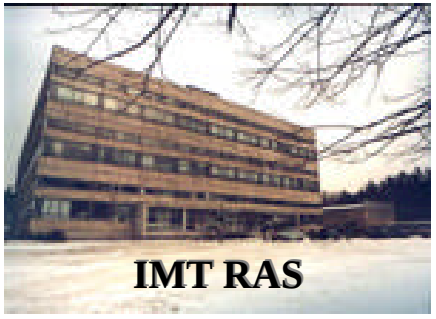
Institute of Microelectronics
Technology RAS,
Chernogolovka, Russia

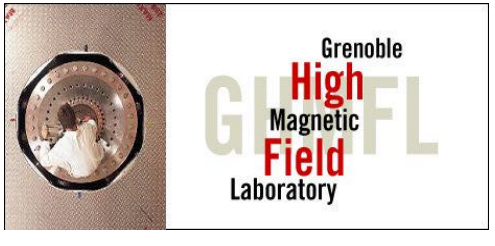
Influence of interlayer interaction on tunnelling between disordered two-dimensional electron systems



Yu.V. Dubrovskii
E.E. Vdovin

V.A.Volkov

L. Eaves
P.C. Main
O.N. Makarovskii
M. Henini



J.-C. Portal

G. Hill

Outline of the talk

1. Short history about our studies of the tunnelling between between disordered 2DES –tunnelling gap formation with magnetic field.

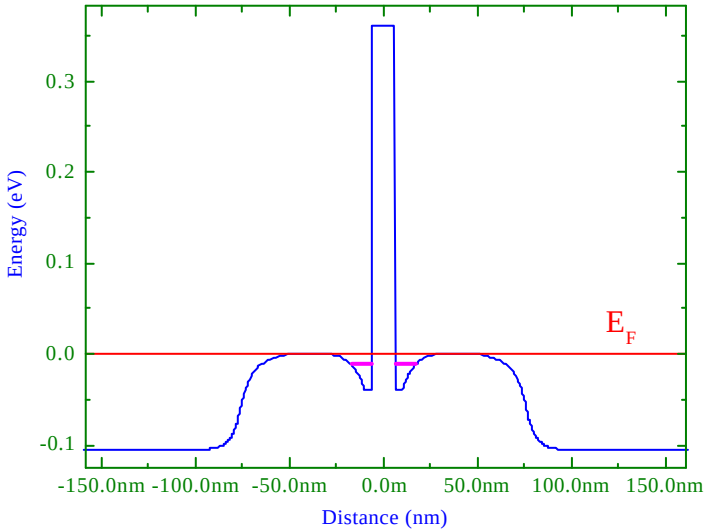
2. Tunnelling between disordered 2DES with small interlayer spacing: experiment. Observation of the enhanced near equilibrium tunnelling conductance (zero bias conductance resonance)

3. Discussions:

   a) Do the found features have relations with Kondo physics?

   b) It is difficult for magnetic field to form tunnelling gap in samples with zero bias conductance resonance

4. Conclusion.

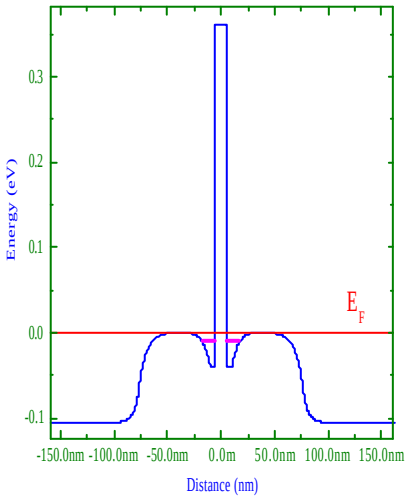


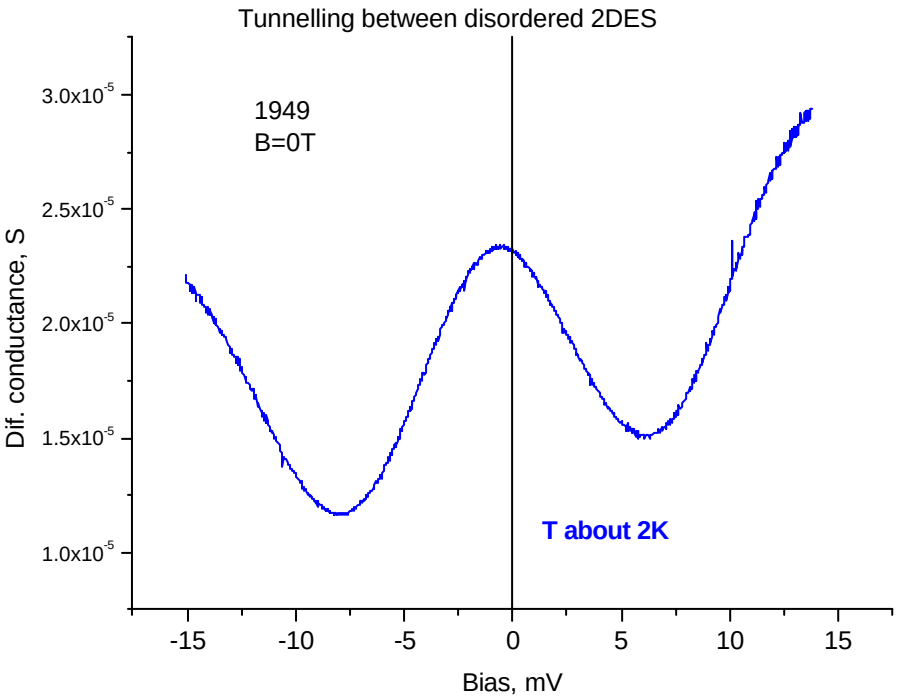
1. 2DES by Si d -doping

$$N_{2D} = 3 \cdot 10^{11} cm^{-2}$$

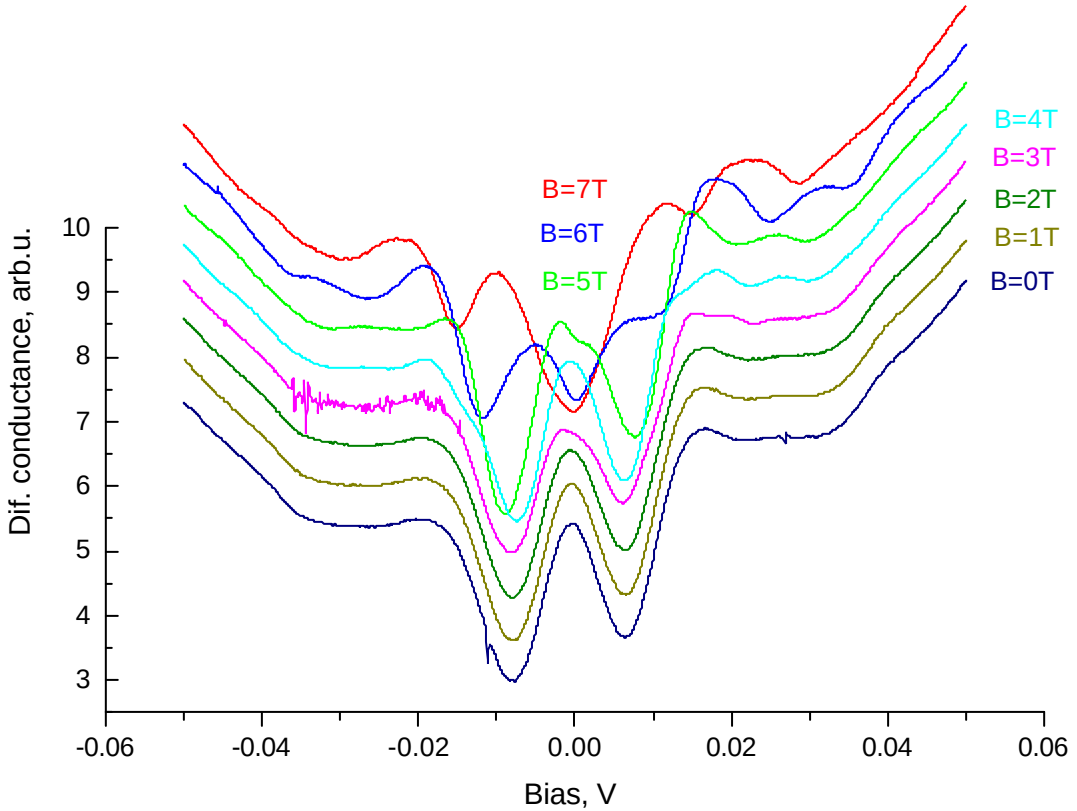
2. In our experiments, electron transport along the layers does not contribute to the measured current which flows perpendicular to the plane of the barrier.

B=0

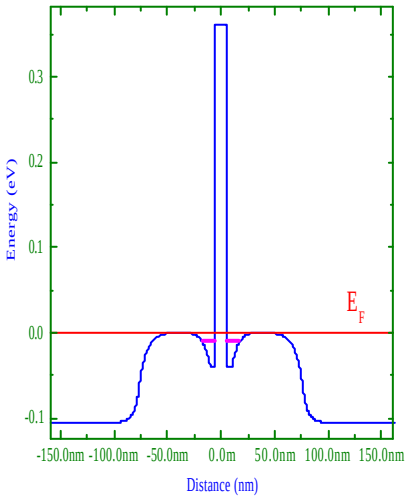

Energy (eV)
0.3
0.2
0.1
0.0
-0.1
E_F
-150.0nm -100.0nm -50.0nm 0.0m 50.0nm 100.0nm 150.0nm
Distance (nm)

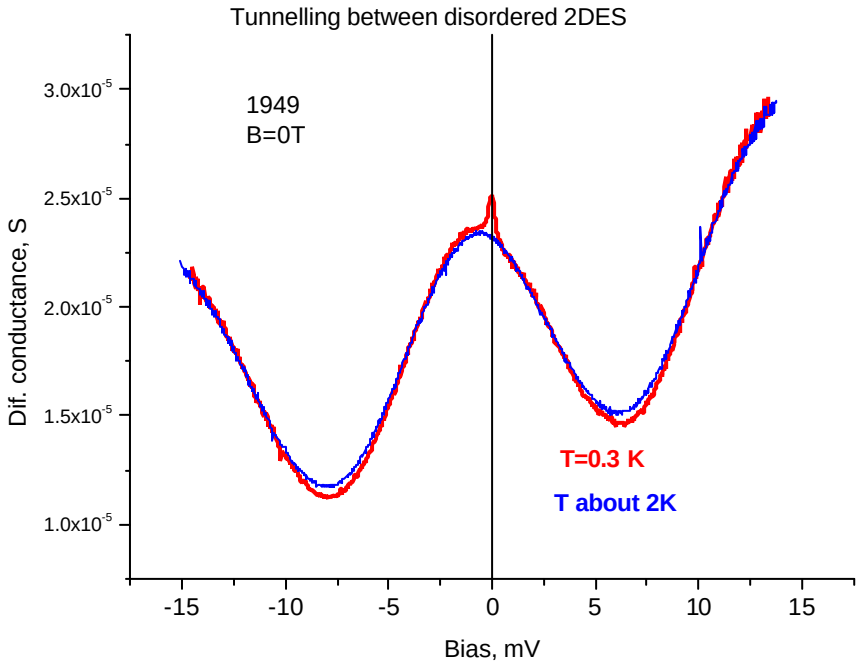

Tunnelling between disordered 2DES
1949
B=0T
T about 2K
Dif. conductance, S
3.0x10^-5
2.5x10^-5
2.0x10^-5
1.5x10^-5
1.0x10^-5
-15
-10
-5
0
5
10
15
Bias, mV

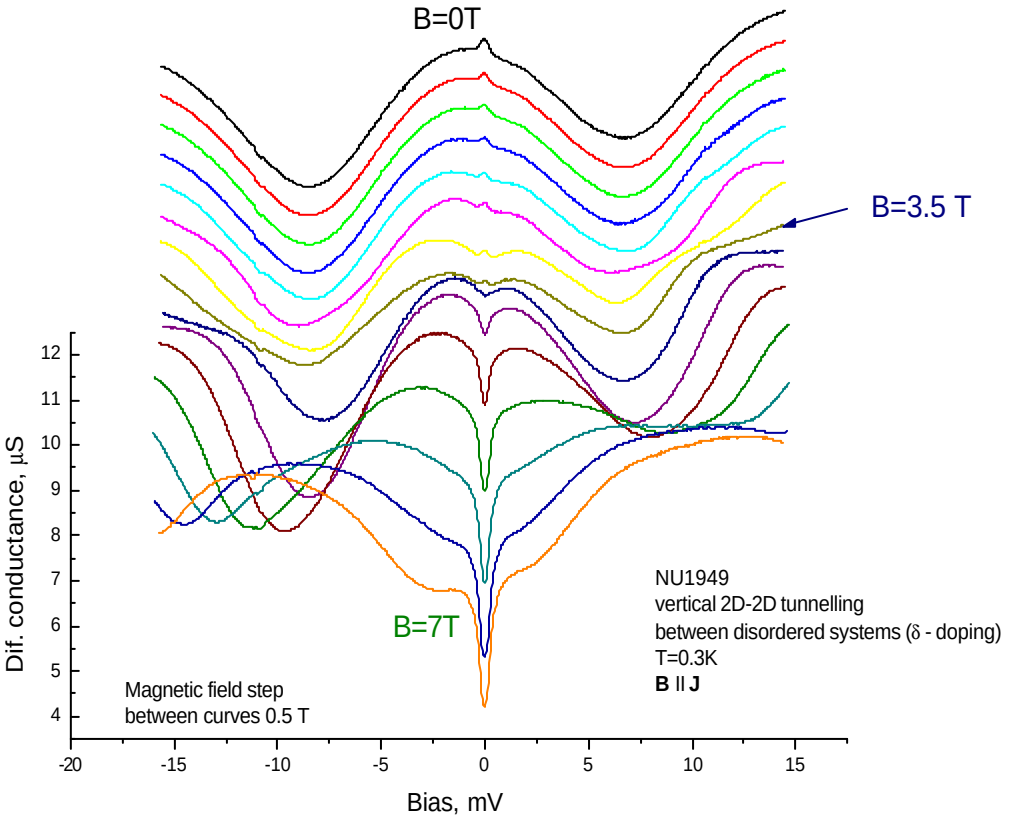
$$D(\varepsilon,B)=c\,(B)+\alpha(B)*|\varepsilon-\varepsilon_F|$$

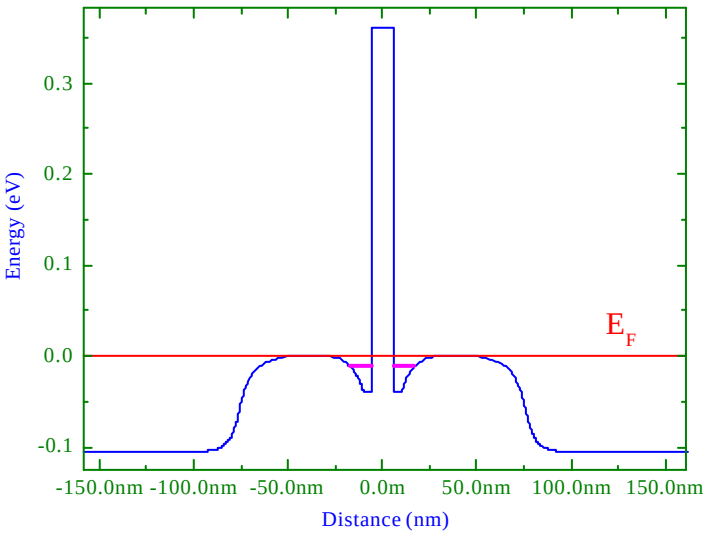


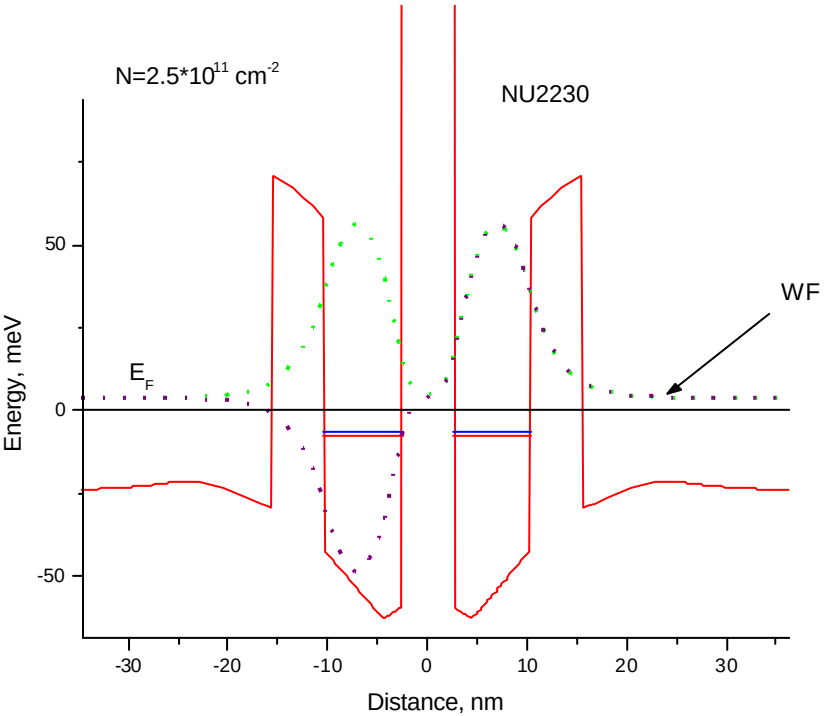
B=0

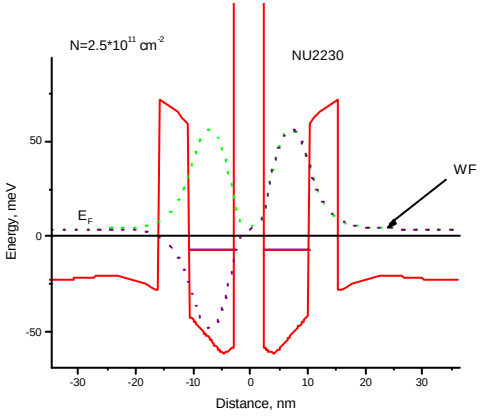

Energy (eV)
0.3
0.2
0.1
0.0
-0.1
E_F
-150.0nm -100.0nm -50.0nm 0.0m 50.0nm 100.0nm 150.0nm
Distance (nm)

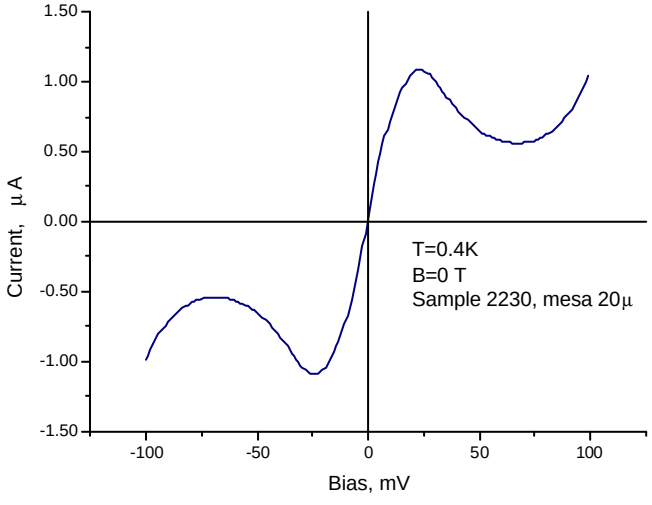

Tunnelling between disordered 2DES
1949
B=0T
T=0.3 K
T about 2K
Dif. conductance, S
3.0x10-5
2.5x10-5
2.0x10-5
1.5x10-5
1.0x10-5
-15
-10
-5
0
5
10
15
Bias, mV

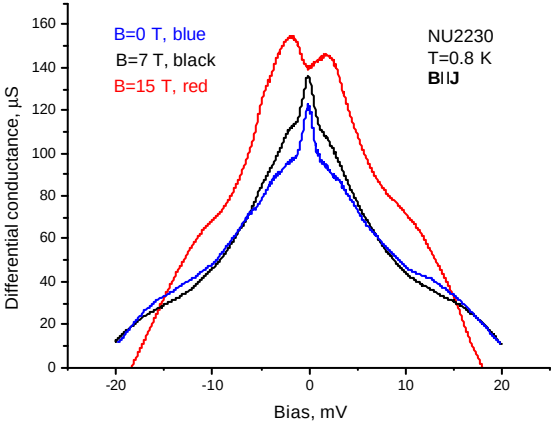

B=0T
B=3.5 T
B=7T
Dif. conductance, μS
Bias, mV
Magnetic field step
between curves 0.5 T
NU1949
vertical 2D-2D tunnelling
between disordered systems (δ - doping)
T=0.3K
B ll J

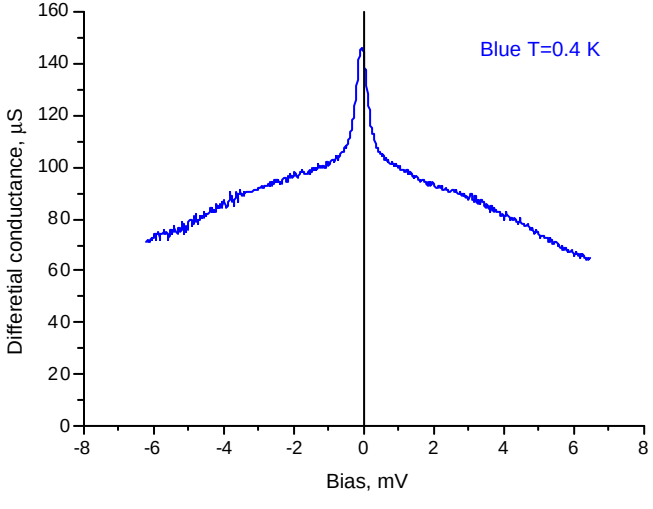

Energy (eV)
0.3
0.2
0.1
0.0
-0.1
E_F
-150.0nm -100.0nm -50.0nm 0.0m 50.0nm 100.0nm 150.0nm
Distance (nm)

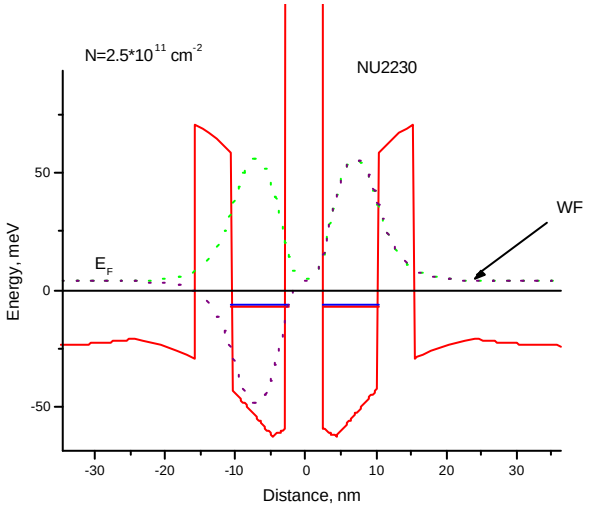

N=2.5*10^11 cm^-2
NU2230
WF
E_F
Energy, meV
50
0
-50
-30 -20 -10 0 10 20 30
Distance, nm

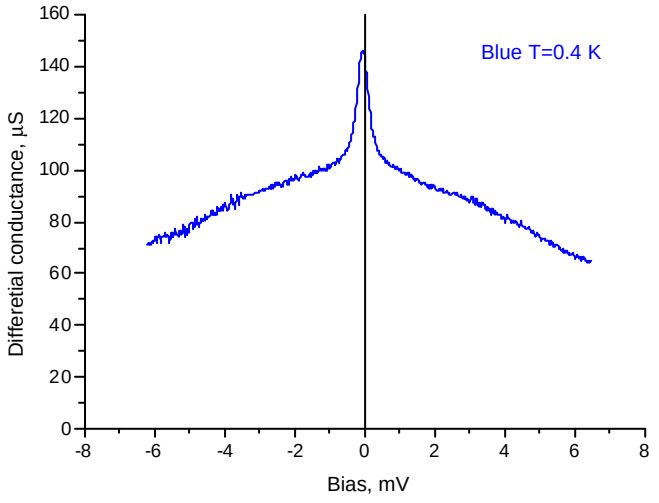

N=2.5*10^11 cm^-2
NU2230
WF
E_F
Energy, meV
Distance, nm

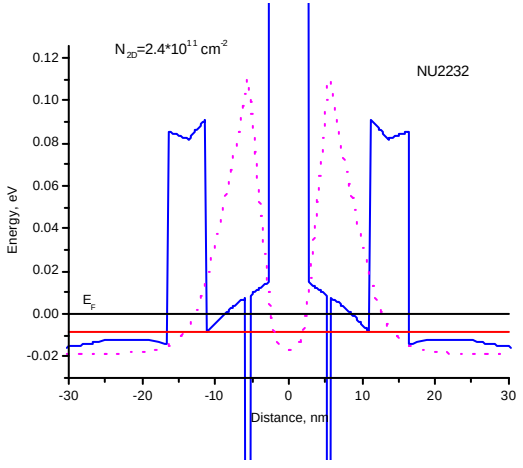

Current, μA
Bias, mV
T=0.4K
B=0 T
Sample 2230, mesa 20μ

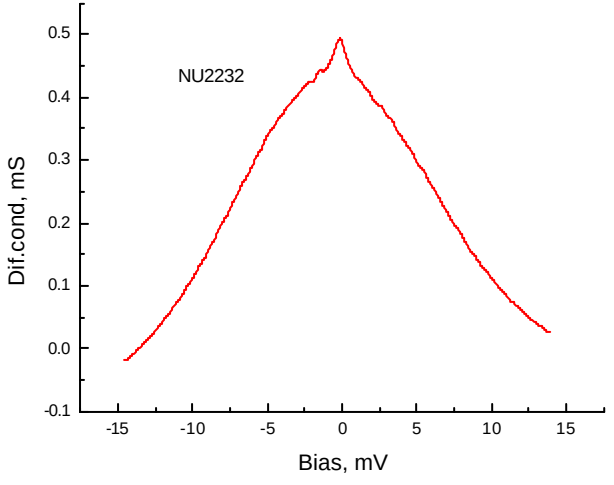

B=0 T, blue
B=7 T, black
B=15 T, red
NU2230
T=0.8 K
B||J
Differential conductance, μS
Bias, mV

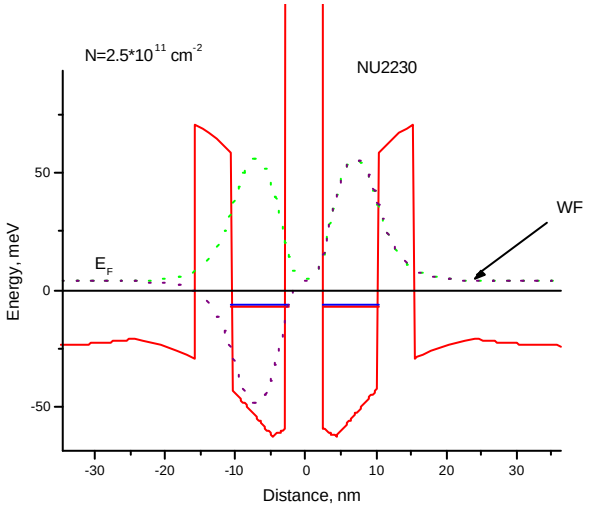

Blue T=0.4 K
Differetial conductance, μS
Bias, mV

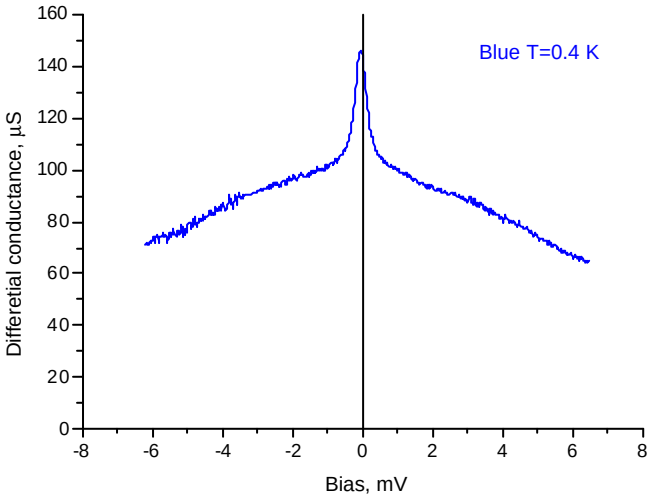

N=2.5*10^11 cm^-2
NU2230
WF
E_F
Energy, meV
Distance, nm

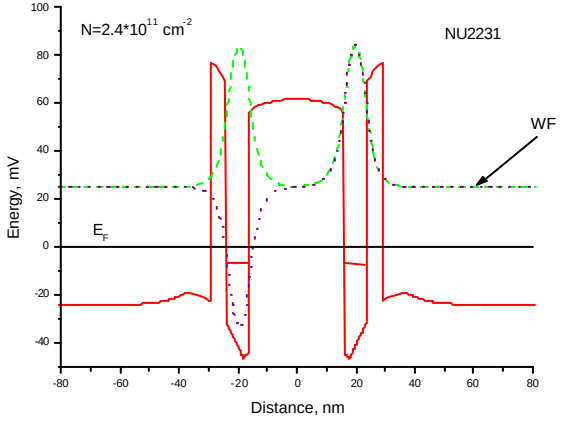

Blue T=0.4 K
Differetial conductance, µS
Bias, mV

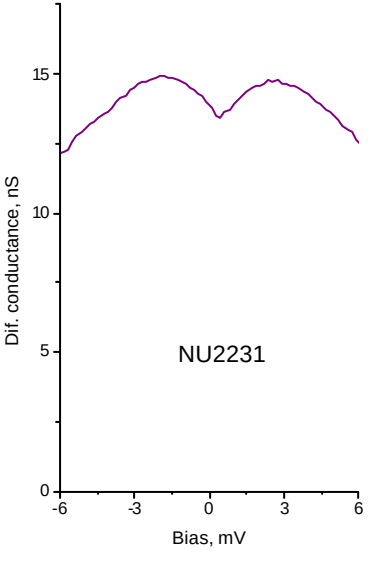

N_2D=2.4*10^11 cm^-2
NU2232
E_F
Energy, eV
Distance, nm

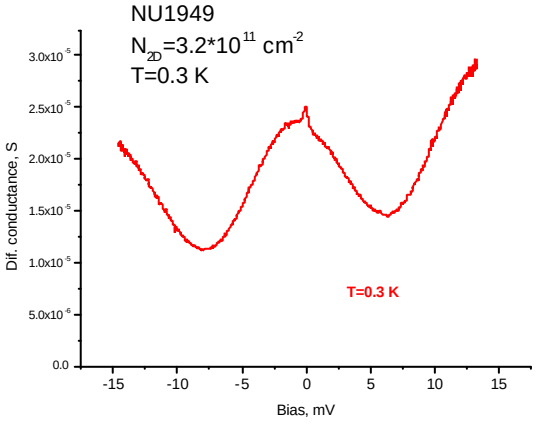

NU2232
Dif.cond, mS
Bias, mV

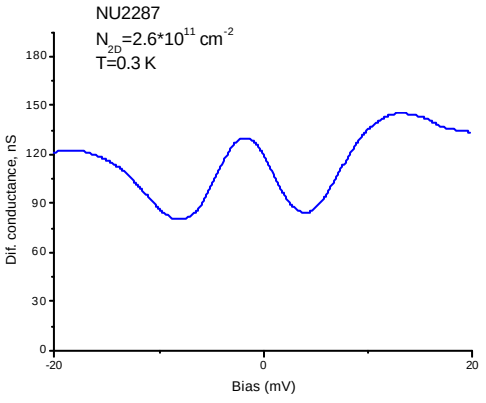

N=2.5*10^11 cm^-2
NU2230
WF
E_F
Energy, meV
Distance, nm

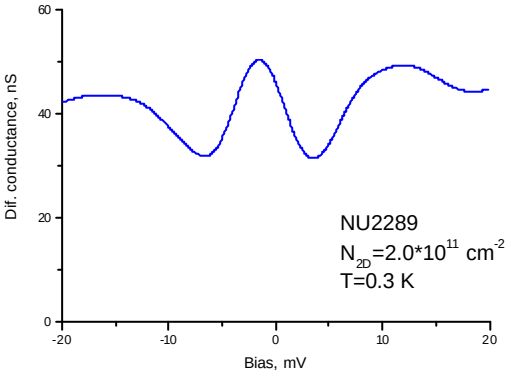

Blue T=0.4 K
Differetial conductance, µS
Bias, mV

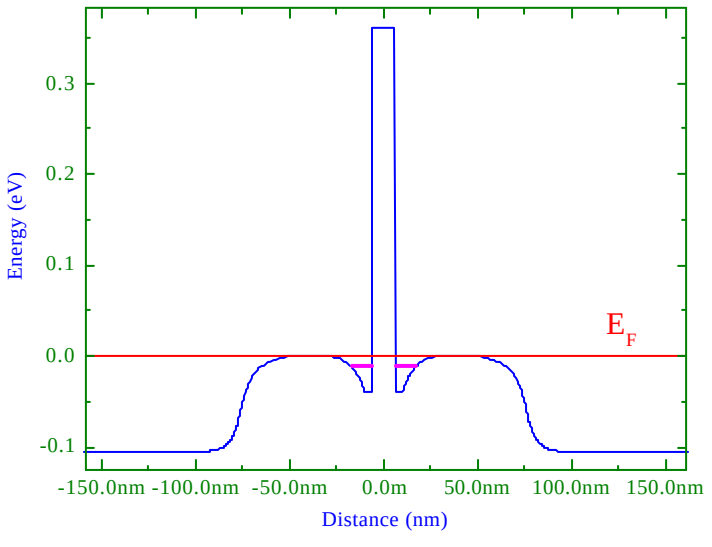

N=2.4*10^11 cm^-2
NU2231
WF
E_F
Energy, mV
Distance, nm


Dif. conductance, nS
NU2231
Bias, mV

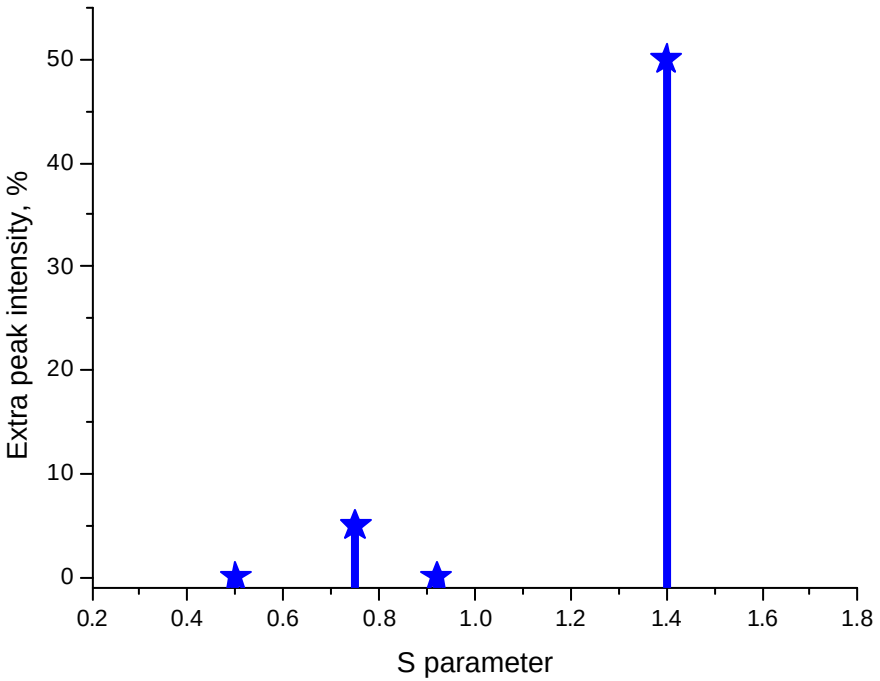

NU1949
N2D=3.2*10^11 cm^-2
T=0.3 K
T=0.3 K
Dif. conductance, S
Bias, mV


NU2287
N2D=2.6*10^11 cm^-2
T=0.3 K
Dif. conductance, nS
Bias (mV)

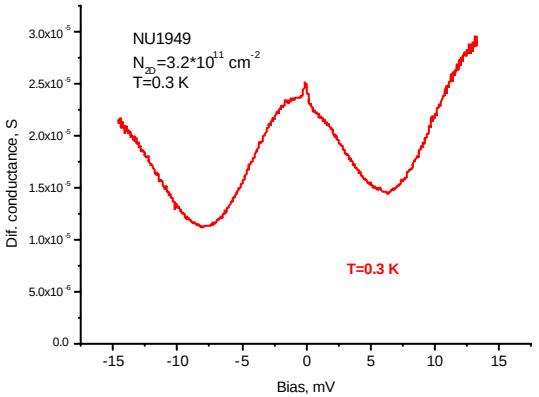

NU2289
N2D=2.0*10^11 cm^-2
T=0.3 K
Dif. conductance, nS
Bias, mV

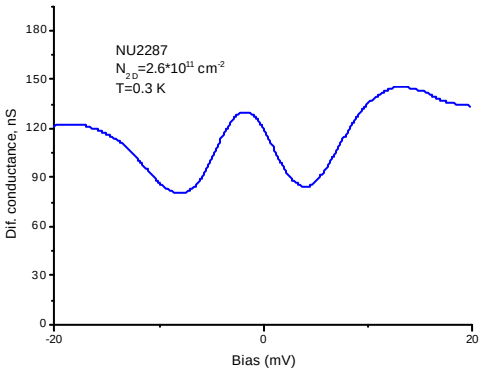

Energy (eV)
EF
Distance (nm)

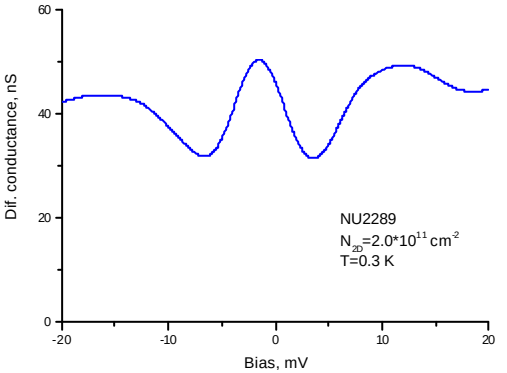
$$S = \left(\frac{e^2}{D^*} \right) \left(e^2 \sqrt{N_e} \right)^{-1}$$

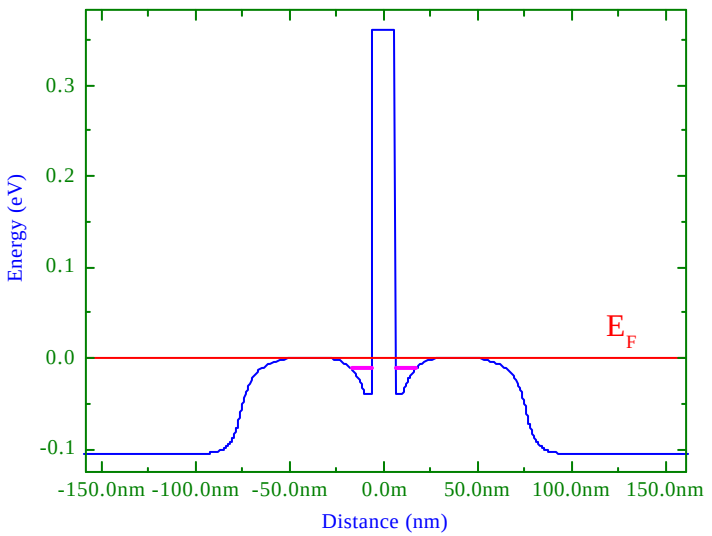


Mobility

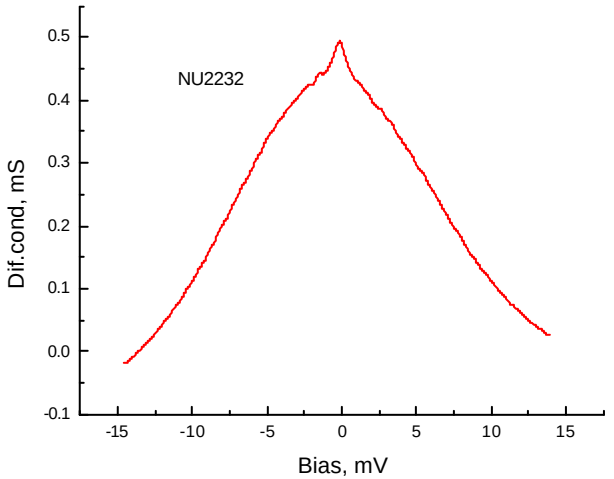

NU1949
N2D=3.2*10^11 cm^-2
T=0.3 K
T=0.3 K
Dif. conductance, S
Bias, mV

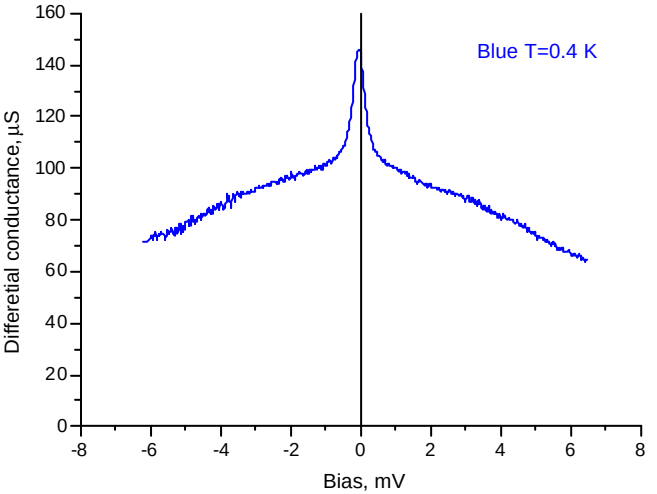

NU2287
N2D=2.6*10^11 cm^-2
T=0.3 K
Dif. conductance, nS
Bias (mV)

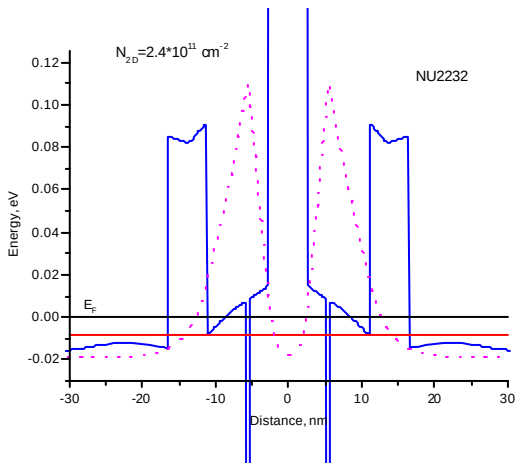

NU2289
N2D=2.0*10^11 cm^-2
T=0.3 K
Dif. conductance, nS
Bias, mV

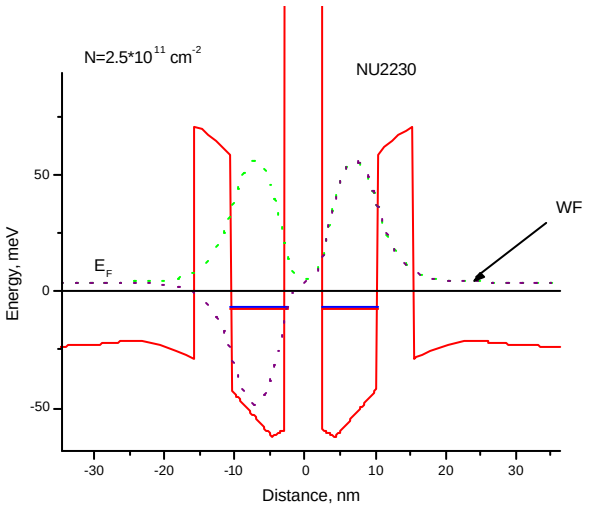

Energy (eV)
E_F
Distance (nm)

Mobility

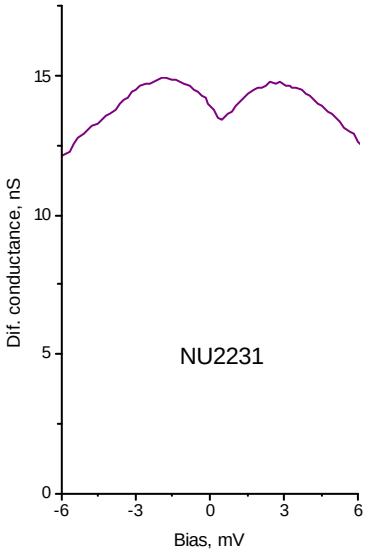

NU2232
Dif.cond, mS
Bias, mV

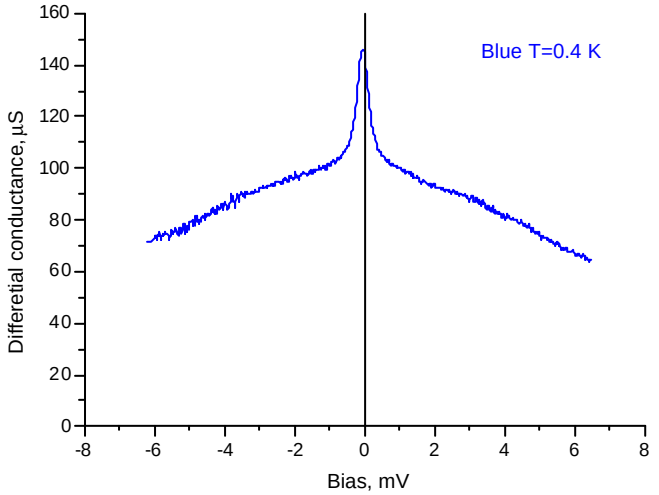

Blue T=0.4 K
Differetial conductance, µS
Bias, mV

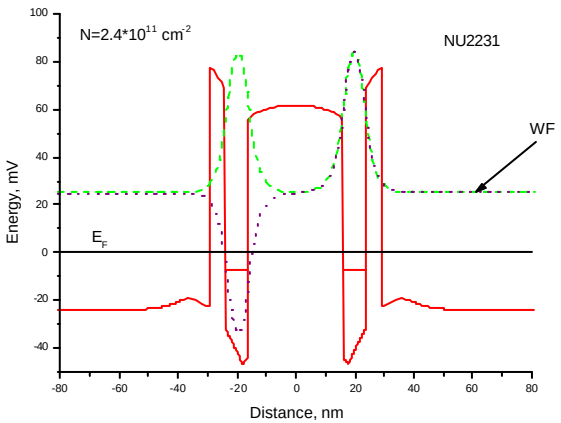

N_2D=2.4*10^11 cm^-2
NU2232
Energy, eV
E_F
Distance, nm

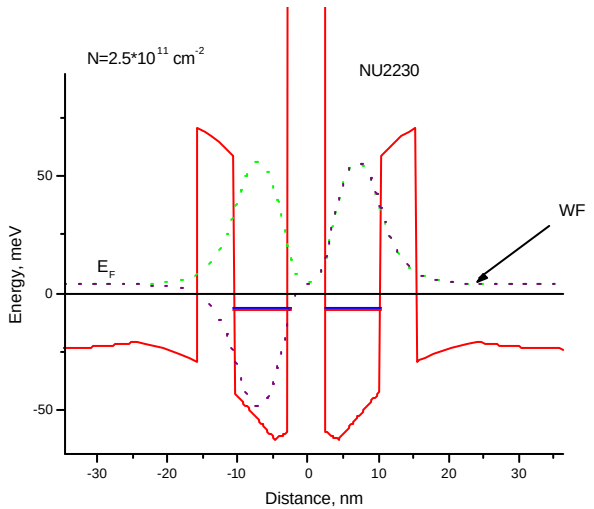

N=2.5*10^11 cm^-2
NU2230
WF
E_F
Energy, meV
Distance, nm

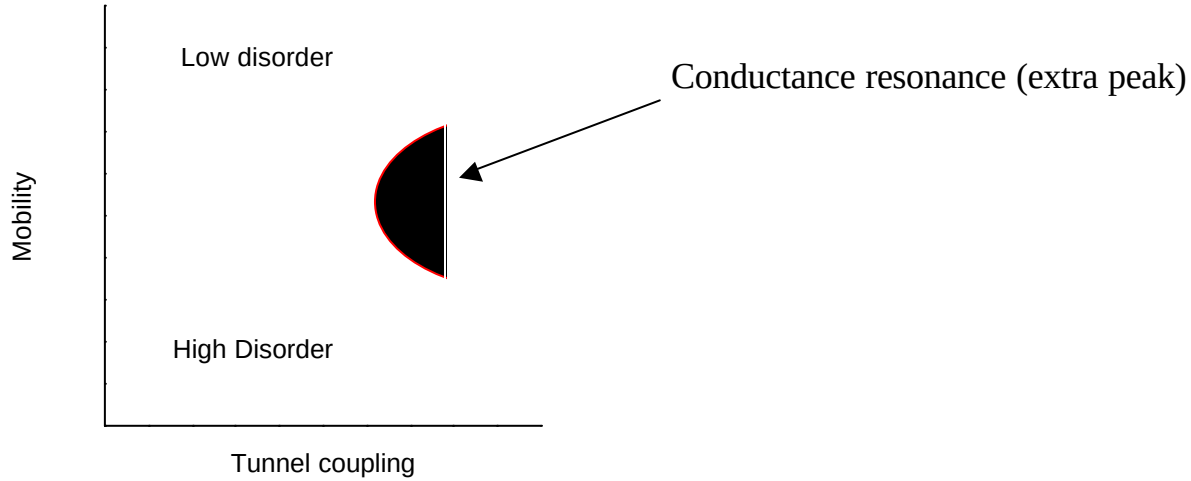
Tunnel coupling

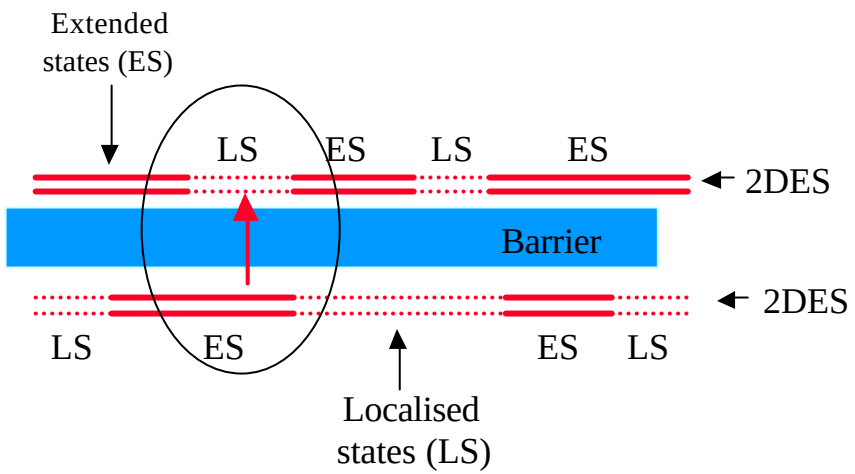


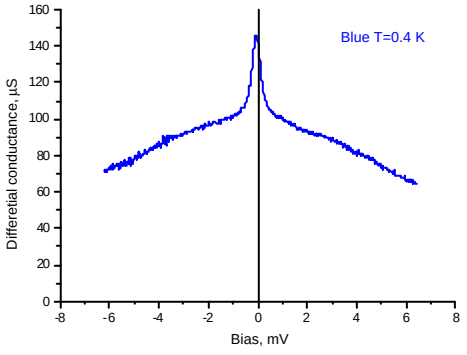


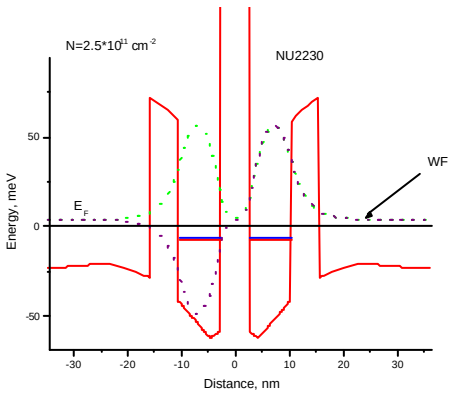


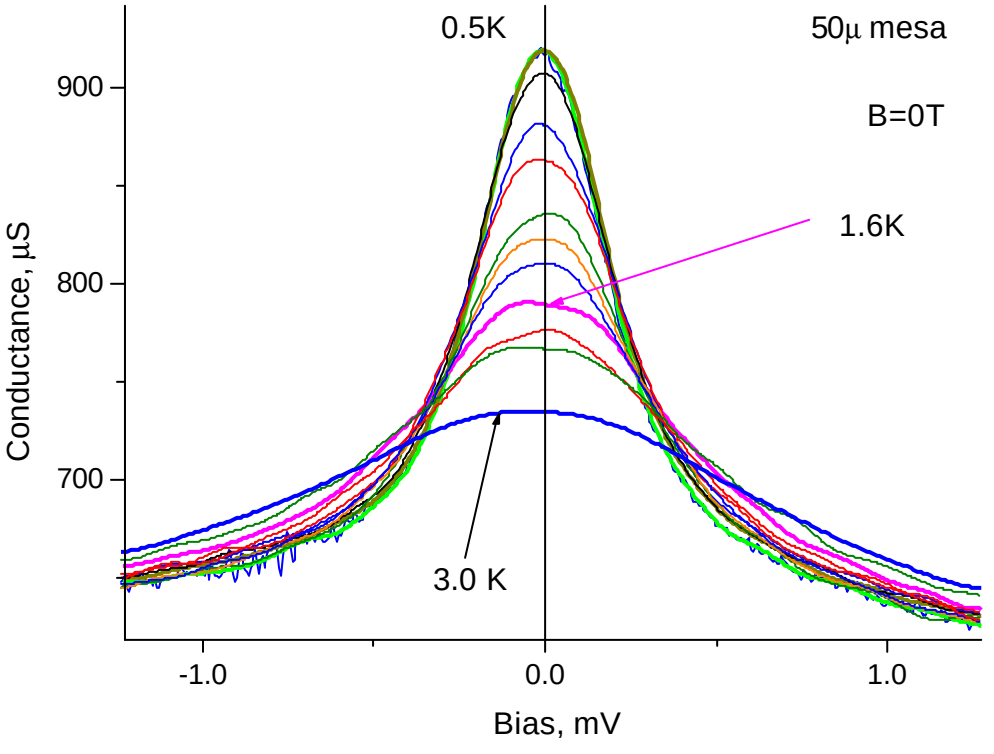


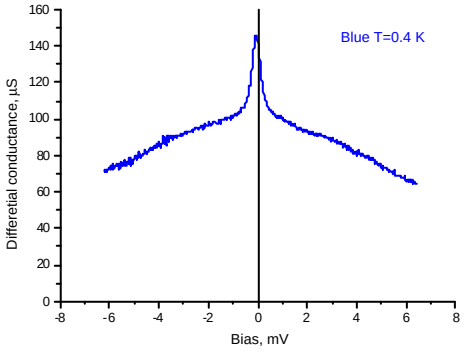

Low disorder
Conductance resonance (extra peak)
Mobility
High Disorder
Tunnel coupling

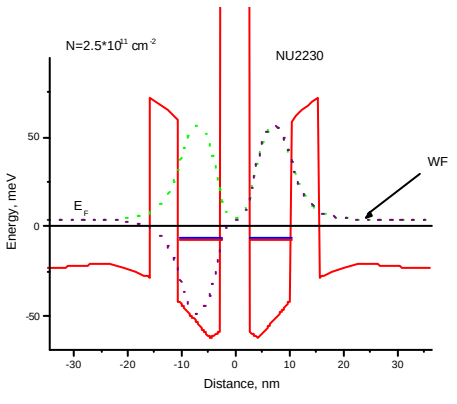

Extended
states (ES)
LS
ES
LS
ES
2DES
Barrier
2DES
LS
ES
ES
LS
Localised
states (LS)

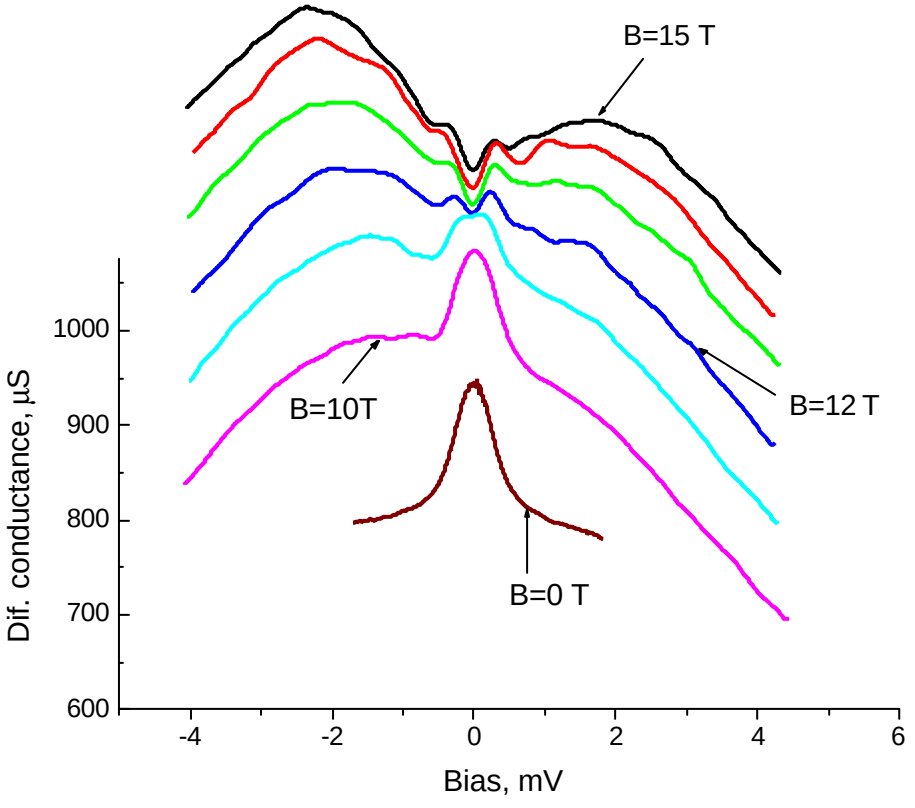

Blue T=0.4 K
Differetial conductance, μS
Bias, mV

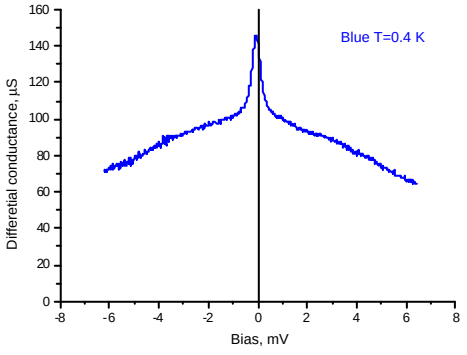

N=2.5*10^11 cm^-2
NU2230
WF
E_F
Energy, meV
Distance, nm

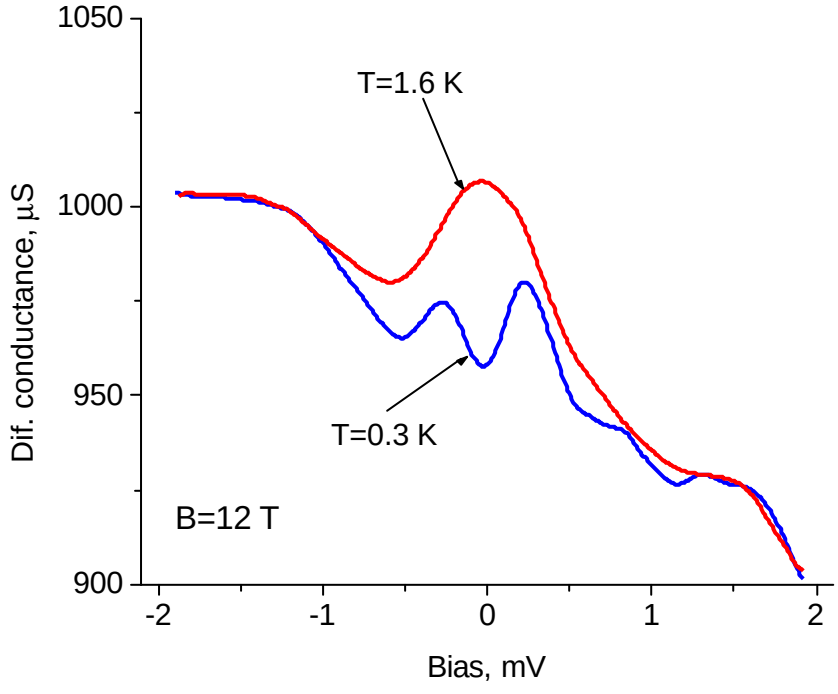

0.5K
50μ mesa
B=0T
1.6K
3.0 K
Conductance, μS
Bias, mV

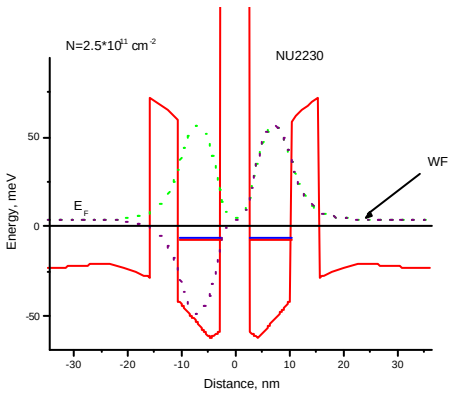

Blue T=0.4 K
Differetial conductance, μS
Bias, mV

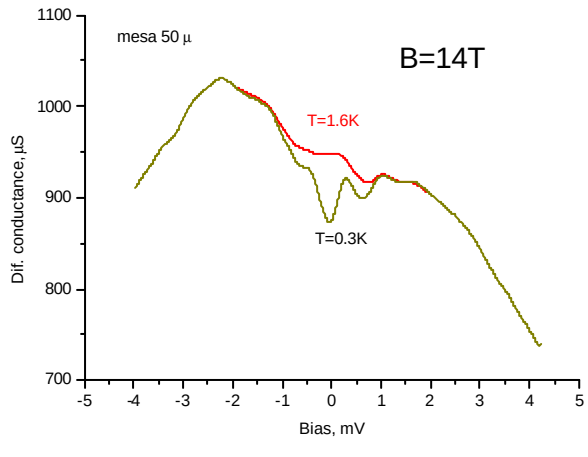

N=2.5*10^11 cm^-2
NU2230
WF
E_F
Energy, meV
Distance, nm

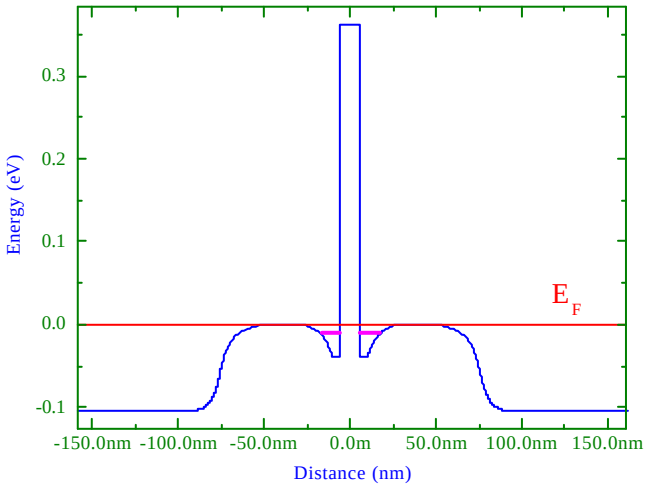

B=15 T
B=12 T
B=10T
B=0 T
Dif. conductance, μS
Bias, mV

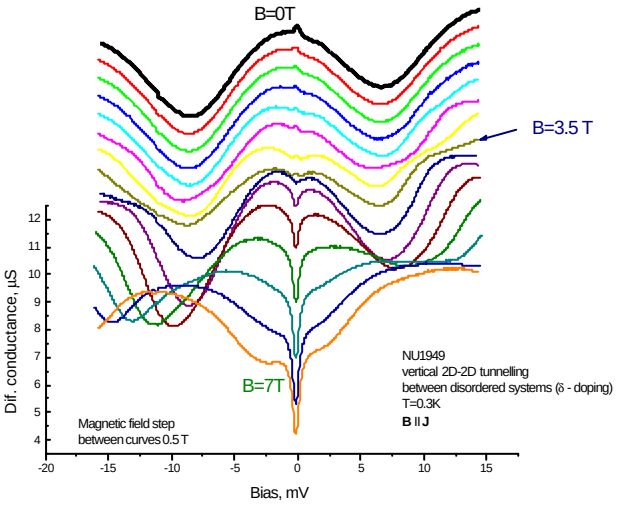

Blue T=0.4 K
Differetial conductance, µS
Bias, mV

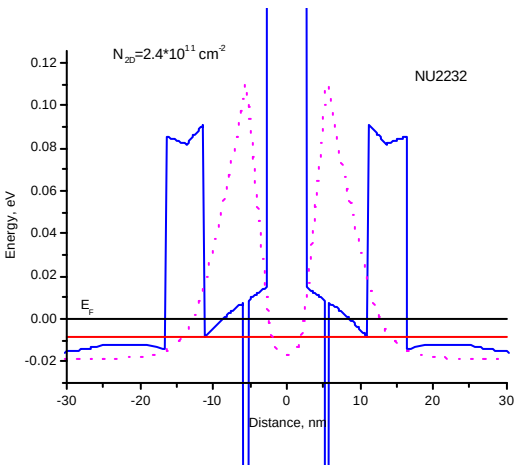

T=1.6 K
T=0.3 K
B=12 T
Dif. conductance, µS
Bias, mV

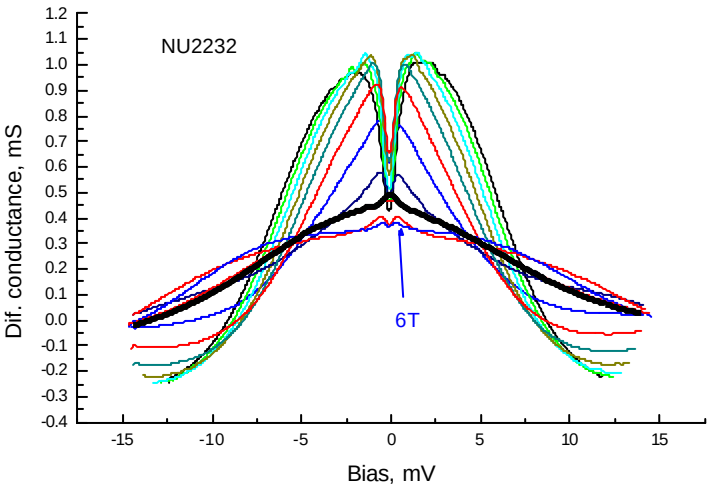

N=2.5*10^11 cm^-2
NU2230
WF
E_F
Energy, meV
Distance, nm

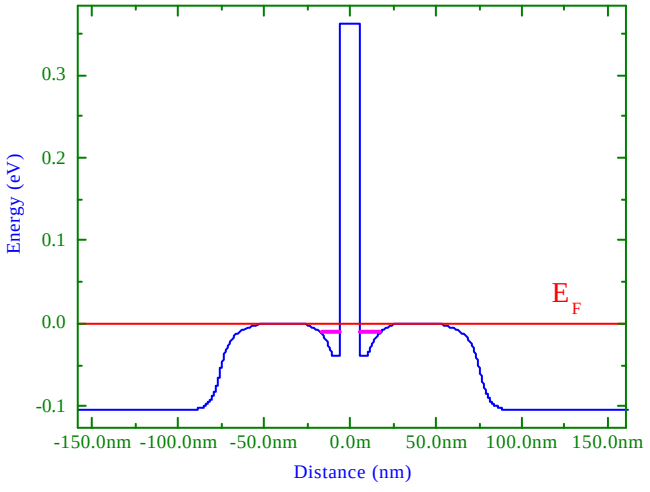

mesa 50 µ
B=14T
T=1.6K
T=0.3K
Dif. conductance, µS
Bias, mV

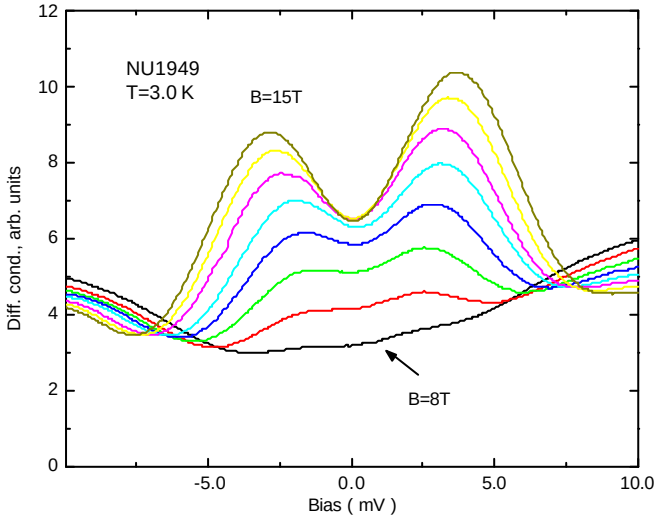

Energy (eV)
0.3
0.2
0.1
0.0
-0.1
E F
-150.0nm -100.0nm -50.0nm 0.0m 50.0nm 100.0nm 150.0nm
Distance (nm)

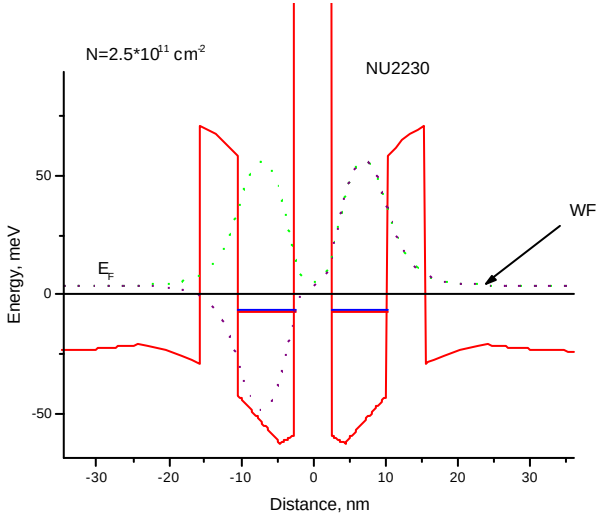

B=0T
B=3.5 T
B=7T
Dif. conductance, μS
Bias, mV
Magnetic field step
between curves 0.5 T
NU1949
vertical 2D-2D tunnelling
between disordered systems (δ - doping)
T=0.3K
B ⊥ J

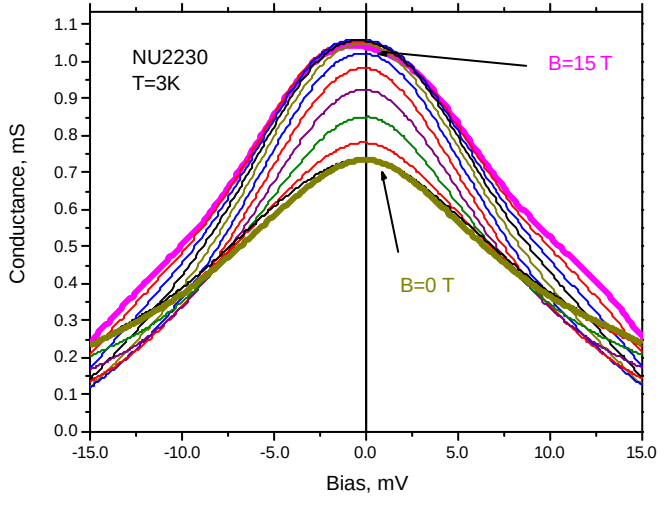

N2D=2.4*10^11 cm^-2
NU2232
Energy, eV
E F
Distance, nm


NU2232
Dif. conductance, mS
6T
Bias, mV


Energy (eV)
0.3
0.2
0.1
0.0
-0.1
E_F
-150.0nm -100.0nm -50.0nm 0.0m 50.0nm 100.0nm 150.0nm
Distance (nm)


NU1949
T=3.0 K
B=15T
B=8T
Diff. cond., arb. units
12
10
8
6
4
2
0
-5.0
0.0
5.0
10.0
Bias (mV)


N=2.5*10^11 cm^-2
NU2230
WF
E_F
Energy, meV
50
0
-50
-30
-20
-10
0
10
20
30
Distance, nm


NU2230
T=3K
B=15 T
B=0 T
Conductance, mS
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
-15.0
-10.0
-5.0
0.0
5.0
10.0
15.0
Bias, mV

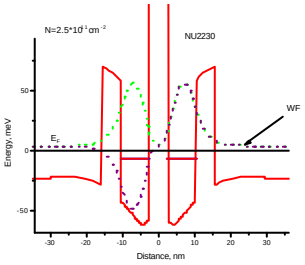
Conclusions

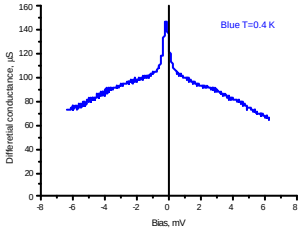
We have studied tunnelling between identical two-dimensional disordered electron systems formed by δ-doping with different interlayer spacing.

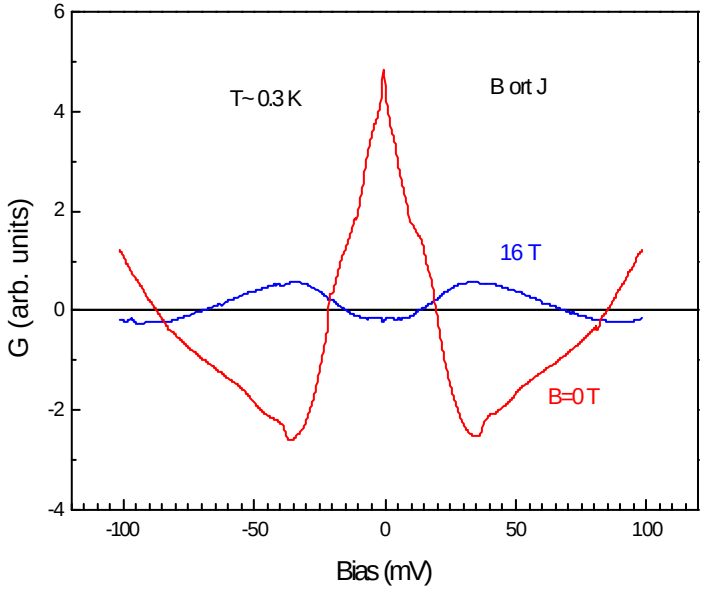
We have presented experimental evidence that appearance of narrow zero bias conductance peak at low temperatures in zero magnetic field is related to interlayer interaction.

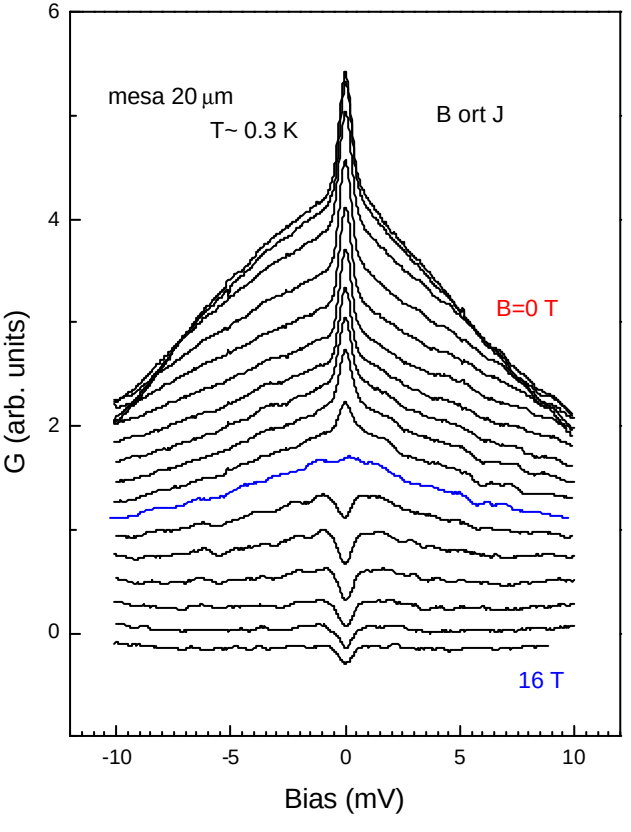
In a magnetic field normal to the layers interplay between two mechanisms influence the near equilibrium tunnelling: one is responsible for gap formation in tunnelling spectrum with magnetic field, second causes additional contribution to the tunnelling current between layers.

We have discussed possible relation of the observed features with Kondo physics.


N=2.5*10^11 cm^-2
NU2230
WF
E_F
Energy, meV
Distance, nm


Blue T=0.4 K
Differetial conductance, μS
Bias, mV


T~ 0.3 K
B ort J
16 T
B=0 T
G (arb. units)
Bias (mV)


mesa 20 μm
T~ 0.3 K
B ort J
B=0 T
16 T
G (arb. units)
Bias (mV)