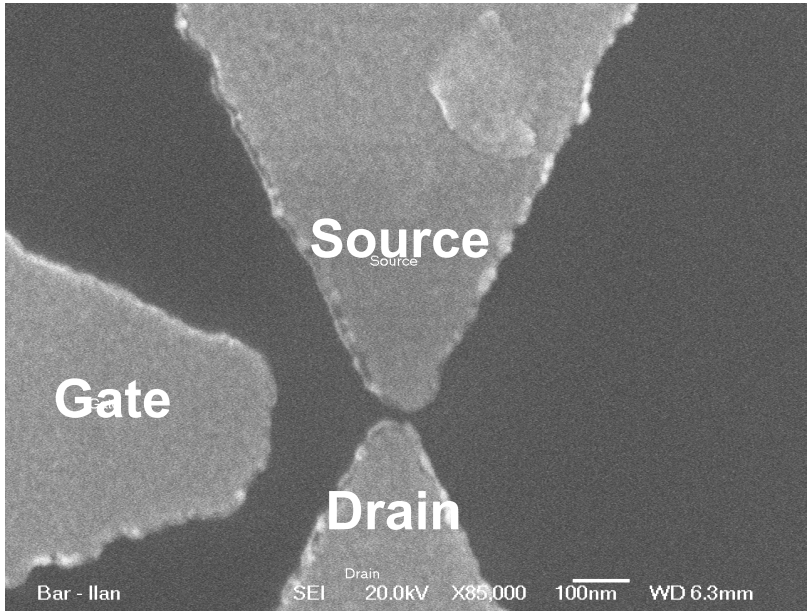
McEuen et-al

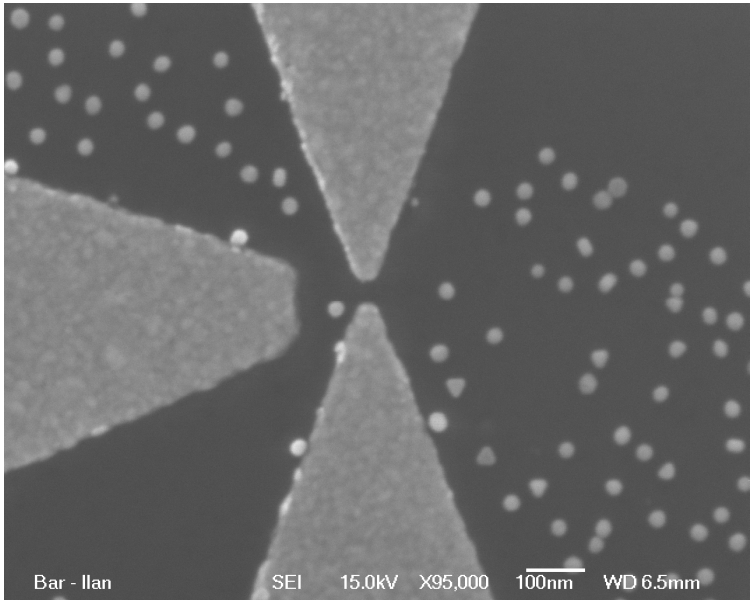
g<<1, CB

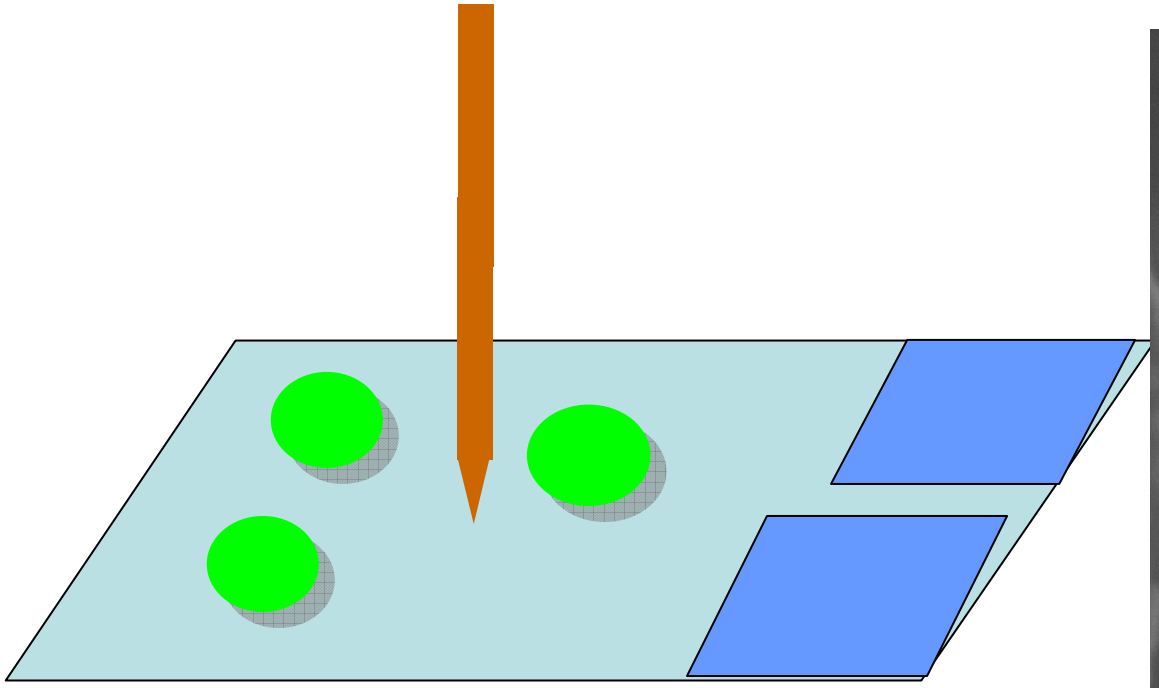


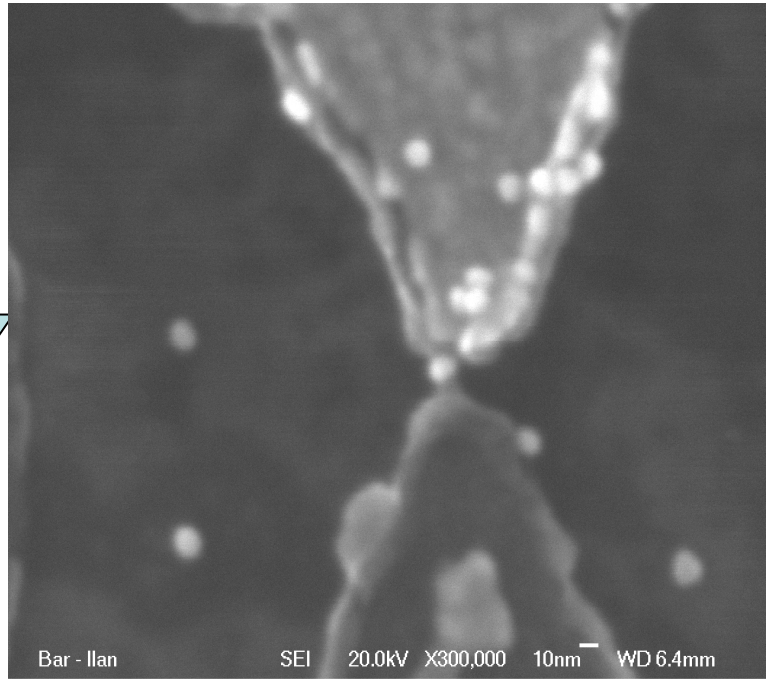
Yakoby et-al

Nanoparticle manipulation

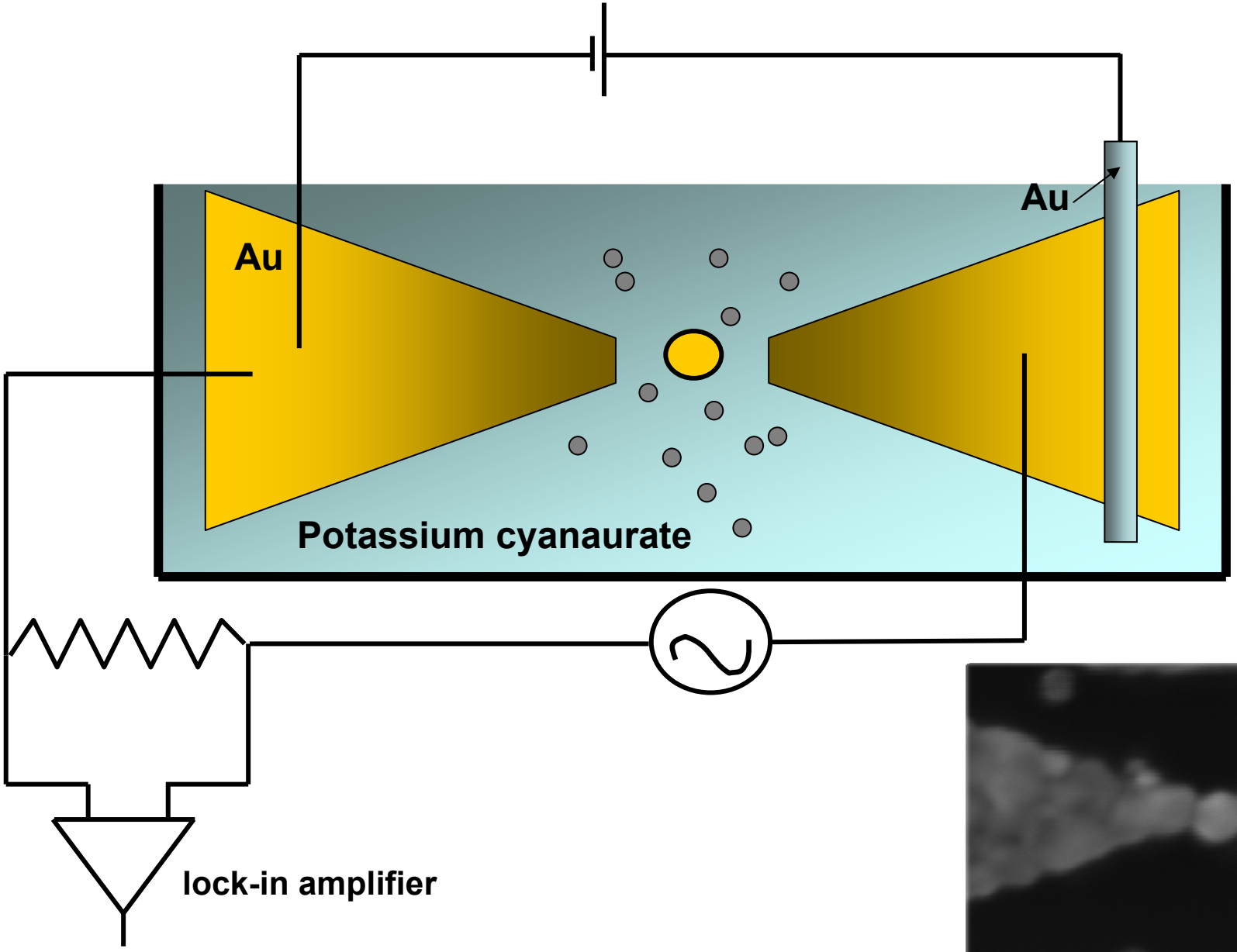


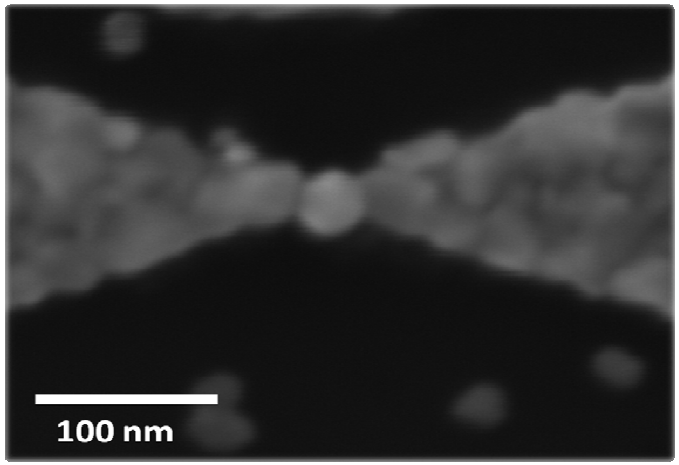


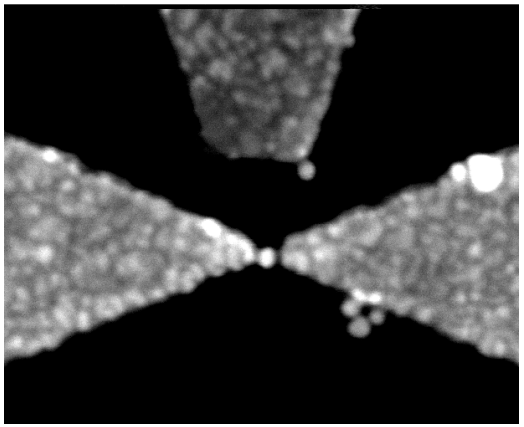


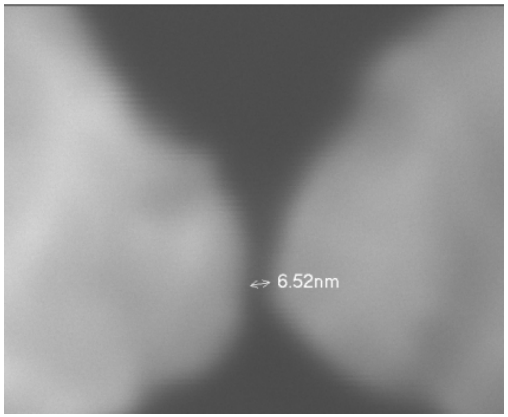


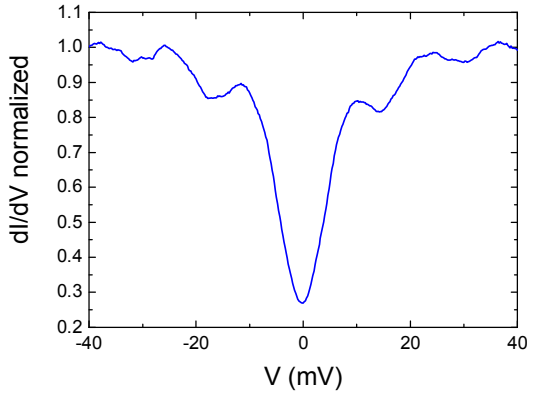
Controlling the dot-lead coupling (electro-deposition)

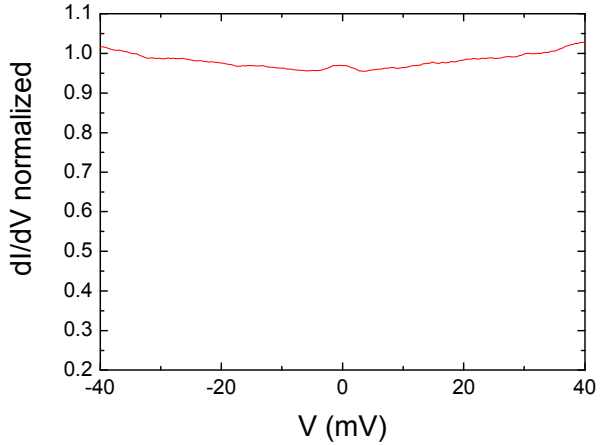


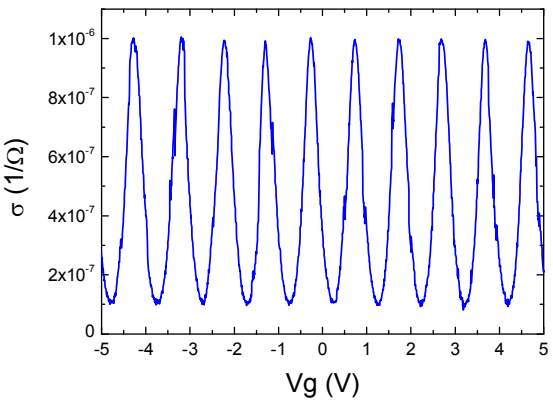


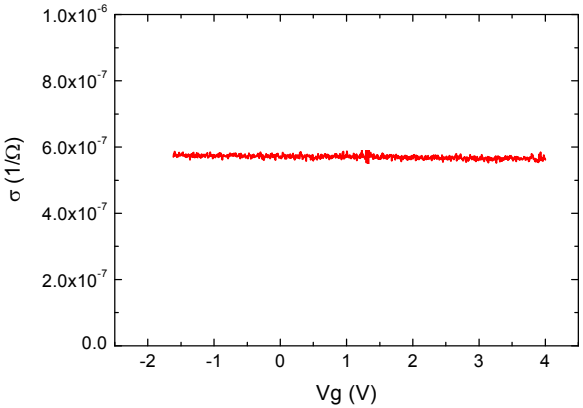



6.52nm


dI/dV normalized
V (mV)


dI/dV normalized
V (mV)


σ (1/Ω)
Vg (V)


σ (1/Ω)
Vg (V)

PHYSICAL REVIEW B VOLUME 56, NUMBER 24 15 DECEMBER 1997-II

Strong electron tunneling through mesoscopic metallic grains

D. S. Golubev
I. E. Tamm Department of Theoretical Physics, P. N. Lebedev Physics Institute, Leninskii Prospect 53, 117924 Moscow, Russia

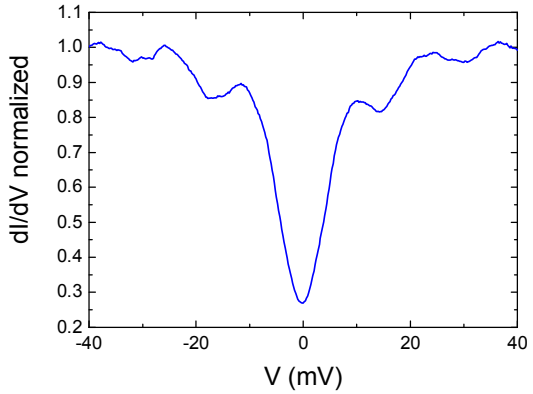
Jürgen König, Herbert Schoeller, and Gerd Schön
Institut für Theoretische Festkörperphysik, Universität Karlsruhe, D-76128 Karlsruhe, Germany

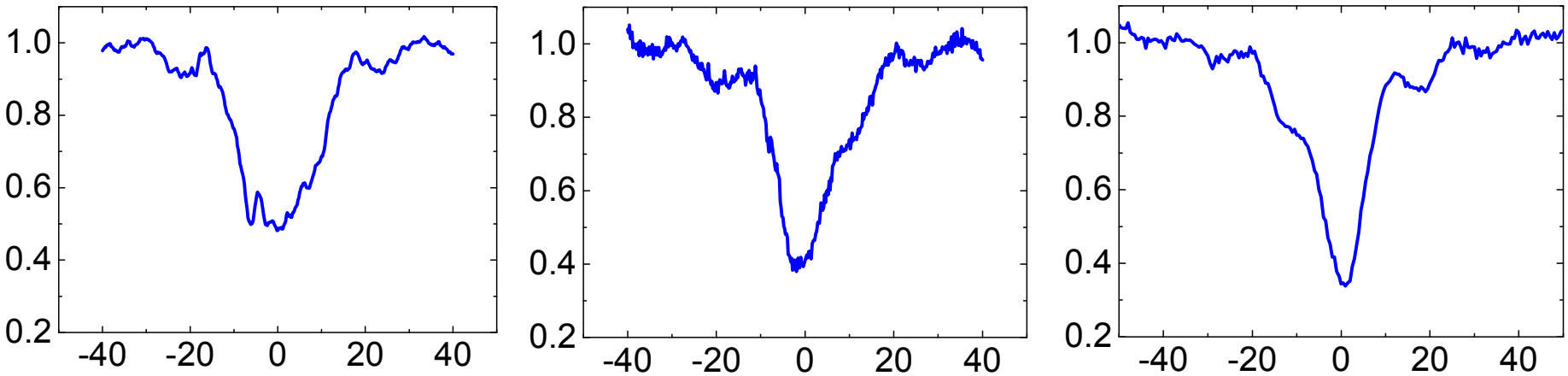
A. D. Zaikin

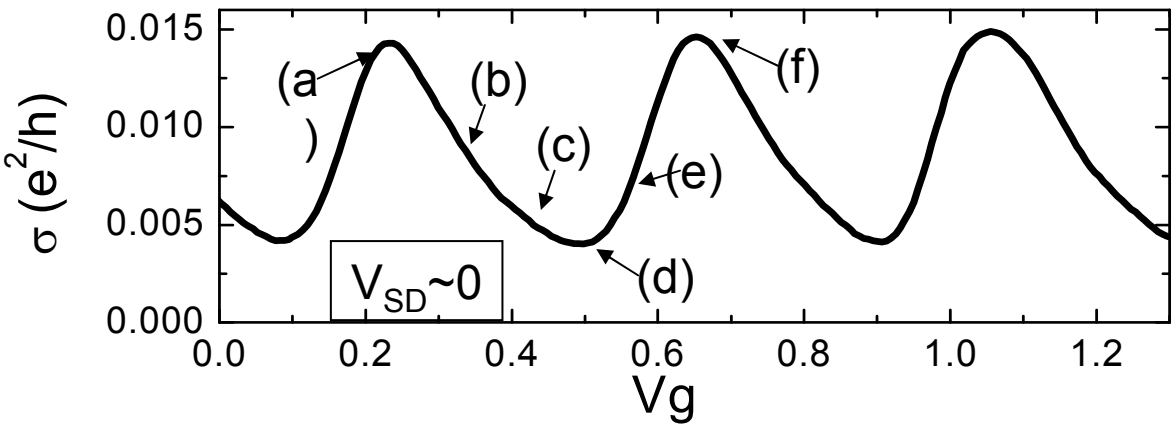
$$I(V) = G_{as}V - I_0(T,V) - \tilde{G}e^{-F(T,V)}V\cos 2\pi N$$

$$\frac{G(V)}{G_{as}} = 1 - \frac{1}{g_D}\left(\ln\left[1+\frac{\hbar^2}{(2\pi t_c\epsilon)^2}\right] - \frac{2}{1+(2\pi t_c\epsilon/\hbar)^2}\right)$$
$$+\exp\left[-\frac{g_D}{2} - \frac{2\pi^2}{\tilde{E}_C}\left(T+\frac{R_D}{R_S}V_{SD}\right)\right]\cos\left(\frac{2\pi V_{SD}}{E_C}+\phi\right)$$

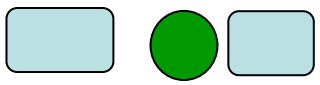
Bitton, Gutman Berkovits and Frydman, arXiv:1007.4300



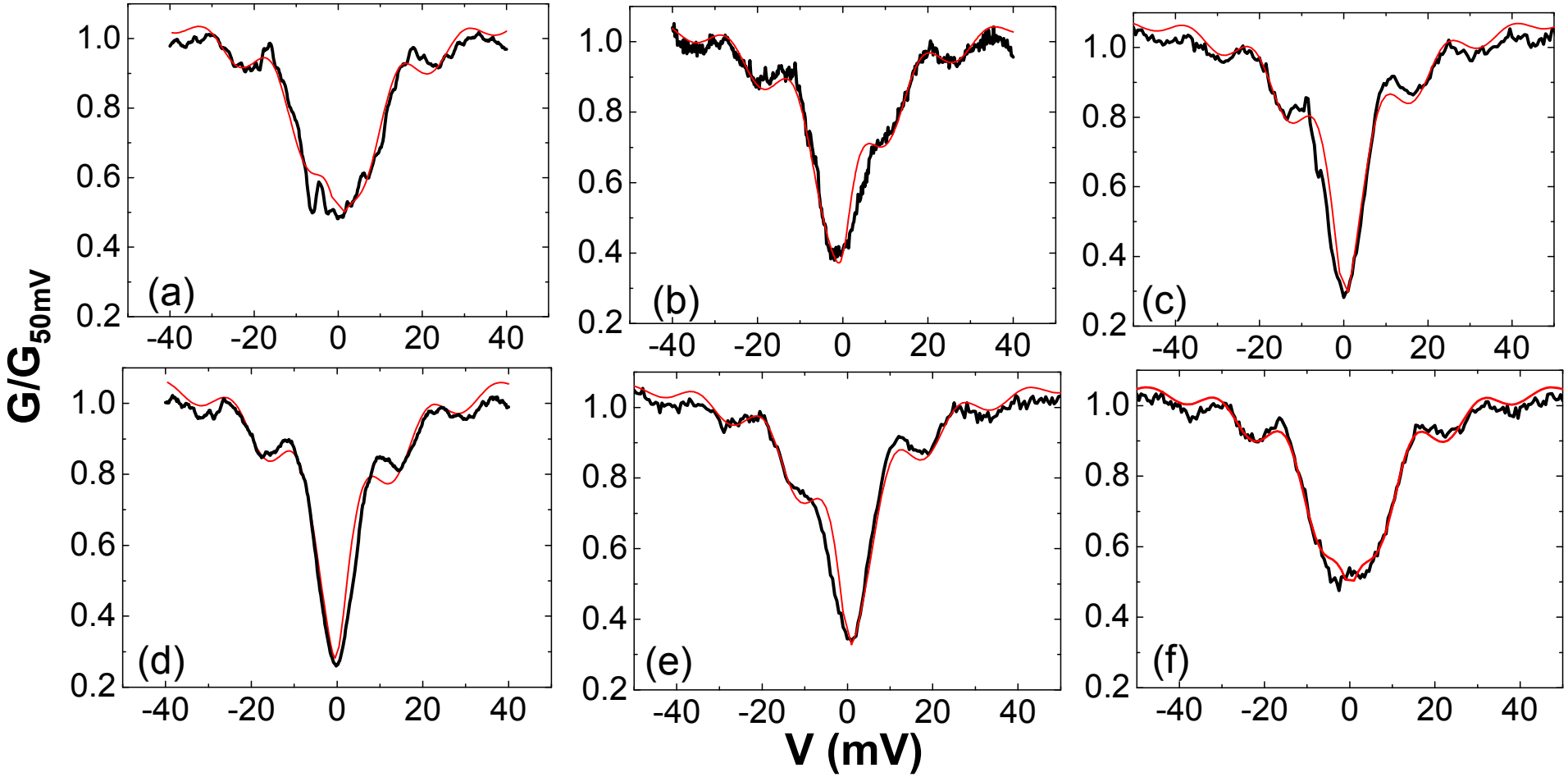


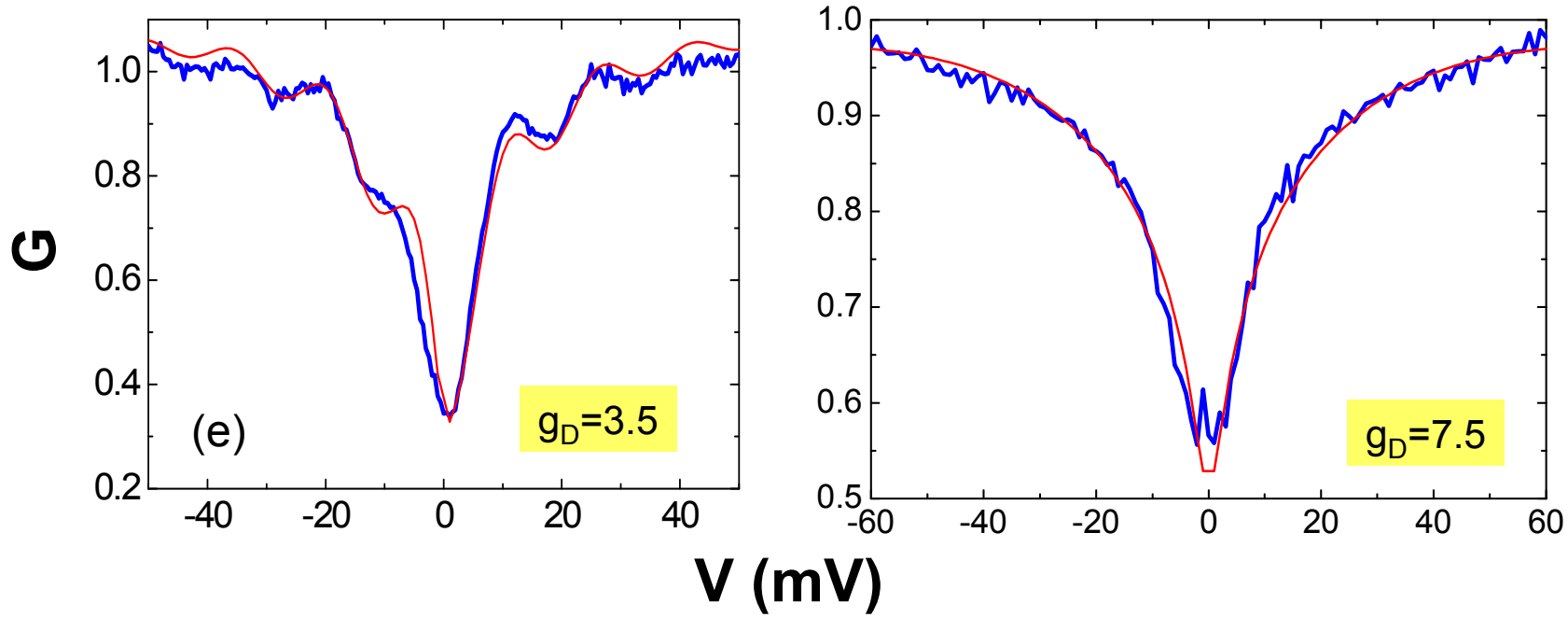


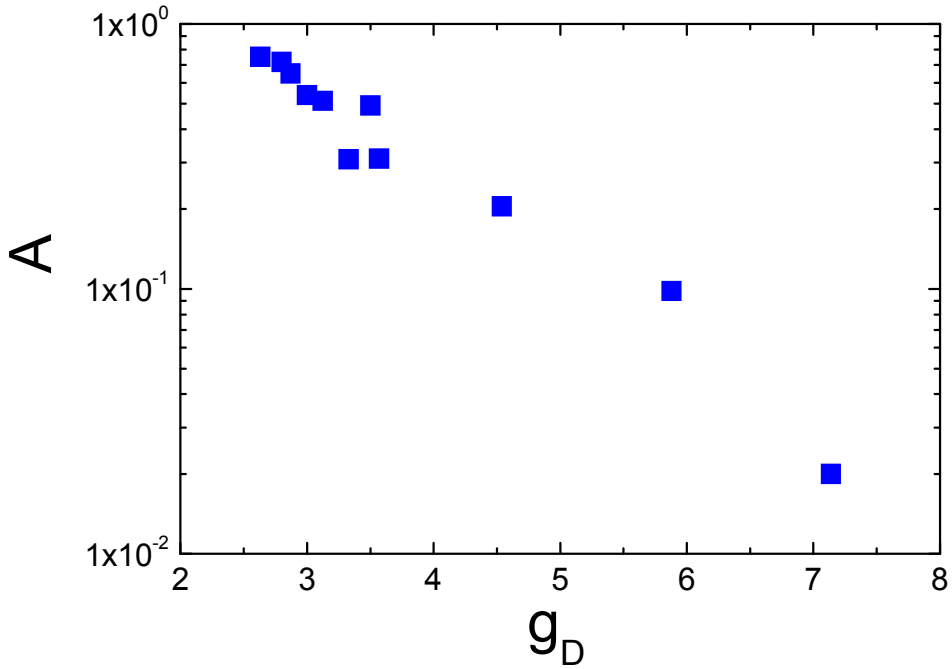
$$\frac{G(V)}{G_{as}} = 1 - \frac{1}{g_D}\left(\ln\left[1+\frac{\hbar^2}{(2\pi t_c\epsilon)^2}\right] - \frac{2}{1+(2\pi t_c\epsilon/\hbar)^2}\right)$$
$$+\exp\left[-\frac{g_D}{2} - \frac{2\pi^2}{\tilde{E}_C}\left(T+\frac{R_D}{R_S}V_{SD}\right)\right]\cos\left(\frac{2\pi V_{SD}}{E_C}+\phi\right)$$

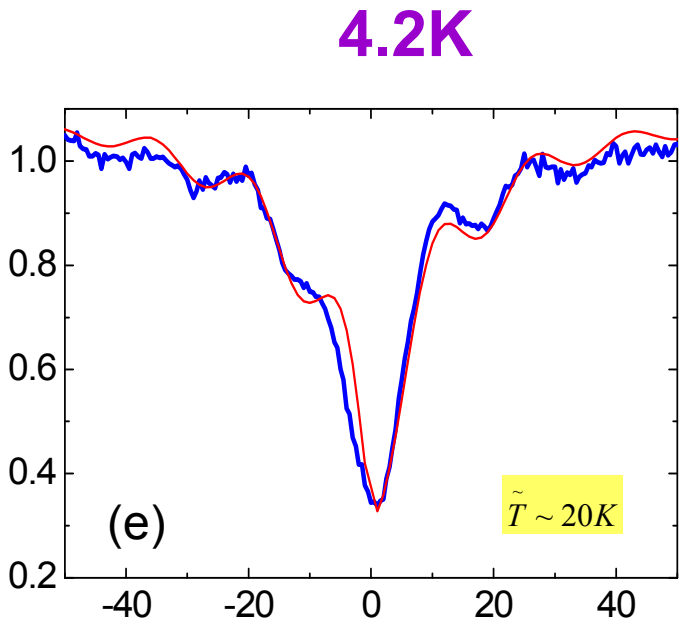


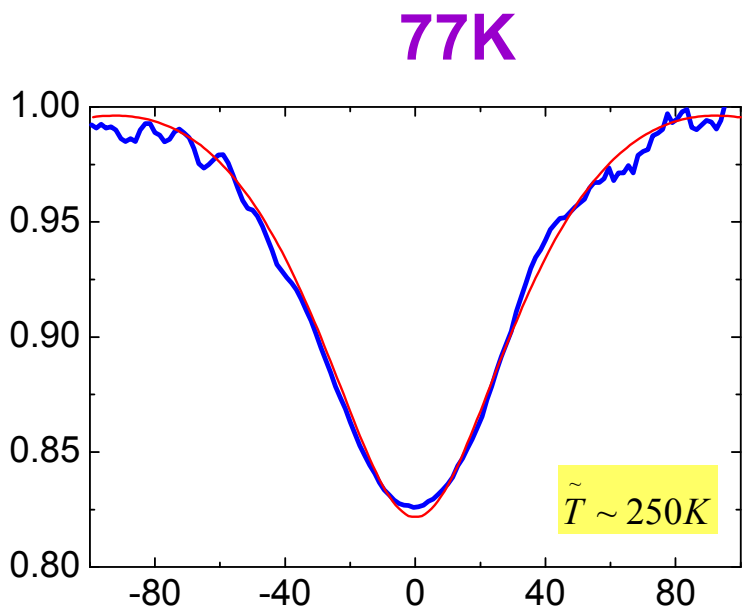
g_D=3.5




G
1.0
0.8
0.6
0.4
0.2
(e)
g_D=3.5
-40
-20
0
20
40
1.0
0.9
0.8
0.7
0.6
0.5
g_D=7.5
-60
-40
-20
0
20
40
60
V (mV)

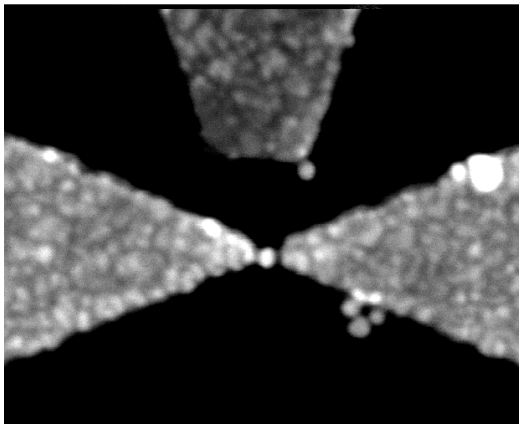

A
$1x10^0$
$1x10^{-1}$
$1x10^{-2}$
2
3
4
5
6
7
8
g_D

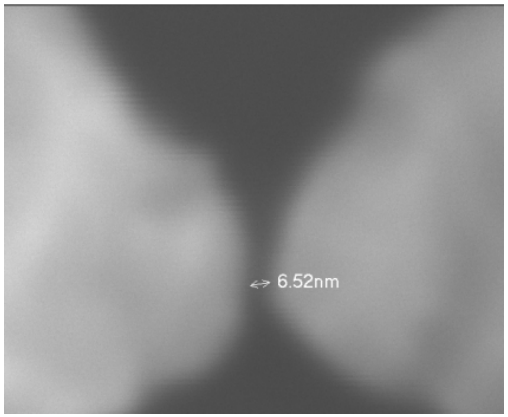


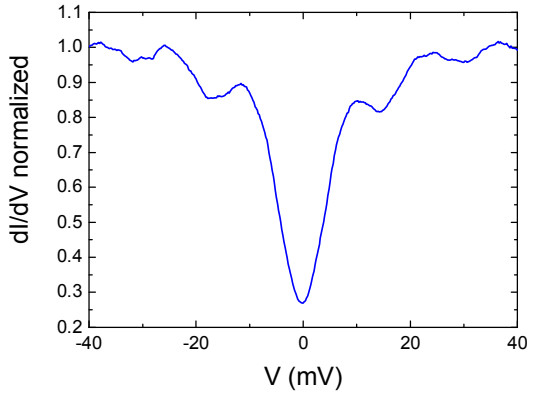


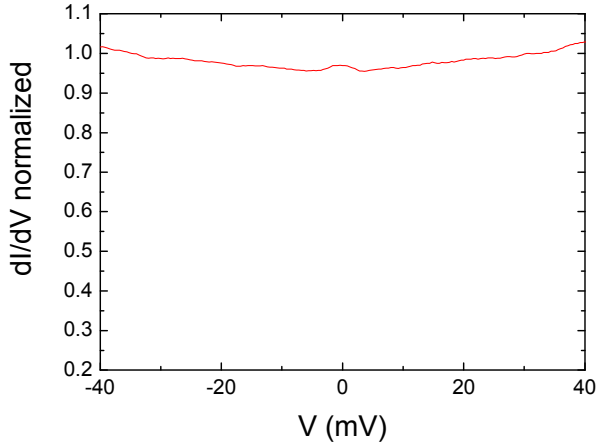
$$\frac{G(V)}{G_{as}} = 1 - \frac{1}{g_D}\left(\ln\left[1+\frac{\hbar^2}{(2\pi t_c\epsilon)^2}\right] - \frac{2}{1+(2\pi t_c\epsilon/\hbar)^2}\right)$$
$$+\exp\left[-\frac{g_D}{2} - \frac{2\pi^2}{\tilde{E}_C}\left(T+\frac{R_D}{R_S}V_{SD}\right)\right]\cos\left(\frac{2\pi V_{SD}}{E_C}+\phi\right), \quad (5)$$

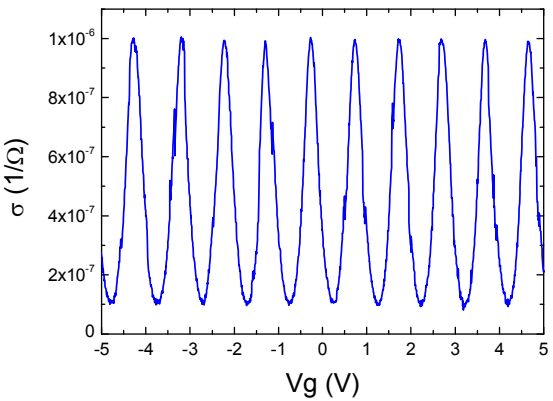
$$\epsilon = (V^2 + \tilde{T}^2)^{1/2}$$

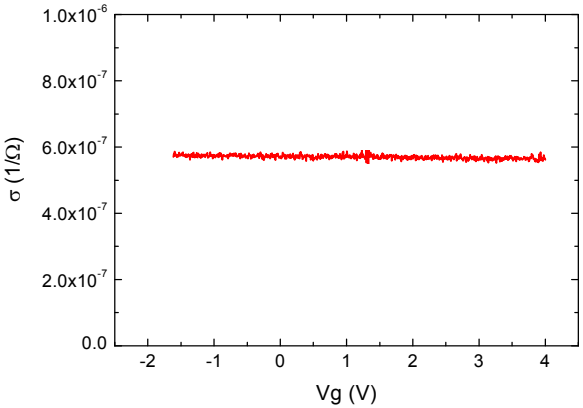


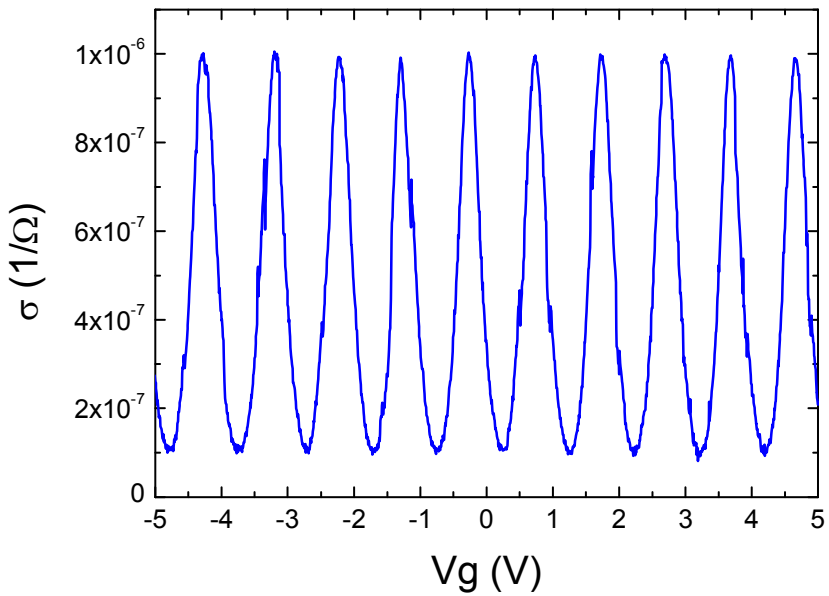

6.52nm

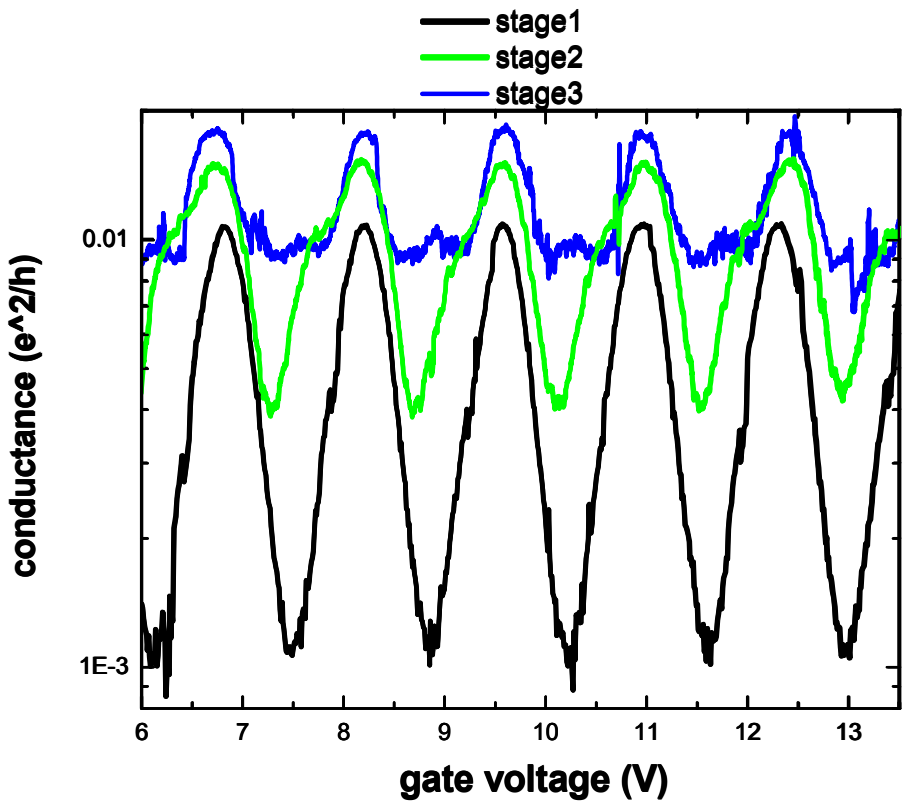

dI/dV normalized
V (mV)

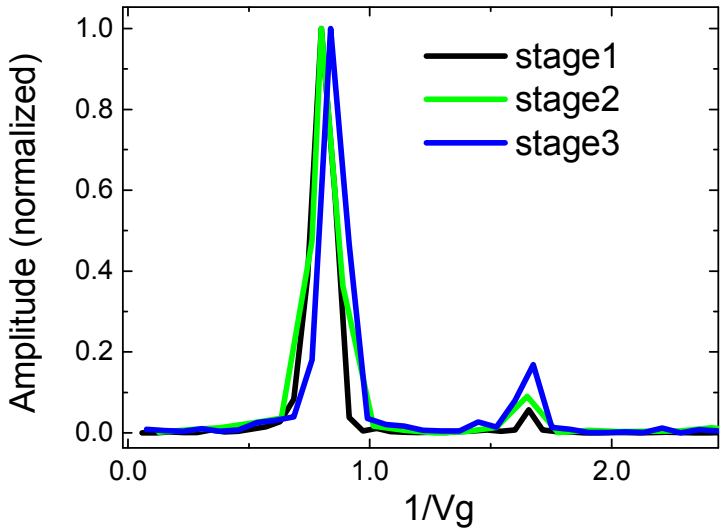

dI/dV normalized
V (mV)

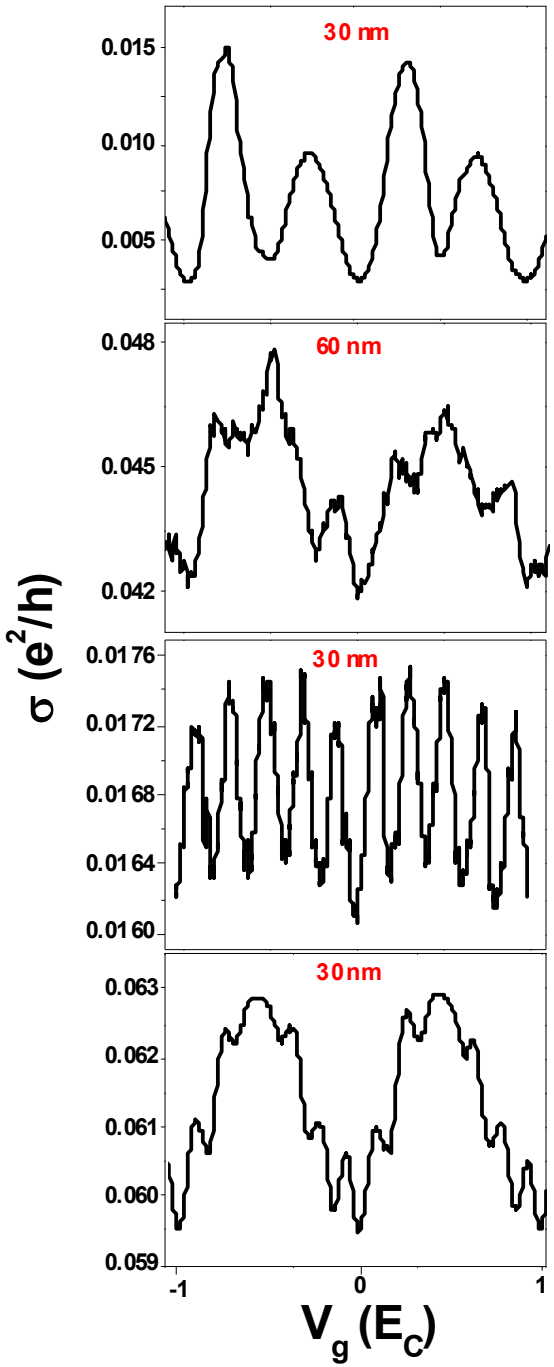

σ (1/Ω)
Vg (V)


σ (1/Ω)
Vg (V)

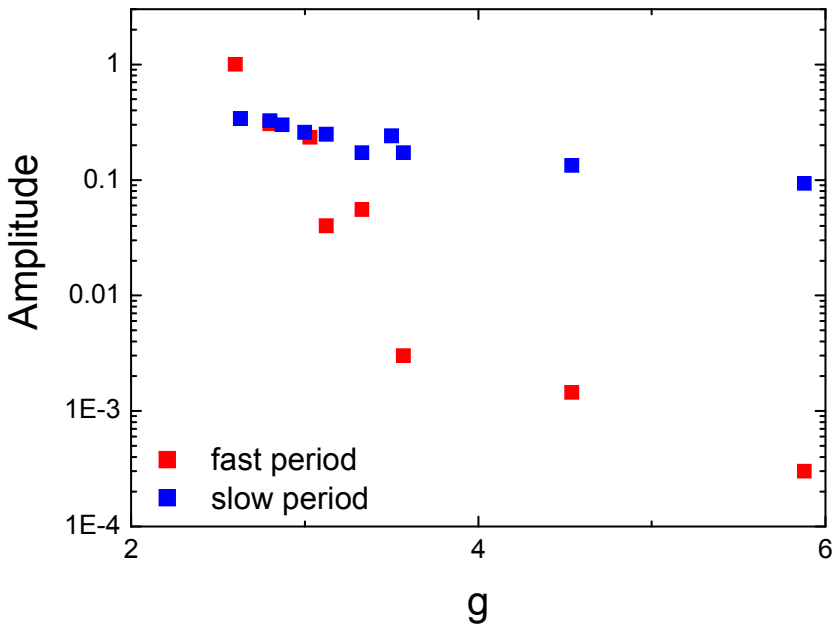

σ (1/Ω)
1x10^-6
8x10^-7
6x10^-7
4x10^-7
2x10^-7
0
-5
-4
-3
-2
-1
0
1
2
3
4
5
Vg (V)

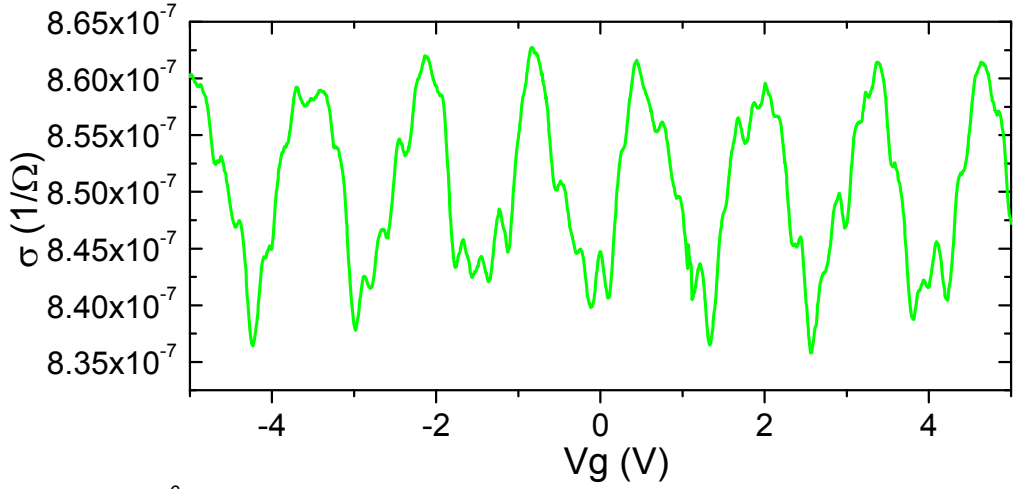

stage1
stage2
stage3
conductance (e^2/h)
0.01
1E-3
6
7
8
9
10
11
12
13
gate voltage (V)

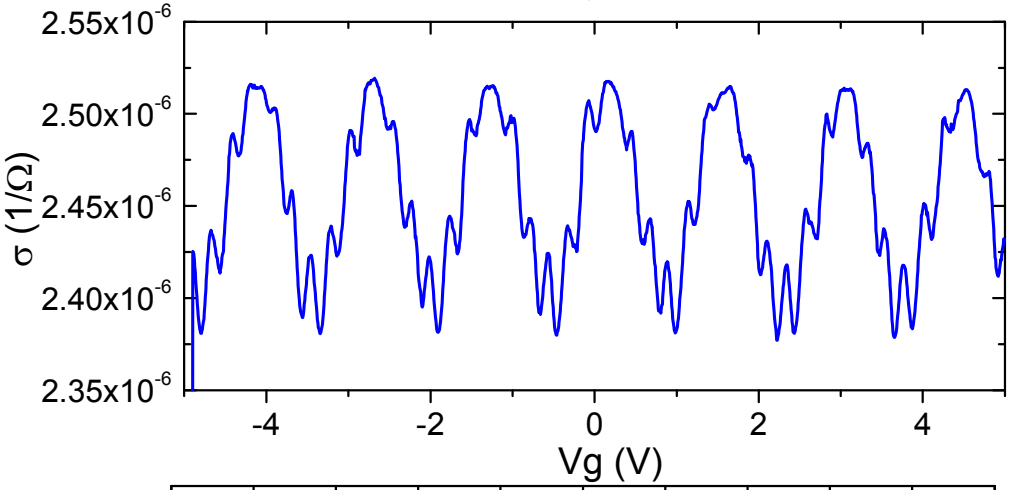

Amplitude (normalized)
1.0
0.8
0.6
0.4
0.2
0.0
stage1
stage2
stage3
0.0
1.0
2.0
1/Vg

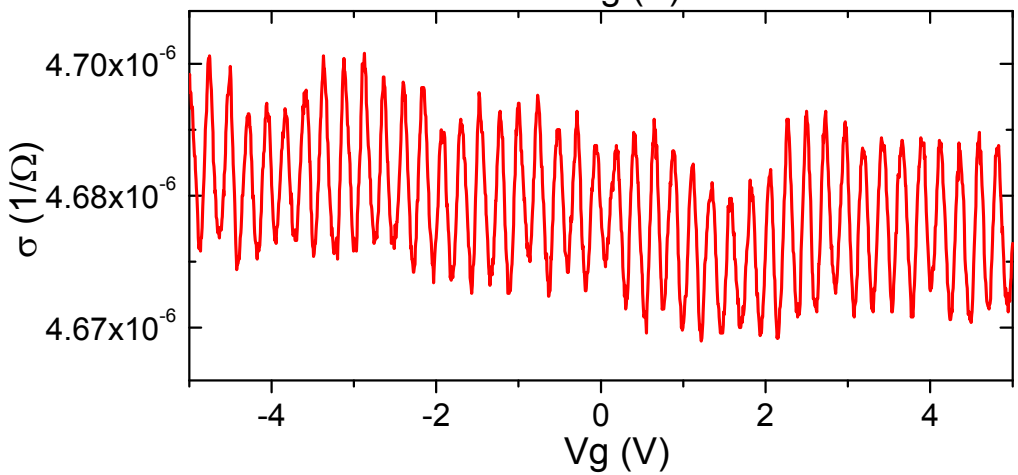

30 nm
0.015
0.010
0.005
60 nm
0.048
0.045
0.042
30 nm
0.0176
0.0172
0.0168
0.0164
0.0160
30nm
0.063
0.062
0.061
0.060
0.059
σ (e²/h)
-1
0
1
V_g (E_C)

Coupling dependence

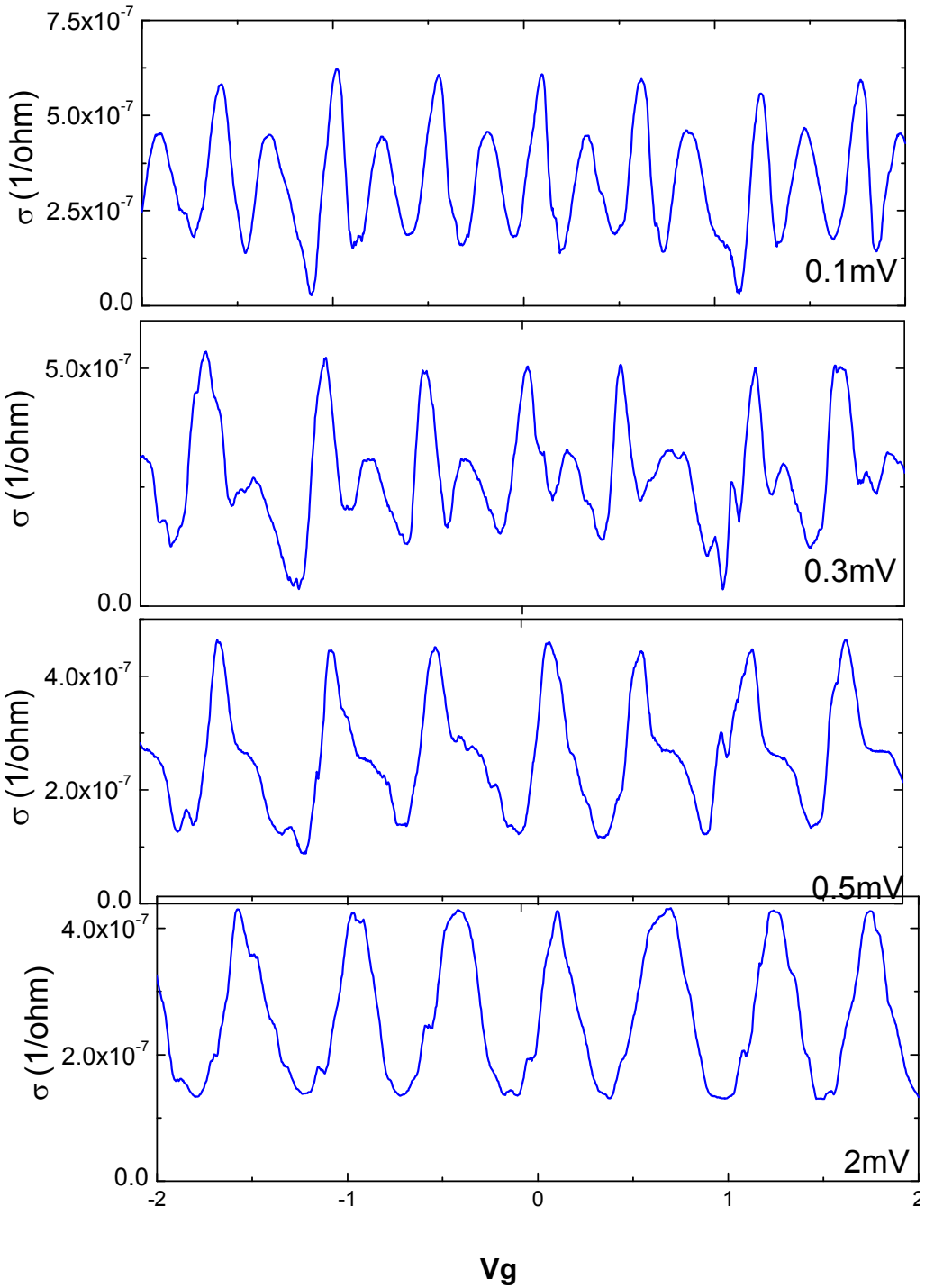


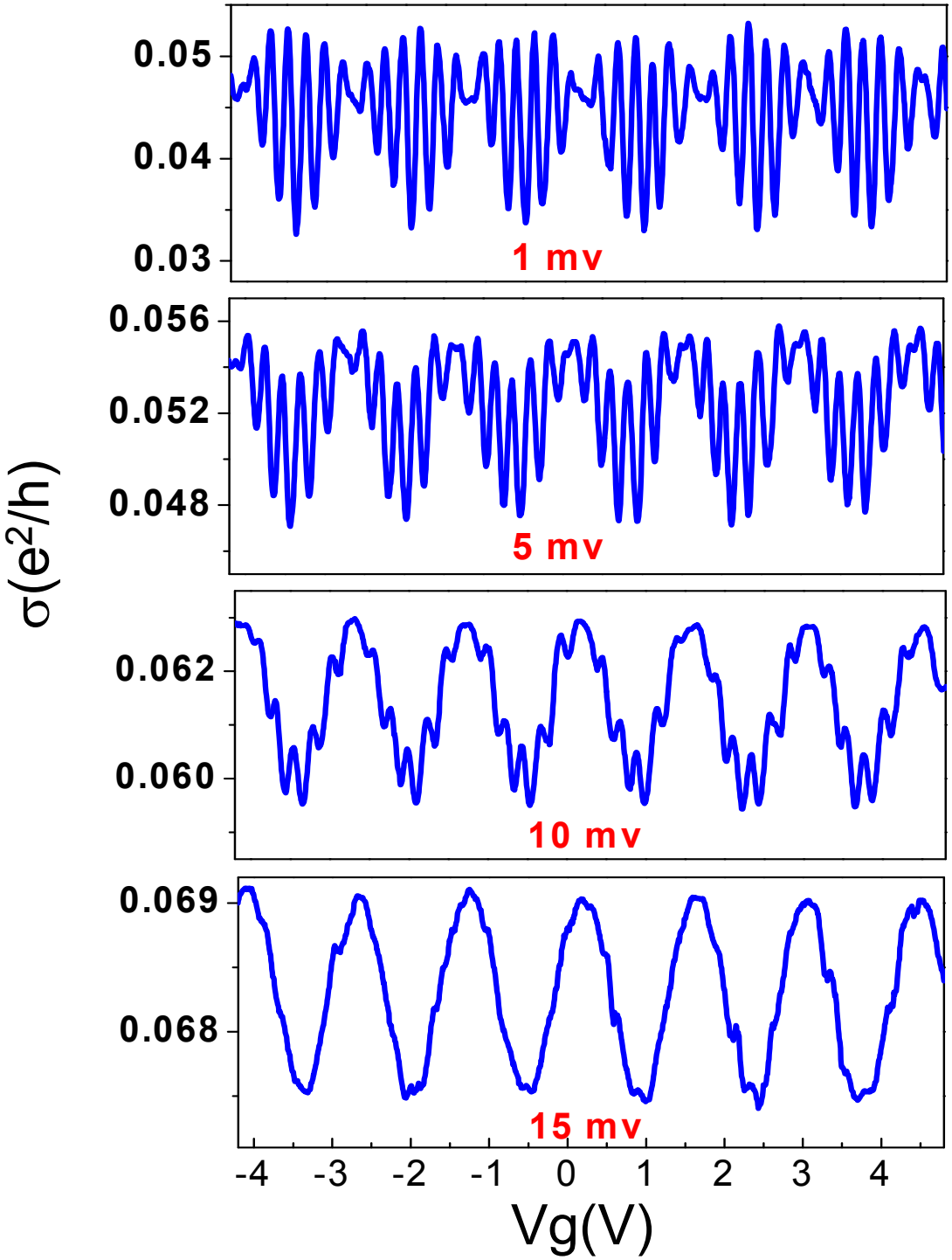


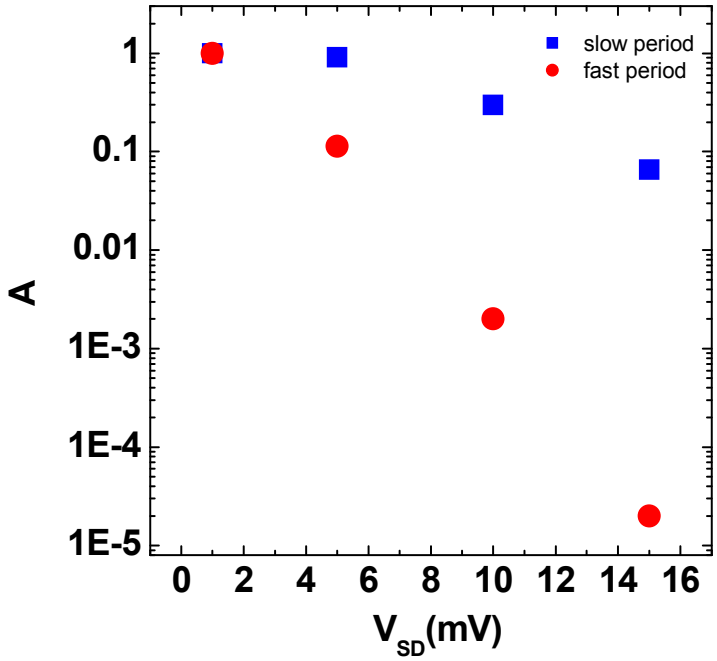




V_{SD} dependence

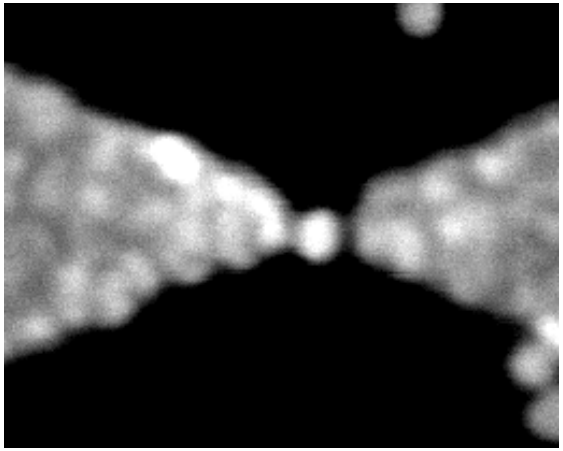



0.05
0.04
0.03
1 mv
0.056
0.052
0.048
5 mv
0.062
0.060
10 mv
0.069
0.068
15 mv
σ(e²/h)
-4
-3
-2
-1
0
1
2
3
4
Vg(V)


slow period
fast period
1
0.1
0.01
1E-3
1E-4
1E-5
A
0
2
4
6
8
10
12
14
16
V_SD(mV)

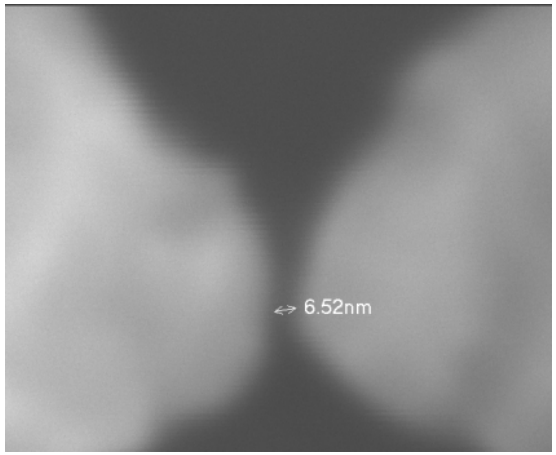
Two dots?

X



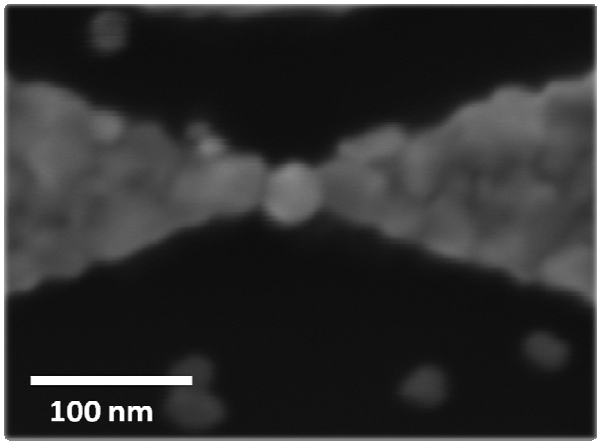
Weak coupling

X



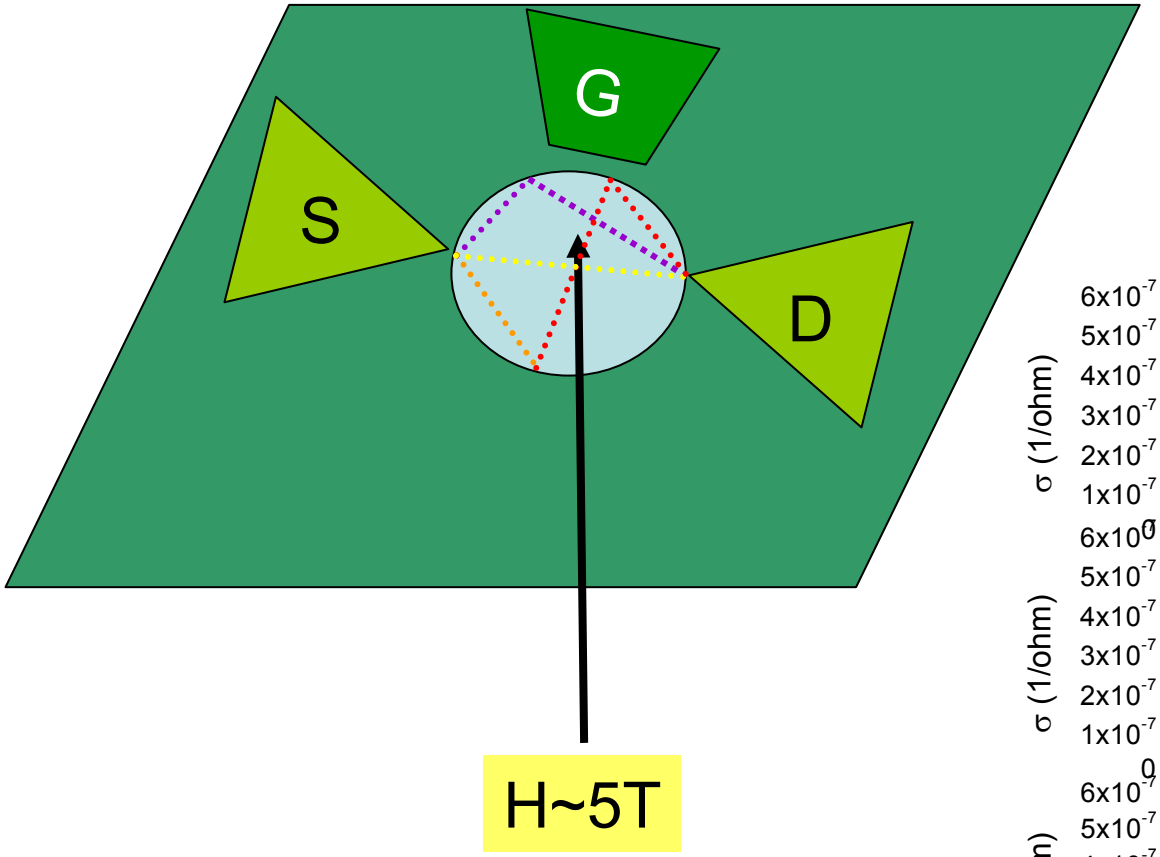
No particle

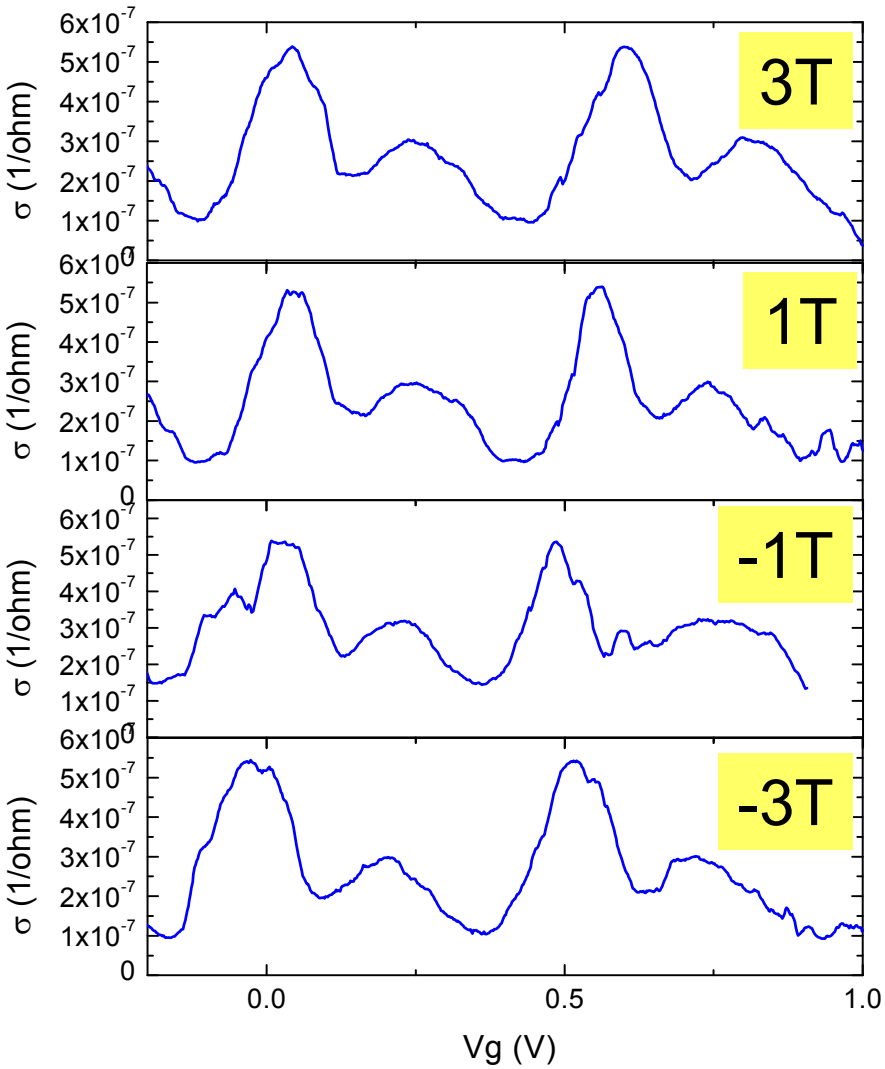
√



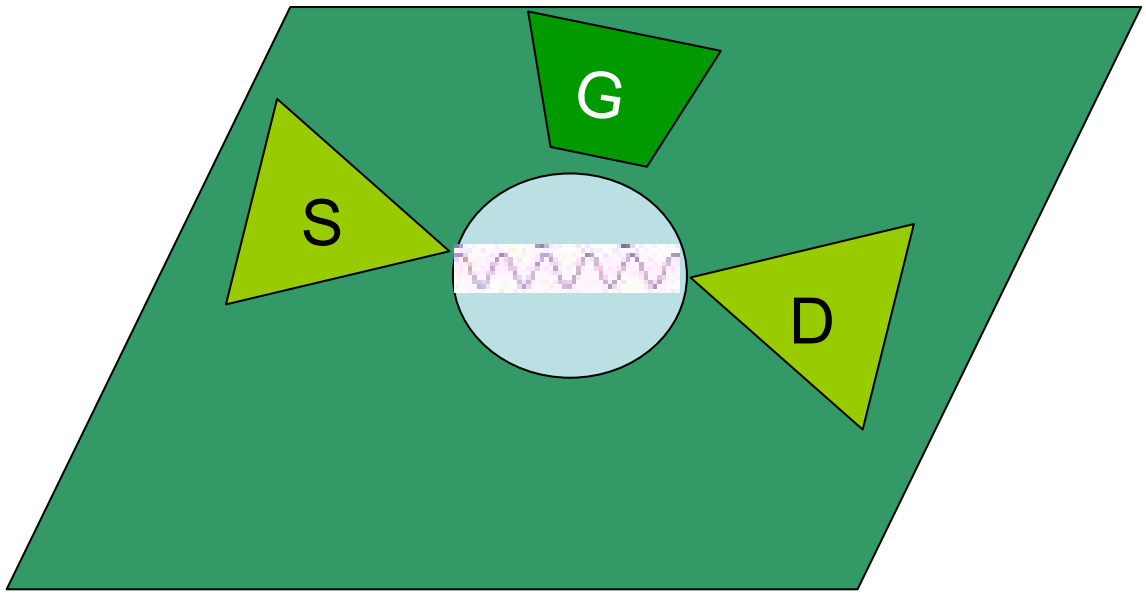
Strong coupling

Interference?

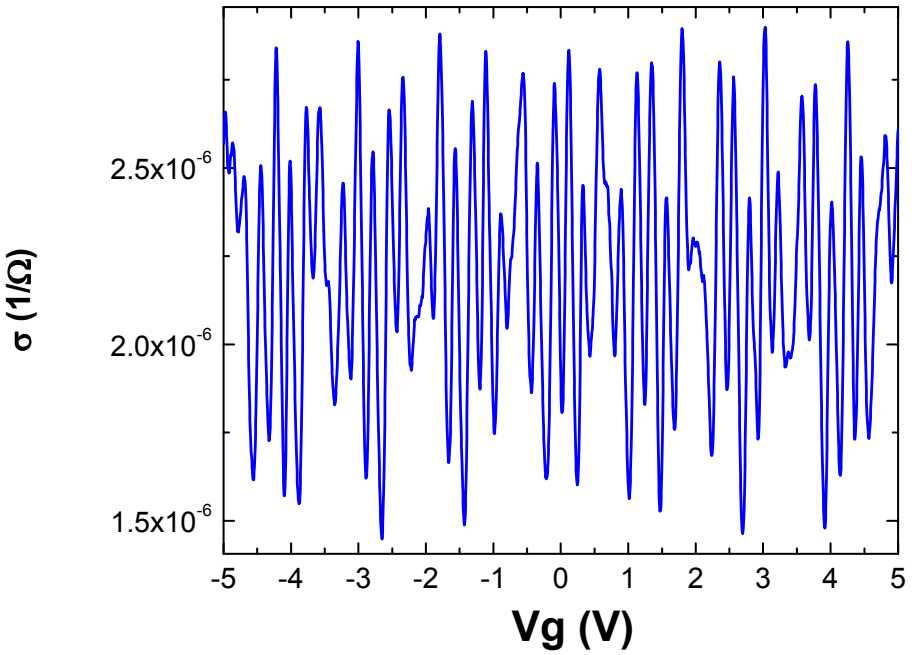


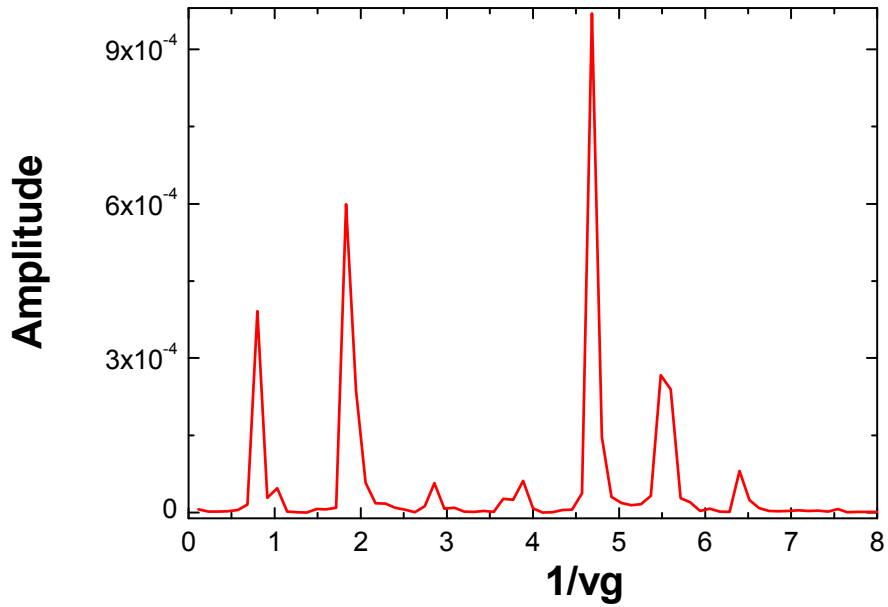


Single trajectory?

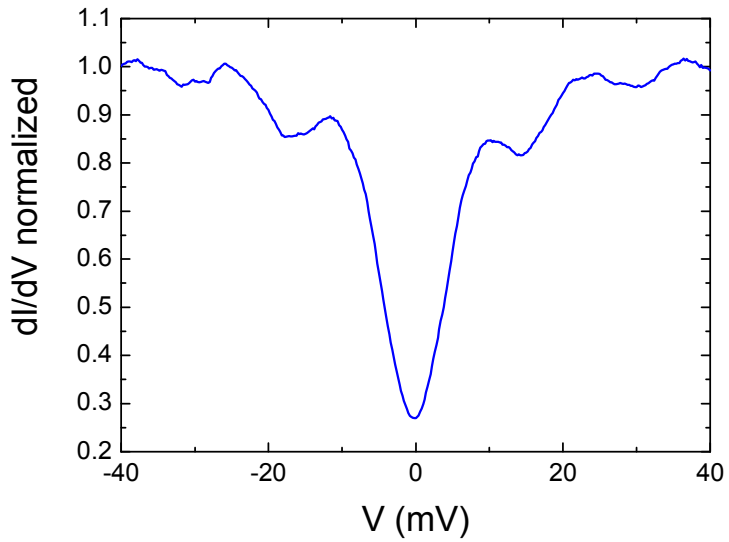


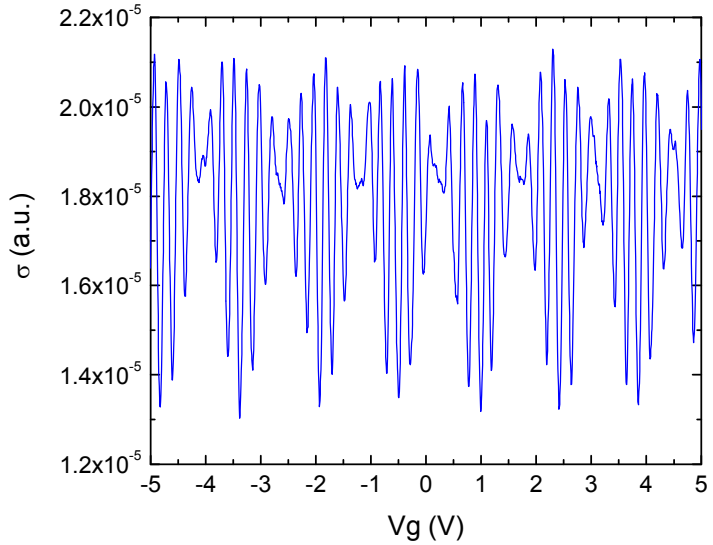
$$T \propto \cos(\frac{L}{\lambda_F})$$


σ (1/Ω)
2.5x10-6
2.0x10-6
1.5x10-6
-5
-4
-3
-2
-1
0
1
2
3
4
5
Vg (V)


Amplitude
9x10-4
6x10-4
3x10-4
0
0
1
2
3
4
5
6
7
8
1/vg

Summary





- **Coupling controlled quantum dots with strong coupling asymmetry have been produced.**
- **The I-V curves show an combination of ZBA and coulomb blockade effects**
- **For strong coupling two gate-voltage periods are observed: one (fast) dominant at low source-drain voltage and the other (slow) at high voltage.**
- **The gate voltage curves seam to combine coulomb blockade effects and an additional process which is very sensitive to the energy.**