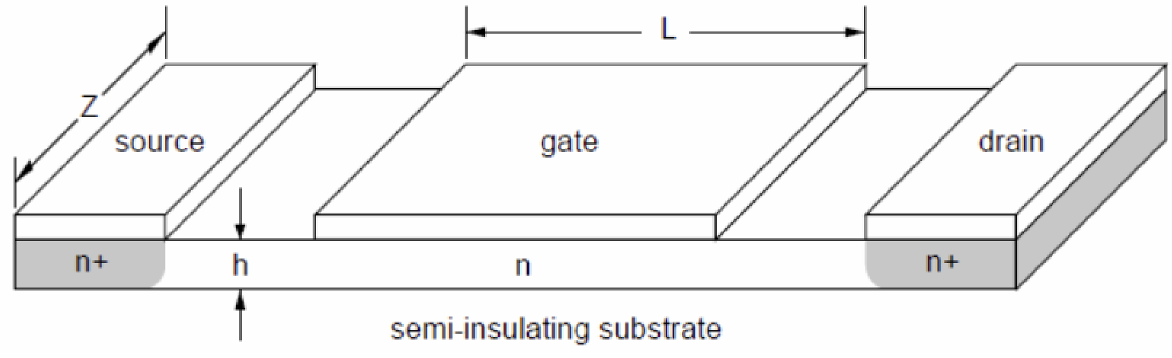
Metal-Semiconductor Field Effect Transistors (MESFETs)

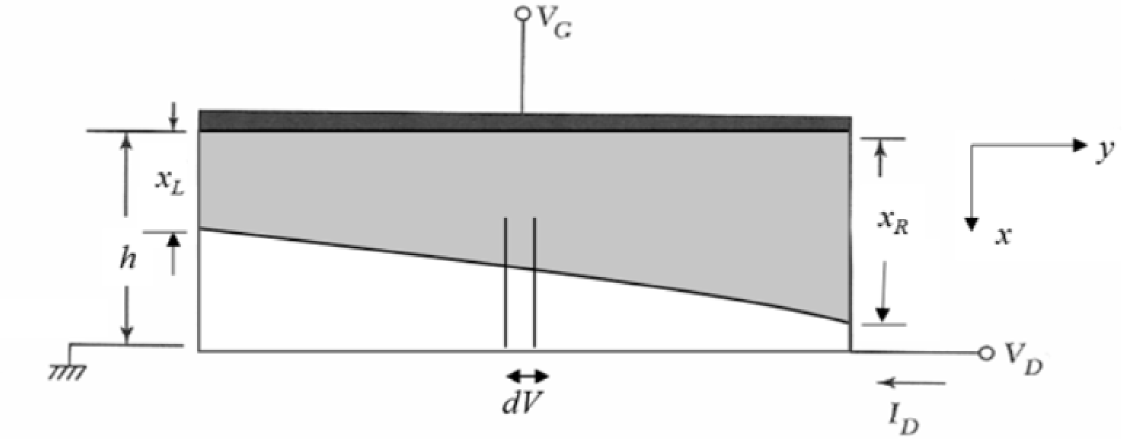
Modulation Doped Field Effect Transistors (MODFETs)

MESFET Gradual Channel Approximation

The description of a MESFET in the gradual channel approximation is almost the same as for a JFET. The difference is how the built-in voltage V_{bi} is calculated. Consider an n-channel MESFET.



A MESFET consists of a semiconducting channel contacted by two ohmic contacts. The metal gate forms a Schottky contact above the channel. The current in the channel flows between the depletion layer of the Schottky diode and a semi-insulating substrate. When the Schottky contact is reverse biased, the depletion width expands and the channel becomes narrower. The thickness of the conducting channel is $h - x_n(y)$ where h is the thickness of the n-doped channel and $x_n(y)$ is the depletion width that depends on the position y along the channel. In the figure below, the gray region of the channel is depleted.



http://lampx.tugraz.at/~hadley/psd/L9/gradualmesfet.php

JFET/MESFET

JFET**:** small gate current (reverse leakage of the gate-to-channel junction)

More gate leakage than MOSFET, less than bipolar.

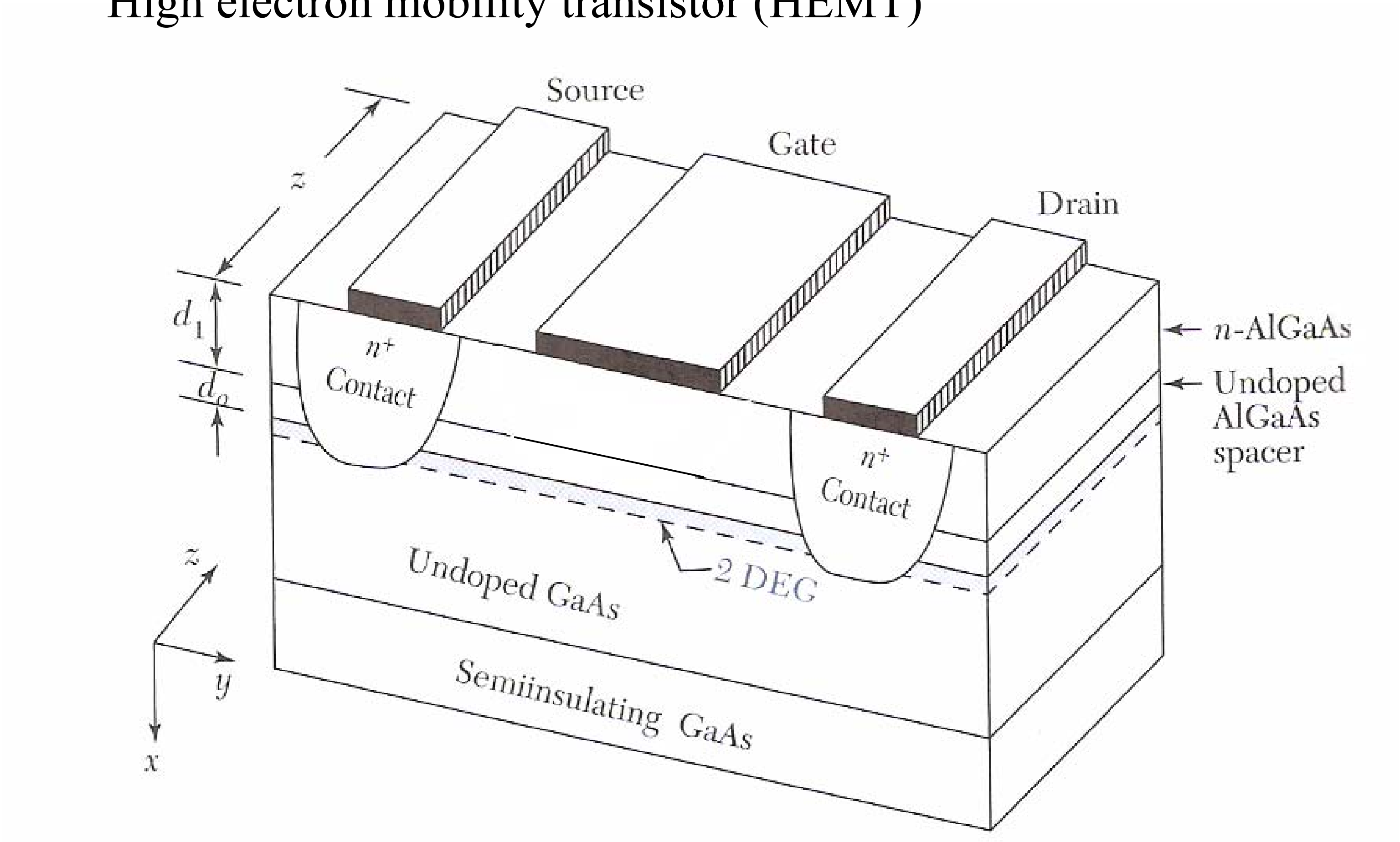
JFET has higher transconductance than the MOSFET.

Used in low-noise, high input-impedance op-amps and sometimes used in switching applications.

MESFET: usually constructed in compound semiconductor technologies lacking high quality surface passivation such as GaAs, InP, or SiC, and are faster but more expensive than silicon-based JFETs or MOSFETs. Production MESFETs are operated up to approximately 30 GHz, and are commonly used for microwave frequency communications and radar. Majority carrier device (like Schottky diode).

MODFET (HEMT)

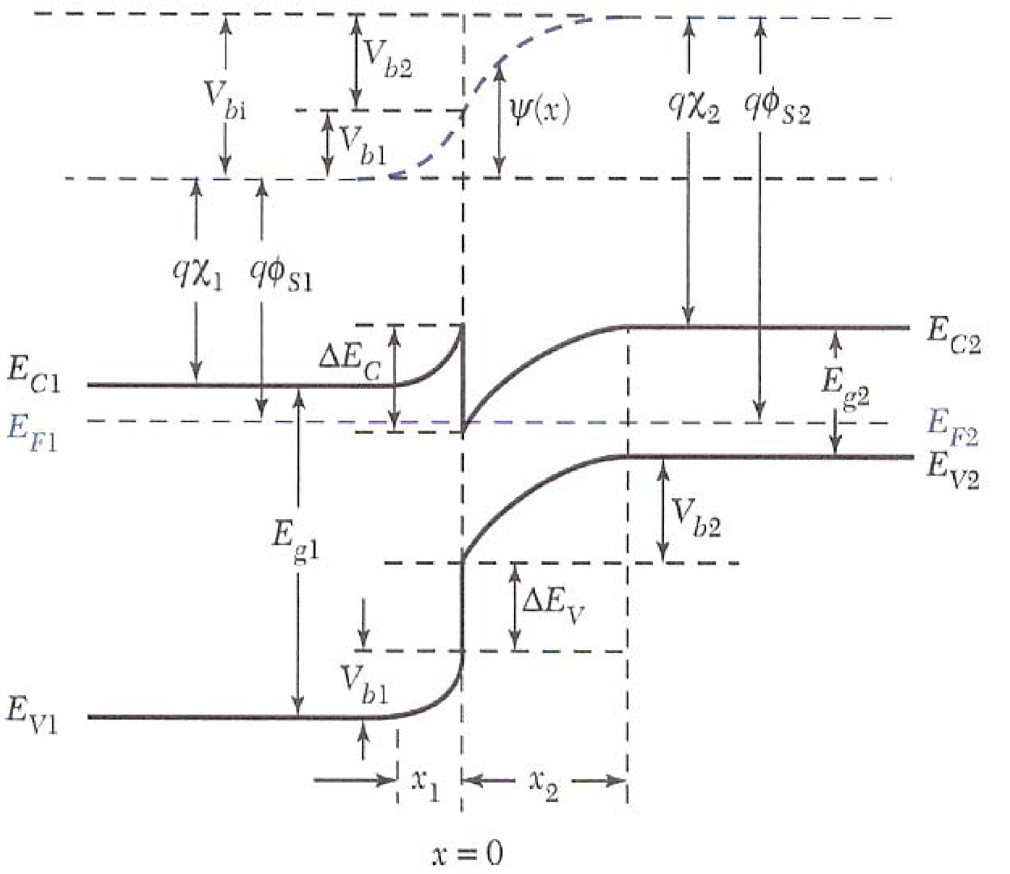
Modulation doped field effect transistor (MODFET)
High electron mobility transistor (HEMT)



V_T = Threshold voltage = voltage where charge is depleted

Heterostructure

pn junction formed from two semiconductors with different band gaps



MODFET/HEMT

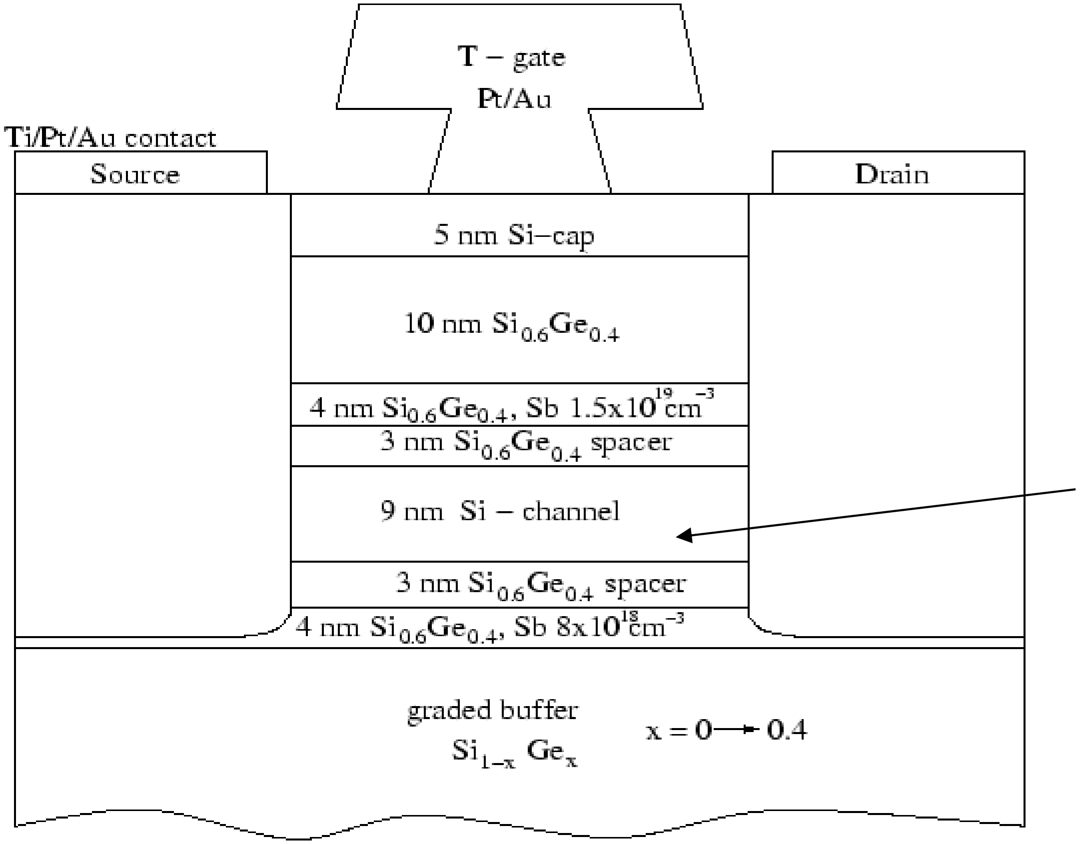


Figure 3.3: S-MODFET structure.

undoped channel

HEMT: HEMT devices are found in cell phones, electronic warfare systems, microwave and millimeter wave communications, radar, and radio astronomy.

PhD Thesis Sergey Smirnov

http://www.iue.tuwien.ac.at/phd/smirnov/node71.html

MODFET (HEMT)

$$j = nev_d = ne\mu_n E_y$$

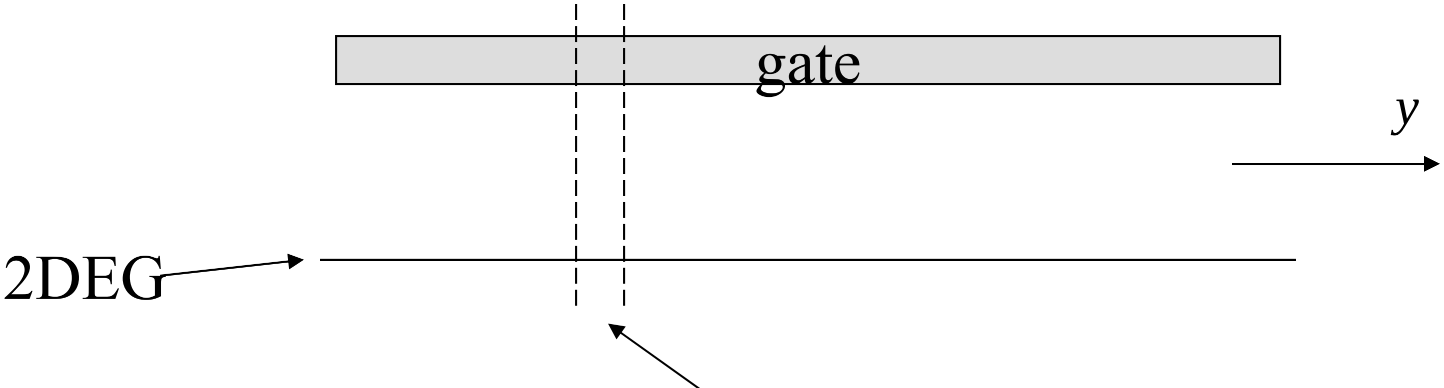
$$I = jZt = Ze\mu_n n_s E_y \qquad n = \frac{n_s}{t}$$

t is the thickness of the 2DEG

n_s is the sheet charge at the interface in C/cm^2.

$V_G - V(y)$ is the voltage between the gate and the 2DEG

$n_s = 0$ when $V_G - V(y) = V_T$



$$q = CV$$

$$-en_s(y) = -C_g\left(V_G - V(y) - V_T\right)$$

MODFET (HEMT)

$-en_s(y) = C_g\left(V_G - V_B(y) - V_T\right)$ is the charge on the 2DEG at point y

The charge is zero when $V_G - V_B(y) = V_T$

solve for n_s

$$n_s(y) = \frac{-C_g\left(V_G - V_B(y) - V_T\right)}{e}$$

Substitute this in Ohm's law:

$$I = jZt = Ze\mu_n n_s E_y$$

MODFET (HEMT)

$$I = jZt = Ze\mu_n n_s E_y$$

$$n_s(y) = \frac{-C_g\left(V_G - V(y) - V_T\right)}{e}$$

substitute n_s in the top equation and substitute $E_y = \frac{-dV(y)}{dy}$

$$I = Z\mu_n C\left(V_G - V_T - V(y)\right)\frac{dV(y)}{dy}$$

integrate along the length of the channel

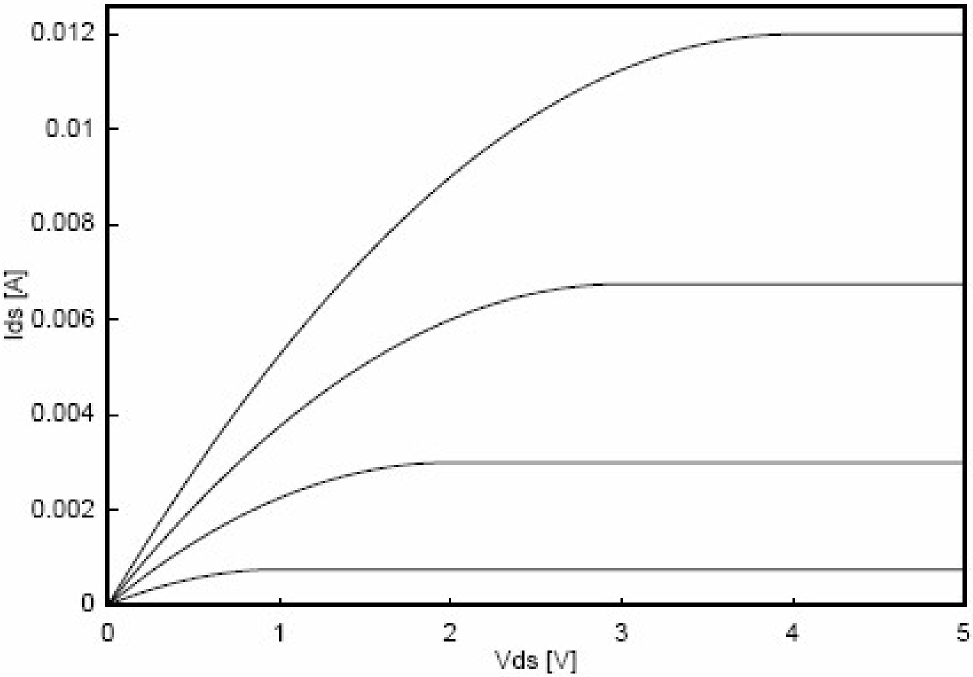
$$\int_0^L I dy = \int_0^{V_D} Z\mu_n C\left(V_G - V_T - V(y)\right)dV$$

$$\boxed{I_D = \frac{Z}{L}\mu_n C\left[\left(V_G - V_T\right)V_D - \frac{V_D^2}{2}\right]}$$

MODFET (HEMT)

$$I = \frac{Z}{L}\mu_n C\left[(V_G - V_T)V_D - \frac{V_D^2}{2}\right]$$

$$\frac{dI}{dV_D} = \frac{Z}{L}\mu_n C\left[(V_G - V_T) - V_D\right] = 0$$

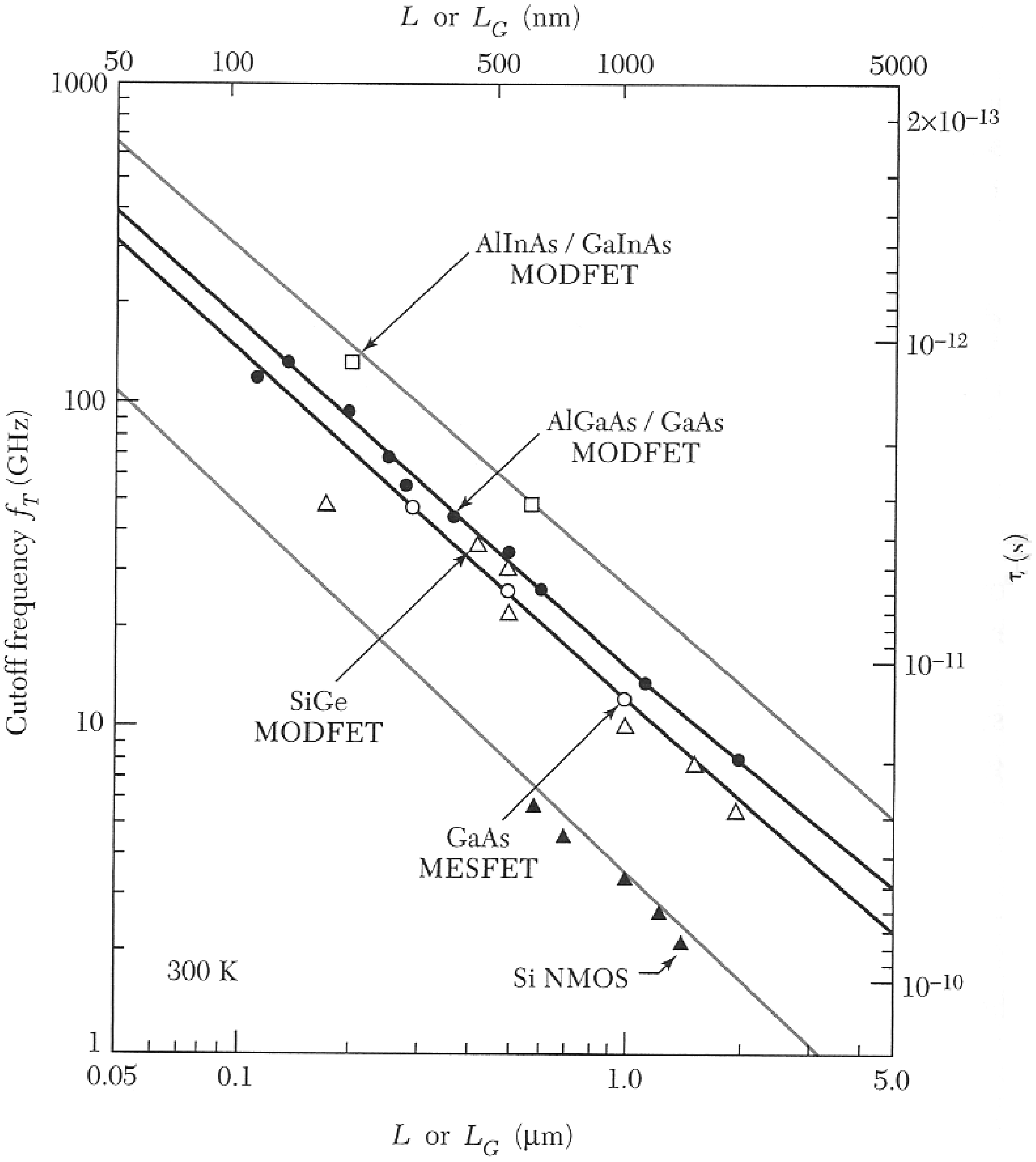


Set the derivative = 0 to find saturation voltage

$$V_{sat} = (V_G - V_T)$$

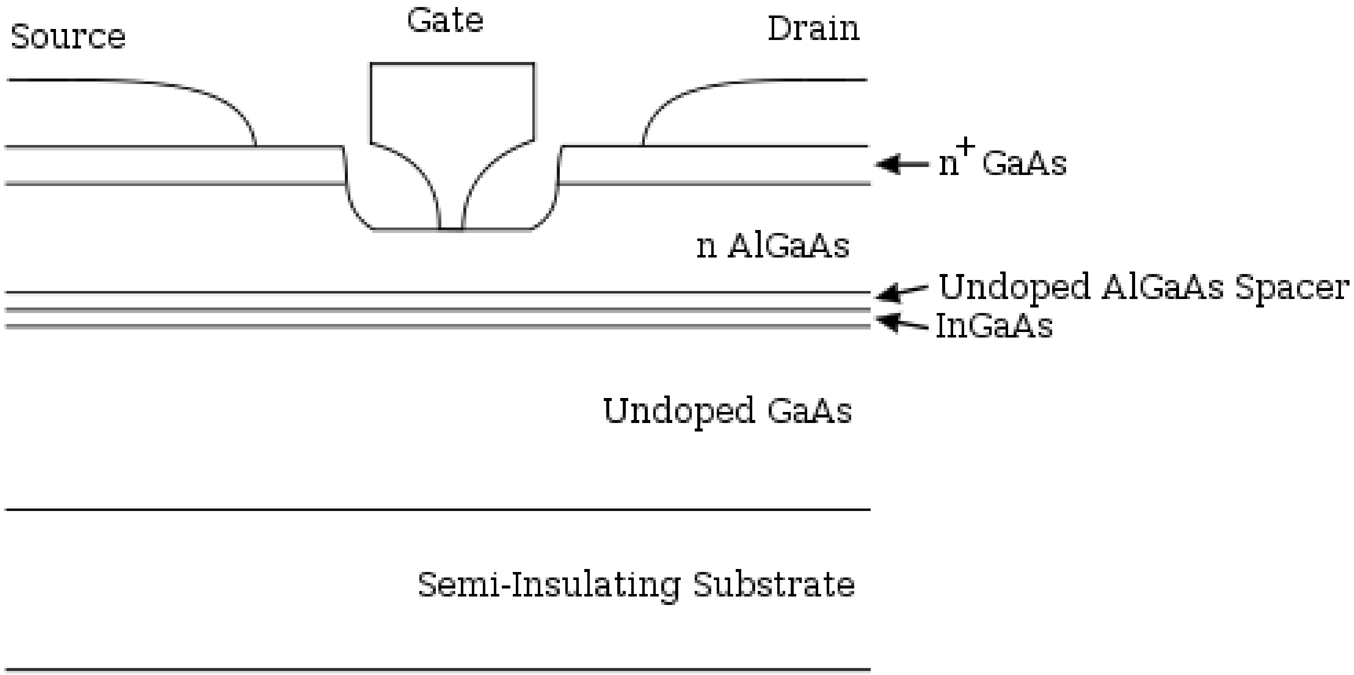
Substitute the saturation voltage into the formula at the top to find saturation current

$$I_{sat} = \frac{Z}{2L}\mu_n C(V_G - V_T)^2$$


L or L_G (nm)
50
100
500
1000
5000
1000
100
10
1
Cutoff frequency f_T (GHz)
2×10^{-13}
10^{-12}
10^{-11}
10^{-10}
τ (s)
AlInAs / GaInAs MODFET
AlGaAs / GaAs MODFET
SiGe MODFET
GaAs MESFET
Si NMOS
300 K
0.05
0.1
1.0
5.0
L or L_G (μm)

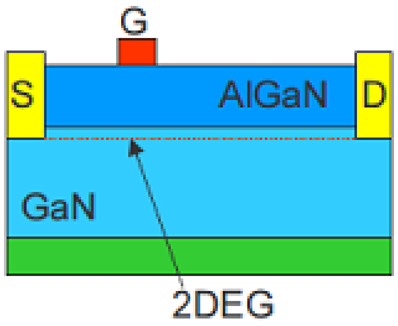
MODFET/HEMT

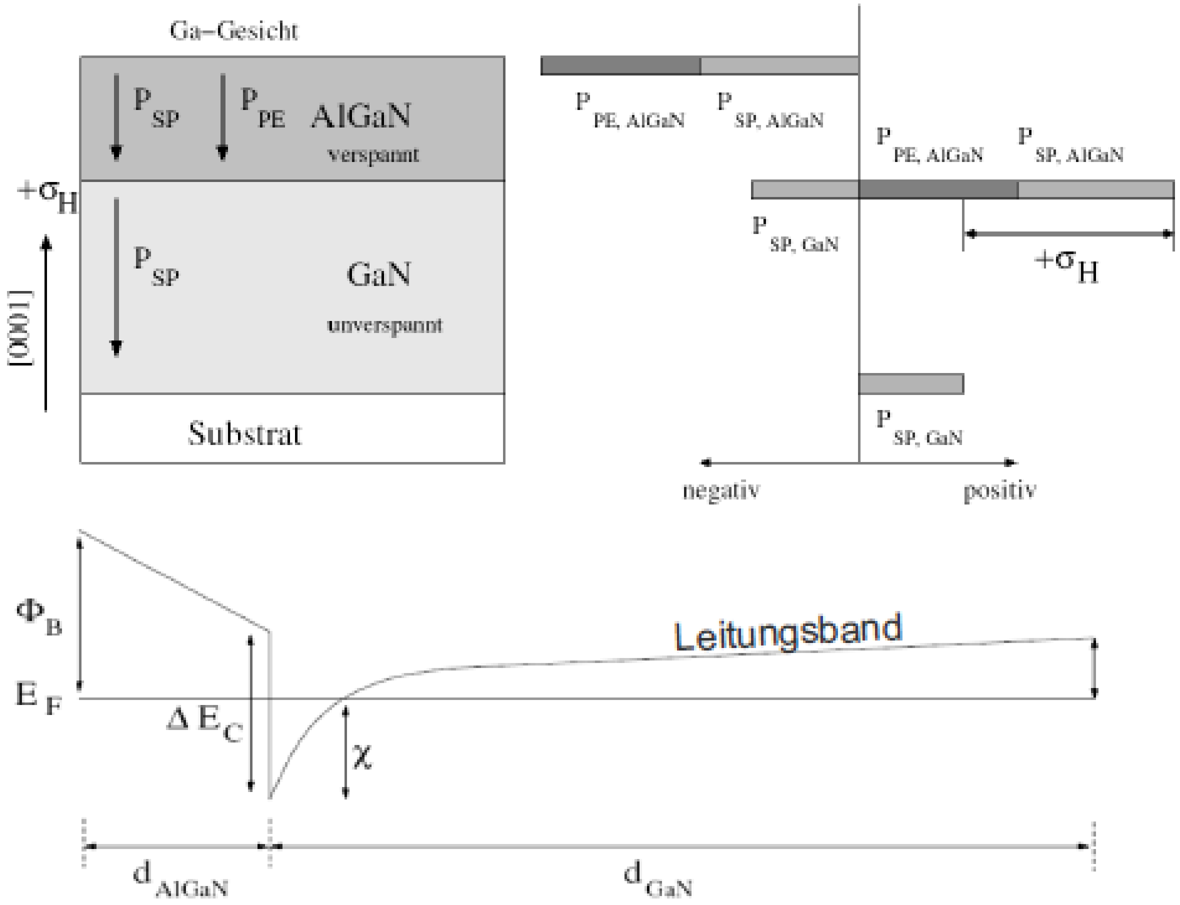
HEMT: HEMT devices are found in many types of equipment ranging from cell phones and DBS receivers to electronic warfare systems, microwave and millimeter wave communications, radar, and radio astronomy. 600 GHz



GaN-HEMT

- E_g(GaN) = 3.4 eV
- E_g(AlGaN) = 3.5 … 6 eV
- P_{SP}(AlGaN) > P_{SP}(GaN)
- AlGaN wächst zug-verspannt auf GaN
- AlGaN hat P_{PE}
- Sprung in P erzeugt Flächenladung
- → 2DEG

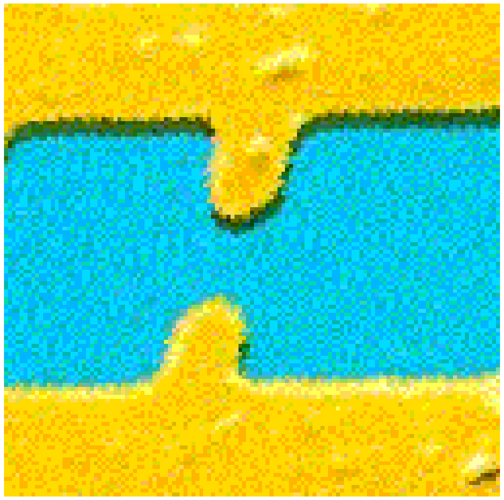


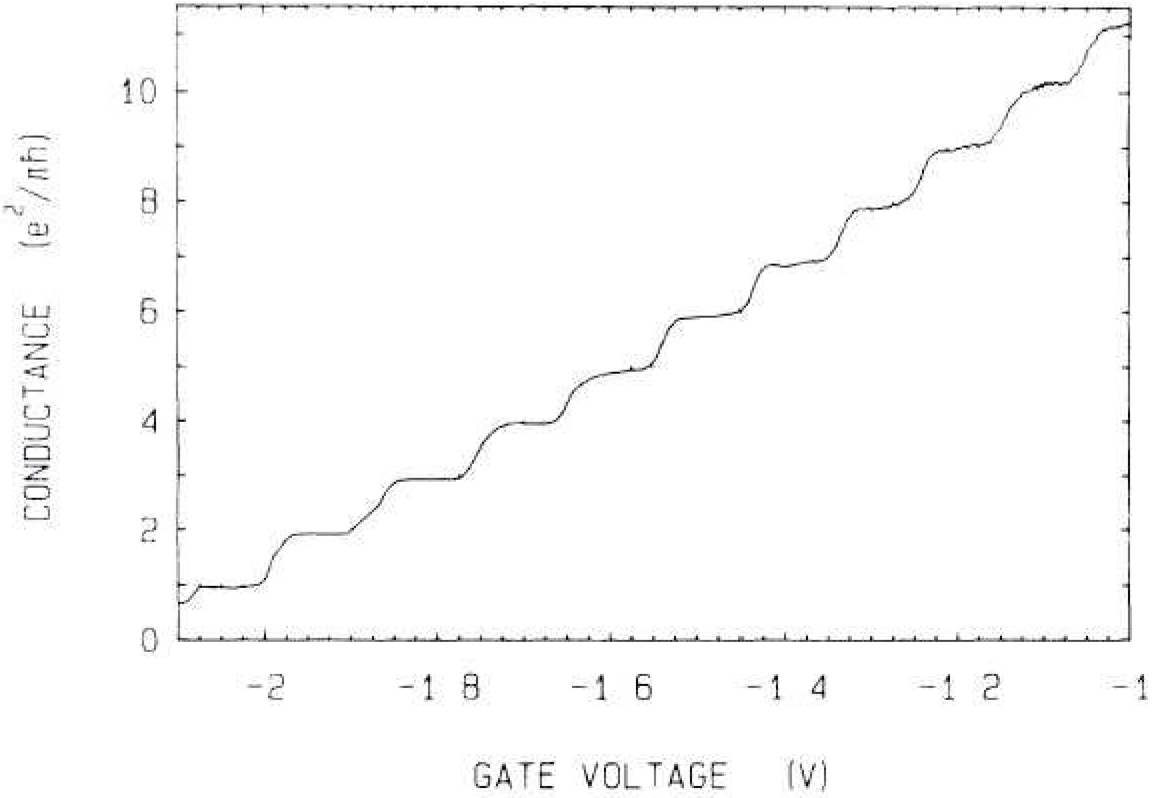


Source: Oliver Hilt, „Bauteile aus GaN“, ETG Tagung Bad Nauheim 2011

Quantized conduction

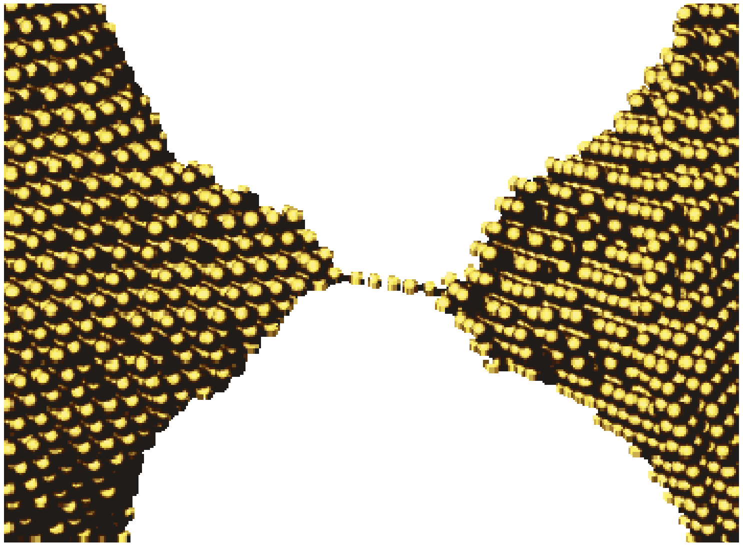
$$R_K = h/e^2 = 25812.807557(18)\ \Omega$$

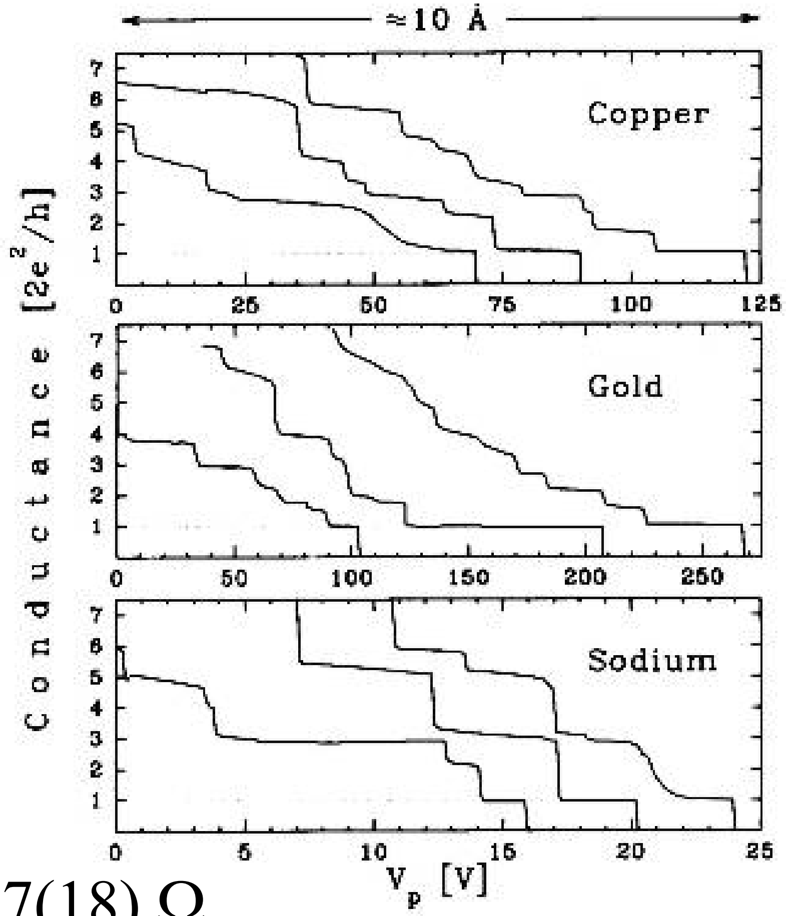




Quantized conductance of point contacts in a two-dimensional electron gas, B. J. van Wees, H. van Houten, C. W. J. Beenakker, J. G. Williamson, L. P. Kouwenhoven, D. van der Marel, and C. T. Foxon, Phys. Rev. Lett. 60, 848-850 (1988).

Quantized conduction

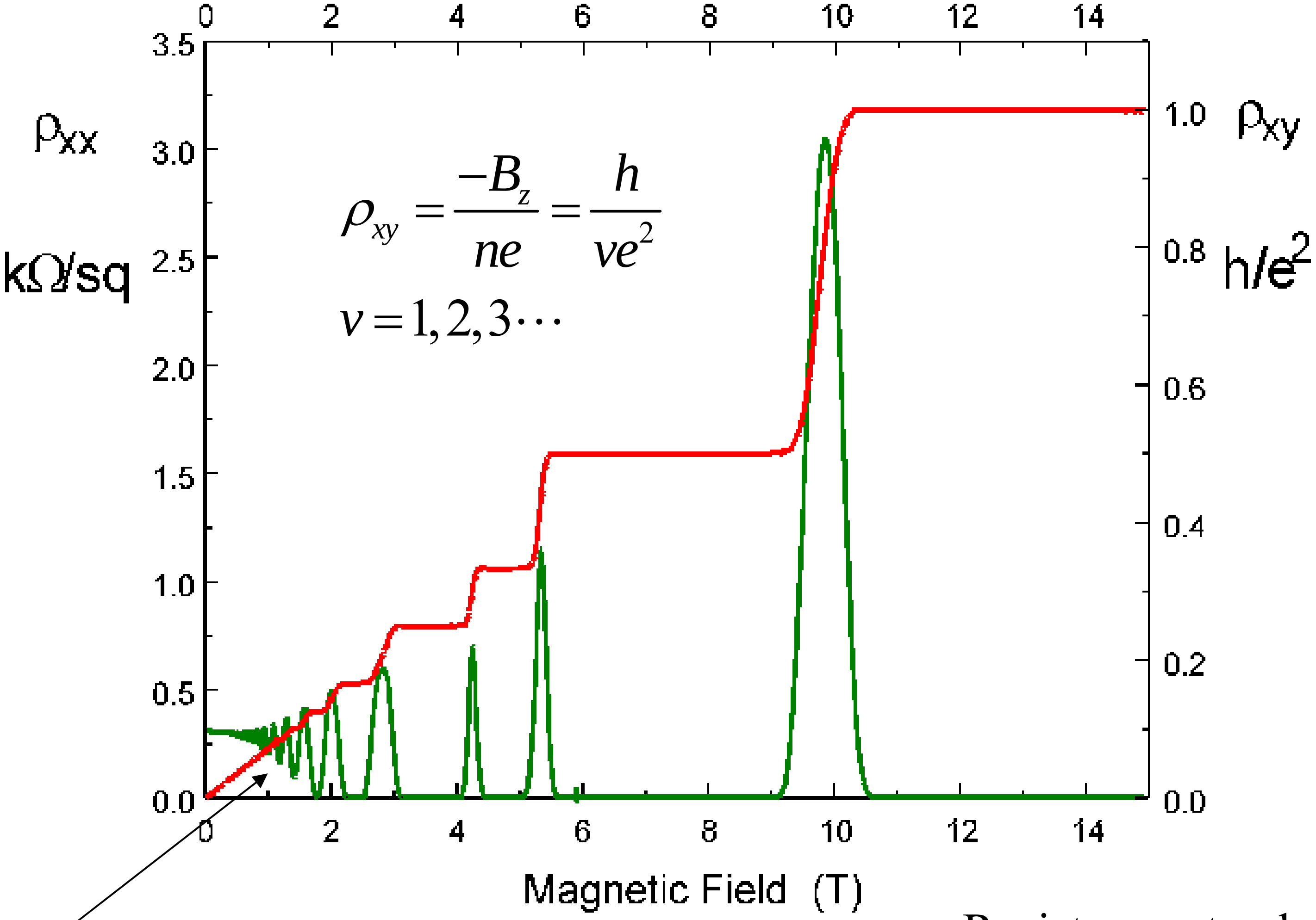




$$R_K = h/e^2 = 25812.807557(18)\ \Omega$$

Formation and Manipulation of a Metallic Wire of Single Gold Atoms, A. I. Yanson, G. Rubio Bollinger, H.E. van den Brom, N. Agraït, J.M. van Ruitenbeek, Nature Oct. 1998.

Quantum Hall Effect



$$\rho_{xy} = \frac{-B_z}{ne} = \frac{h}{\nu e^2}$$

$$\nu = 1, 2, 3 \cdots$$

Shubnikov-De Haas oscillations

Resistance standard
25812.807557(18) Ω