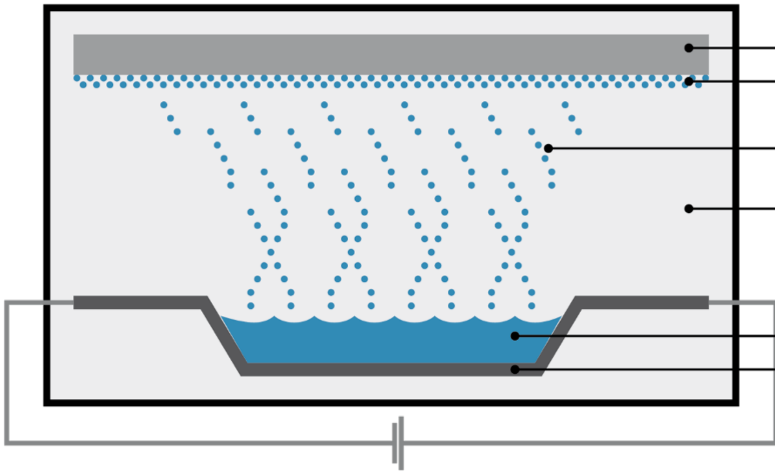
Physical Vapor Deposition (PVD)

Thermal evaporation
E-beam evaporation
Knudsen cell, Effusion cell
Molecular Beam Epitaxy (MBE)
Sputtering
Laser ablation

Thermal evaporation



Coil

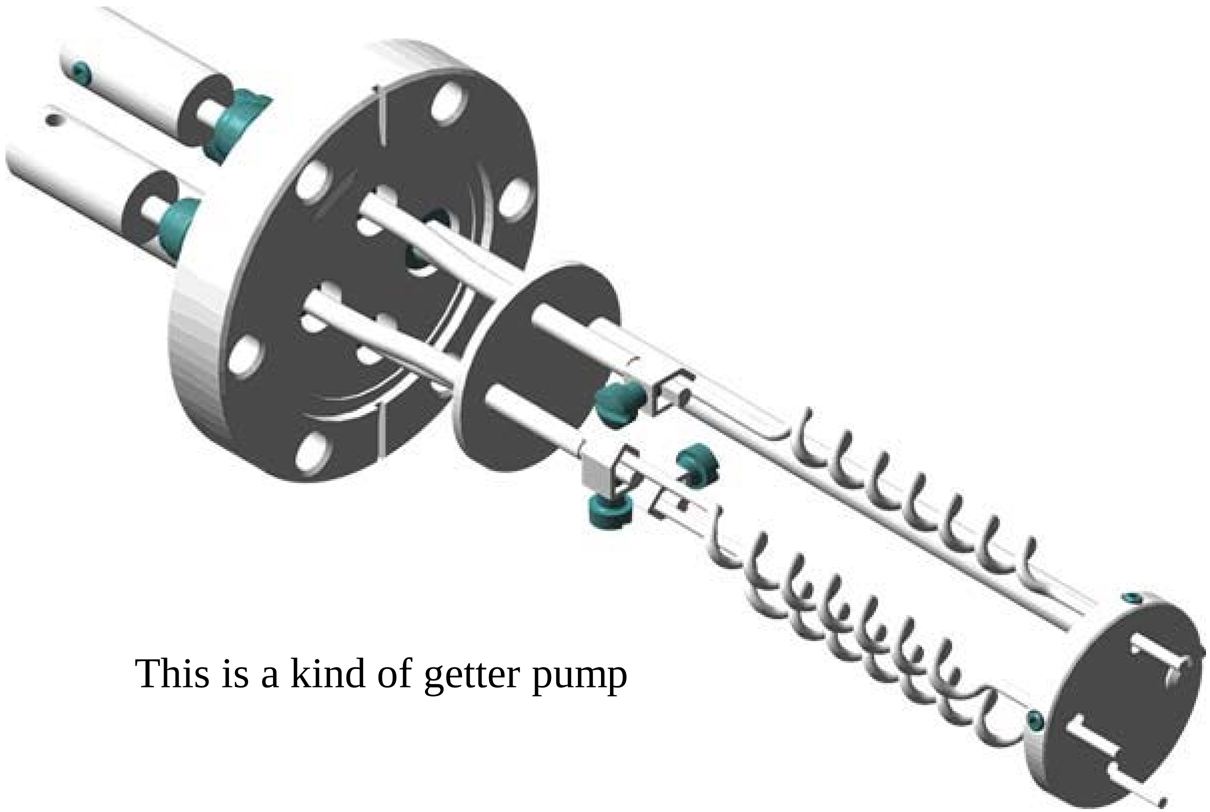
Boat

Knudsen cell

Covers substrate features like snow.
Polycrystalline films.

http://www.plansee.com/en/Products-System-components-and-accessories-Coating-systems-Evaporation-boats-100.htm

Titanium Sublimation Pump (TSP)

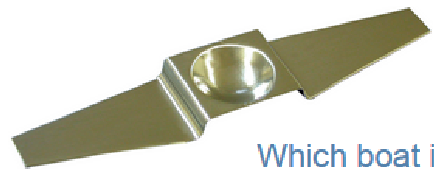


This is a kind of getter pump

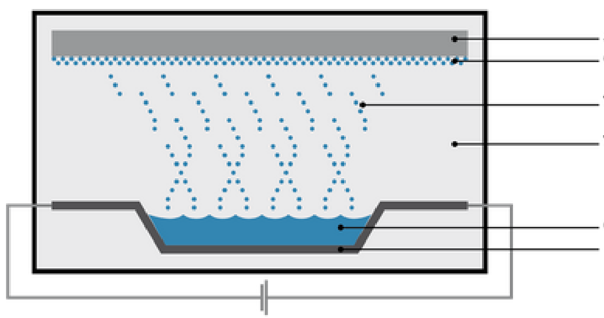
http://www.lesker.com/newweb/vacuum_pumps/ionpump_gamma_ionpump_tisub.cfm

Hot and clean.
Evaporation boats made from strong metals.

Thermal vacuum evaporation (resistance evaporation) is a coating method used as part of the PVD process (Physical Vapor Deposition). The material that is to form the subsequent layer is heated in a vacuum chamber until it evaporates.



The vapor formed by the **material condenses on the substrate** and form
Because many coating materials react with water, nitrogen and oxygen, th
performed in a high vacuum. The high temperatures that are required are g
using resistance heaters or, in some cases, induction heaters, electron be
Evaporation boats are manufactured from refractory metals such as molyb
tantalum to help them withstand these high temperatures as well as the cl
caused by the coating material.



In the vacuum evaporation process resistant layers are produced, for exam
silver, chromium, titanium nitride or silica. The result: gleaming watches, fl
top-quality electronic components. You can be assured of long service live
dimensional accuracy: Thanks to our many years of experience, we are al
material and geometries of our evaporation boats to meet the precise requ
processes. We would be very happy to advise you.

Our metals for vacuum evaporation.

We produce boats designed to hold the material for evaporation. These are manufactured from
tungsten, molybdenum, molybdenum lanthanum (ML), molybdenum yttrium oxide (MY) or

Get to know us.

Your contact person for evaporation boats and crucibles in

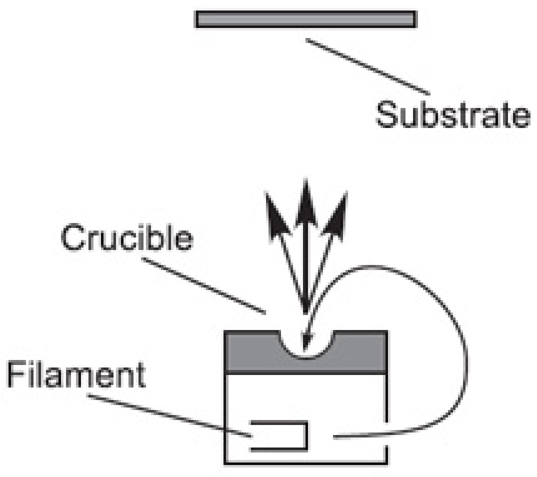
Austria

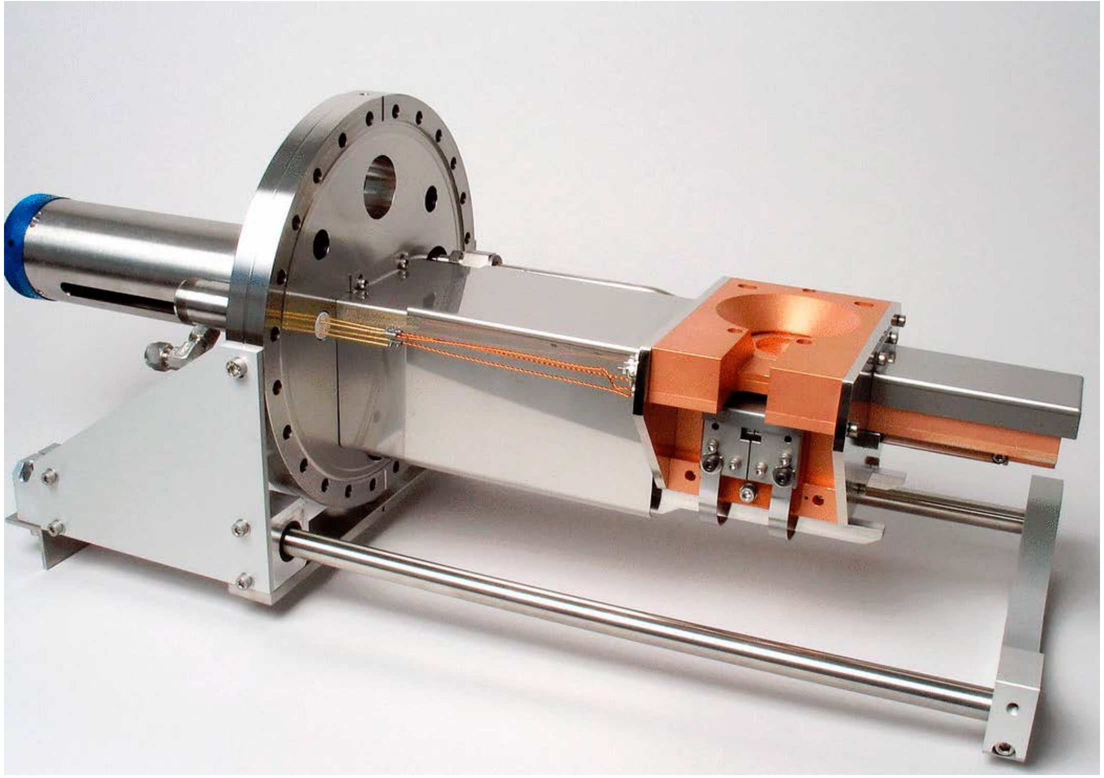
Which boat is right for your coating material?

Are you looking for the right evaporation boat for your coating material? Boats with one plus are suitable for your material. And boats marked with two pluses are particularly highly recommended. Would you like to find out more? Let's talk in person.

Coating material	Density [g/cm³]	Melting point [°C]	Boiling point [°C]	Evaporation boat W	Mo	Ta
Al	2.7	660	2467	+		
AlF_3	2.9	1291	N/A		++	++
Al/1 – 4% Cu	2.7	650	N/A	+		
Al/0.1 – 2% Si	2.7	640	N/A	+		
Al/4% Cu/1% Si	2.7	640	N/A	+		
Ag	10.5	961	2212	++	++	
As_2S_3	3.4	300	707		++	
Au	19.3	1063	2966	++	+	
B_2O_3	2.5	460	2247		++	
BaF_2	4.9	1280	2260	++	++	++
$BaTiO_3$	6.0	1600	N/A	+		+
BeO	3.0	2530	4120	+		
Bi	9.8	271	1560	++	++	++
BiF_3	5.3	727	900		++	++
Bi_2O_3	8.9	820	1890	+	+	

Electron-beam evaporation





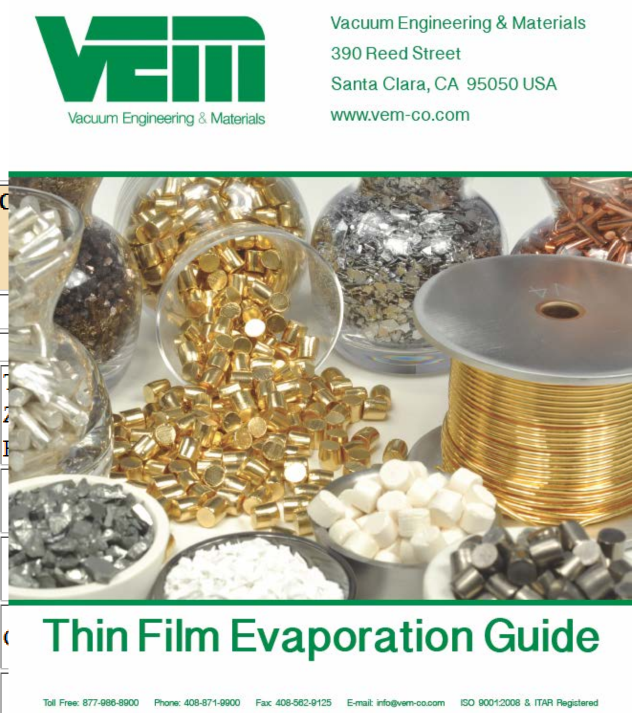
http://www.polyteknik.com/E-Beam_Evaporation.html
http://www.directindustry.com/prod/omicron/evaporators-electron-beam-20757-1062065.html

NAVIGATION MENU

- Cleanroom Home
- Photonics Home
- Semiconductor Properties
- Everything Wafers
- Microfabrication Processes
- Optical References
- Cleanroom Equipment
- Safety and Protocol
- User Resources
- External Links

Thin Film Evaporation

Common Materials Reference and Guide*



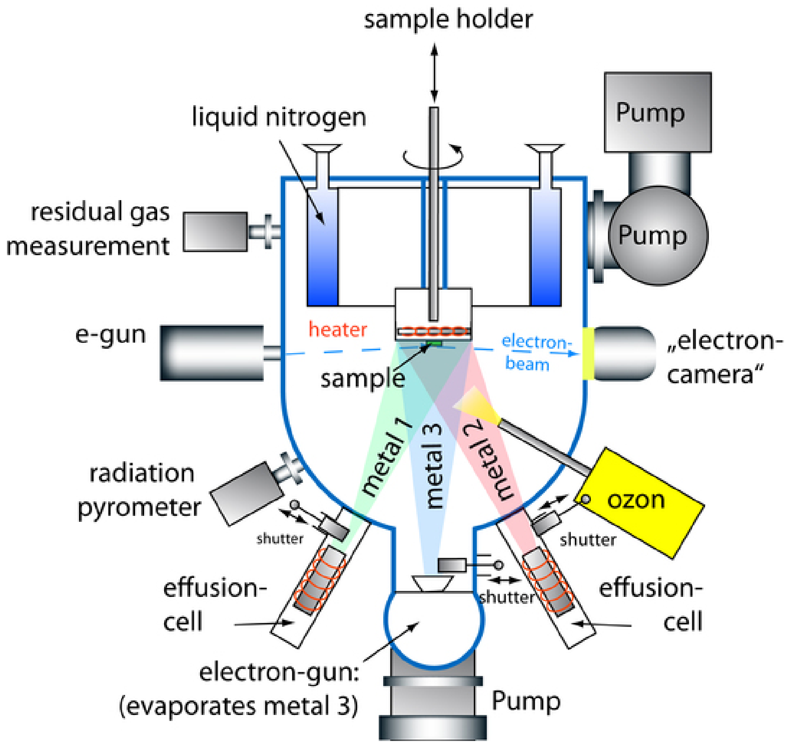
A

A B C D E F G H I J K L M N O P Q R S T U V W X Y Z

Element	Symbol	Melting Point °C	Density (bulk, g/cm^3)	Z-ratio	Temperature°C @ Vapor Pressure (Torr) 10^{-8}	10^{-6}	10^{-4}	Evaporation Method	C		
Aluminum	Al	660	2.700	1.080	677	821	1010	eBeam (Xlnt), Thermal	[illegible]	[illegible]	[illegible]
Aluminum Antimonide	AlSb	1080	4.3	--	--	--	--	--	[illegible]	[illegible]	[illegible]
Aluminum Arsenide	AlAs	1600	3.7	--	--	--	~1300	--	[illegible]	[illegible]	[illegible]
Aluminum Bromide	AlBr$_3$	97	3.01	--	--	--	~50	--	[illegible]	[illegible]	[illegible]
Aluminum Carbide	Al$_4$C$_3$	1400	2.36	--	--	--	~800	ebeam (Fair)	[illegible]	[illegible]	[illegible]
Aluminum 2% Copper	Al2%Cu	640	2.8	--	--	--	--	--	--	--	Wire feed and flash. Difficult from dual sources
Aluminum Fluoride	AlF$_3$	1257 sublimes	3.07	--	410	490	700 (........sublimes........)	eBeam (Poor)	G	Mo, W	n = 1.38 @ .55µ
Aluminum Nitride	AlN	-- sublimes	3.26	--	--	--	~1750	ebeam (Fair)	--	--	Decomposes. Reactive evaporate in 10^{-3} N_2 with glow discharge.
Aluminum Oxide (Alumina)	Al$_2$O$_3$	2045	3.970	0.336	--	--	1550	eBeam (Xlnt), sputter	--	W	Sapphire xlnt in ebeam, forms smooth, hard films. n=1.66

http://www.cleanroom.byu.edu/TFE_materials.phtml

Electron-beam evaporation



http://www.eps.hw.ac.uk/institutes/photonics-quantum-sciences/mbe.htm
http://www.fkf.mpg.de/273938/30_Oxide_MBE_Lab

Electron-beam evaporation

Electron accelerating voltages: 3 kV – 40 kV

10 - 100 kW power

High vacuum

x-rays and secondary electrons are emitted

deposition rate from 0.1 μm / min to 100 μm / min

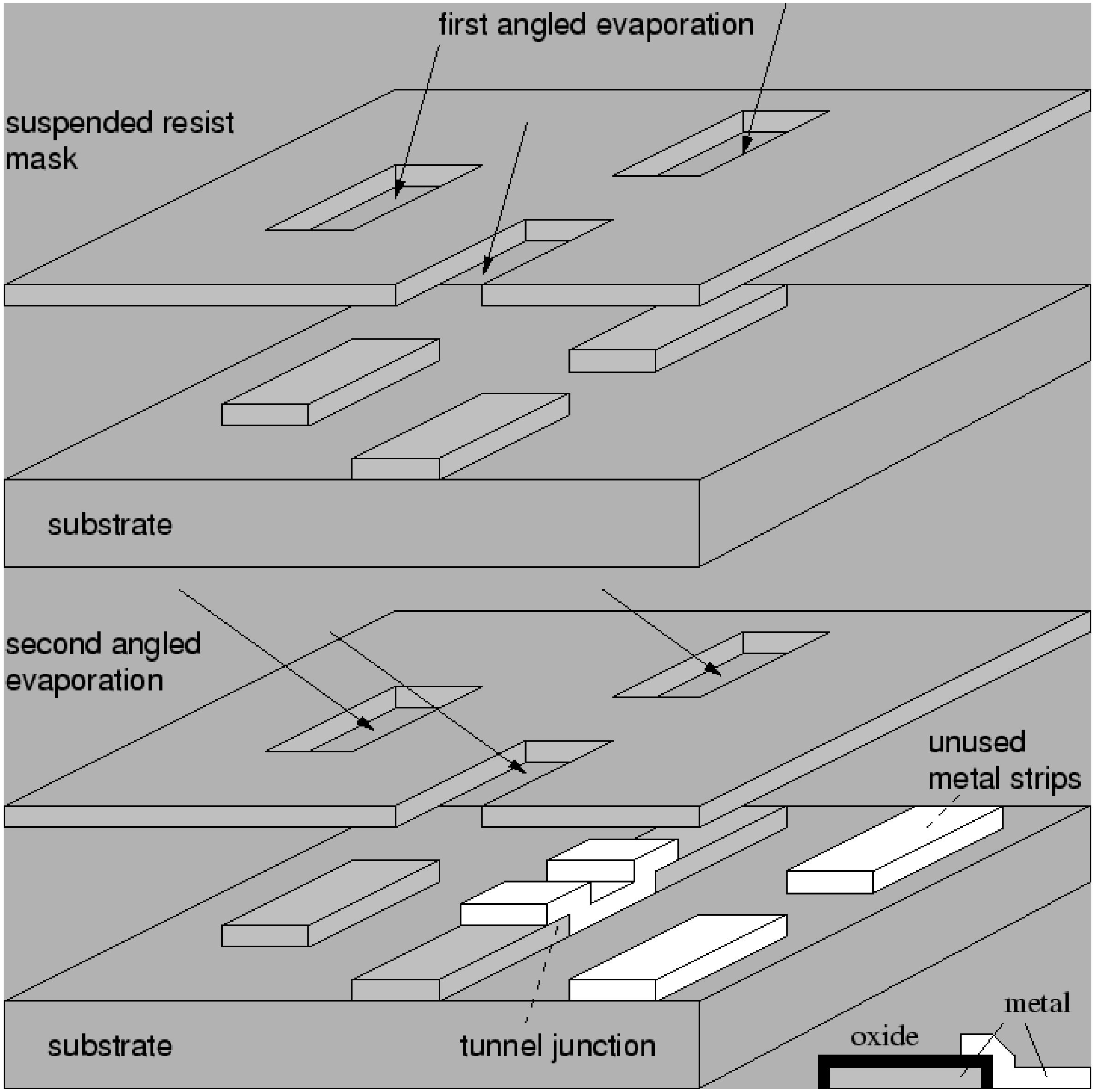
Alloys can be difficult because the components evaporate at different rates

Co-evaporation is sometimes used for alloys

line-of-sight deposition process

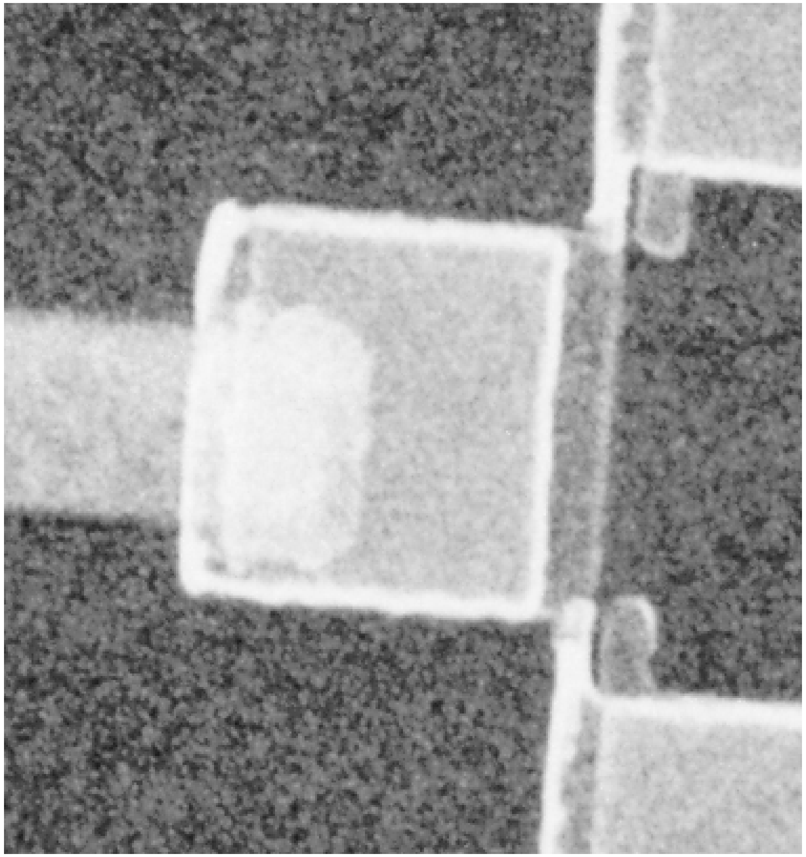
Not suitable for large areas or coating complex shapes

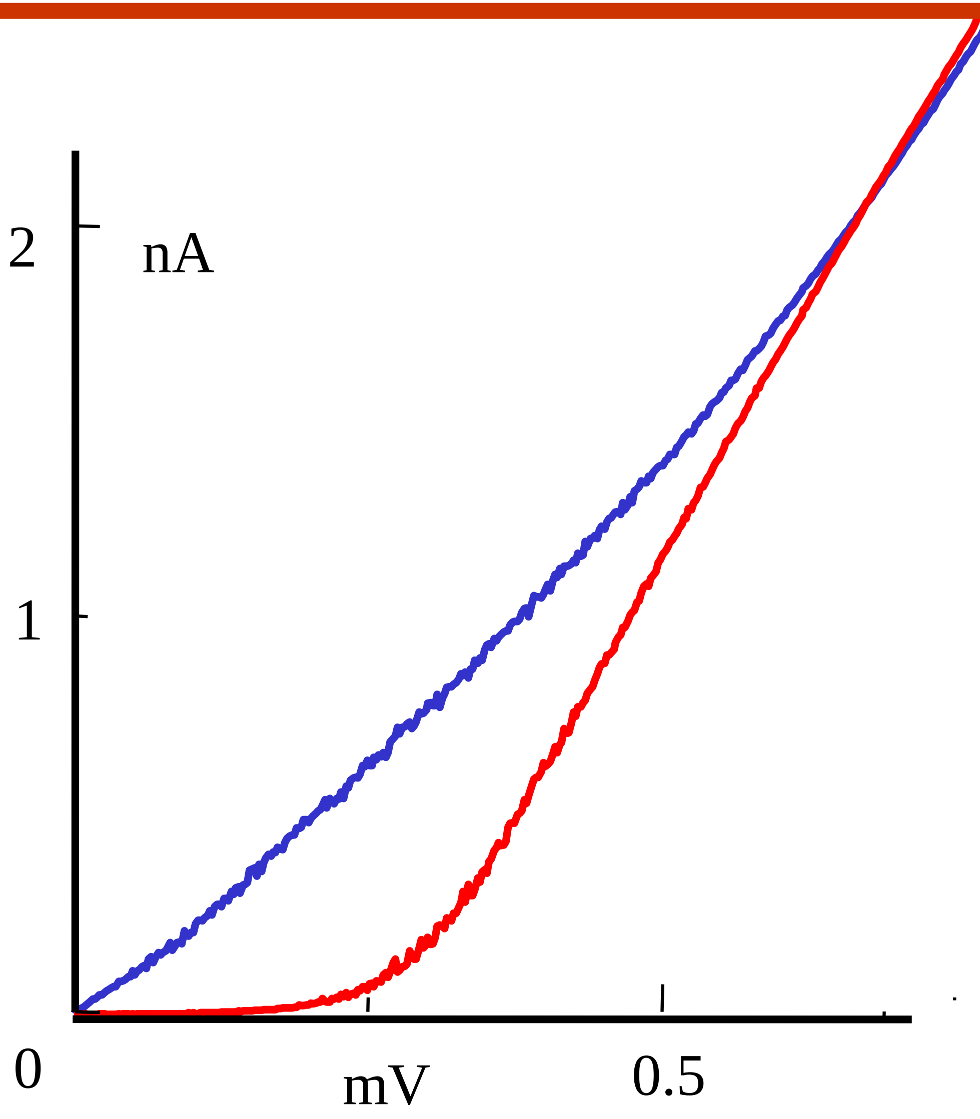
Shadow evaporation



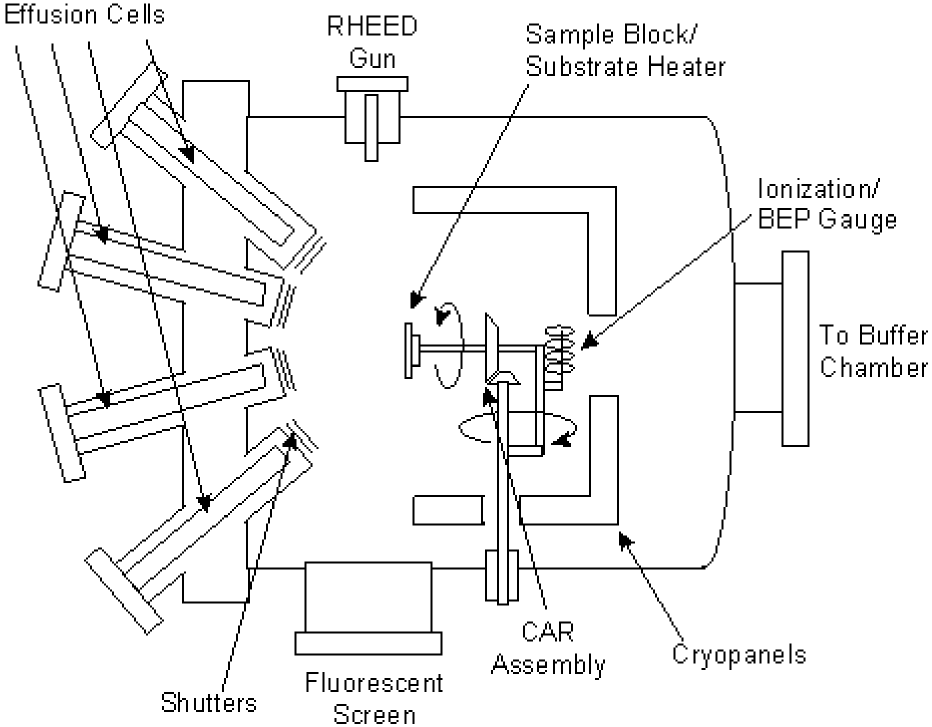
http://www.iue.tuwien.ac.at/phd/wasshuber/node51.html

Single electron transistor



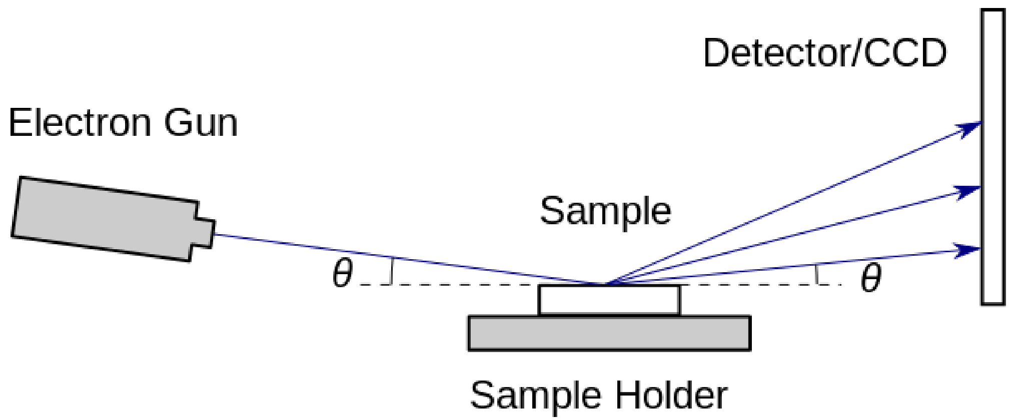


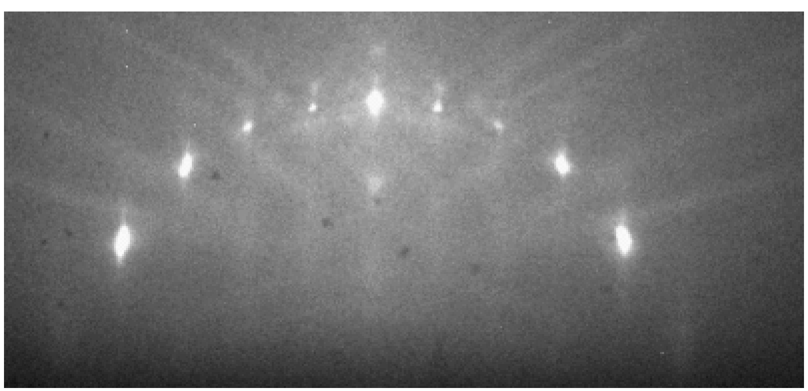
Molecular Beam Epitaxy (MBE)

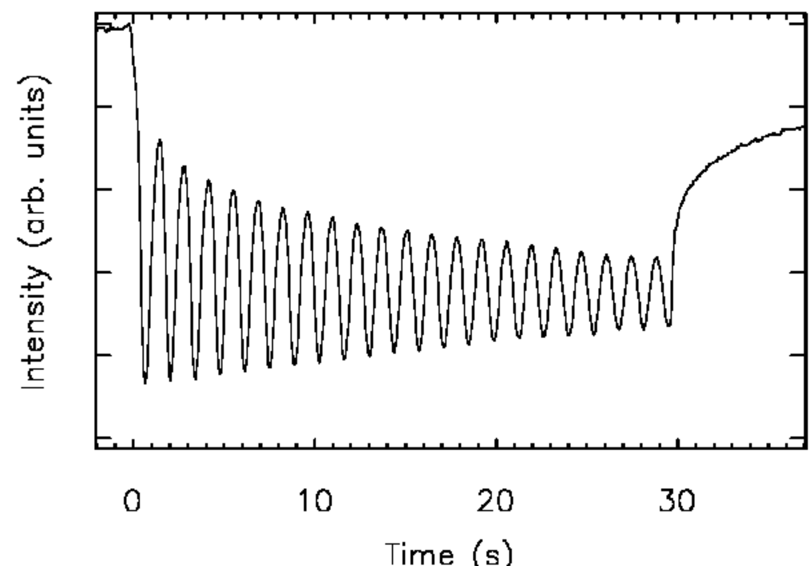


http://lase.mer.utexas.edu/mbe.php

RHEED
(Reflection high-energy electron diffraction)

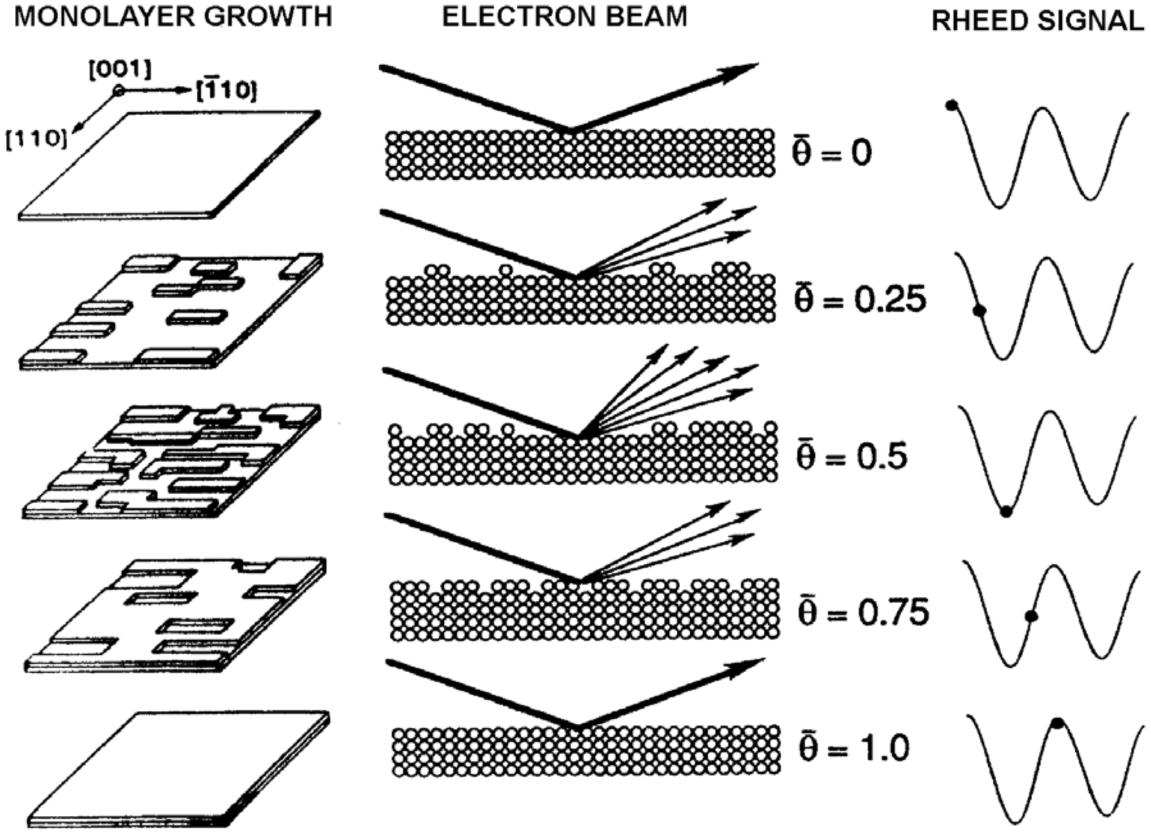






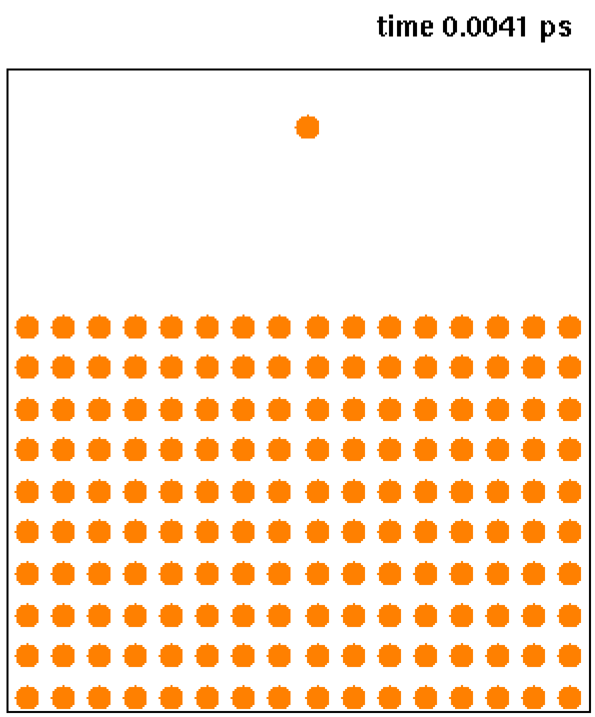
http://asumbe.eas.asu.edu/formermembers/wolfgang/thesis/sect131.html
http://en.wikipedia.org/wiki/Reflection_high-energy_electron_diffraction#mediaviewer/File:RHEED.svg

RHEED



M. Ohring, *The Material Science of Thin Films*, Academic Press, 1992.

Molecular dynamics



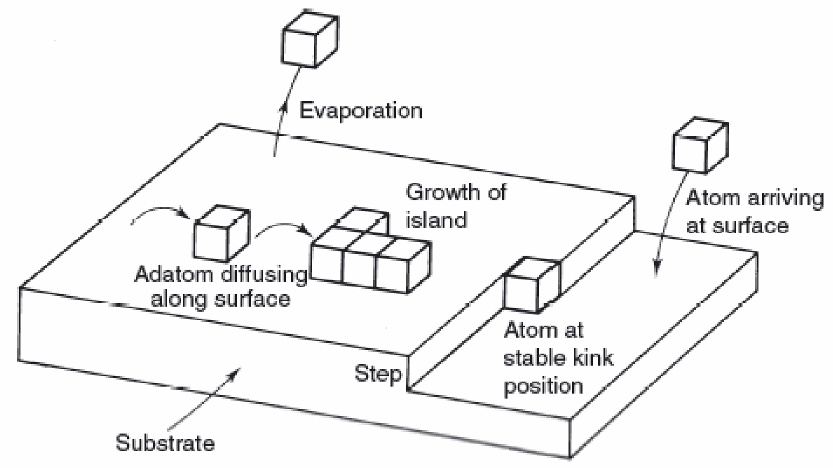


Figure 6.8 Terrace step kink (TSK) growth model of epitaxy: growth proceeds at kinks, and adatoms on flat surface diffuse to energetically favorable positions at kinks. Wafer miscut creates terraced structure. Reproduced from Jenkins (1995)

Calculate the motions of the atoms at the surface.

Growth modes

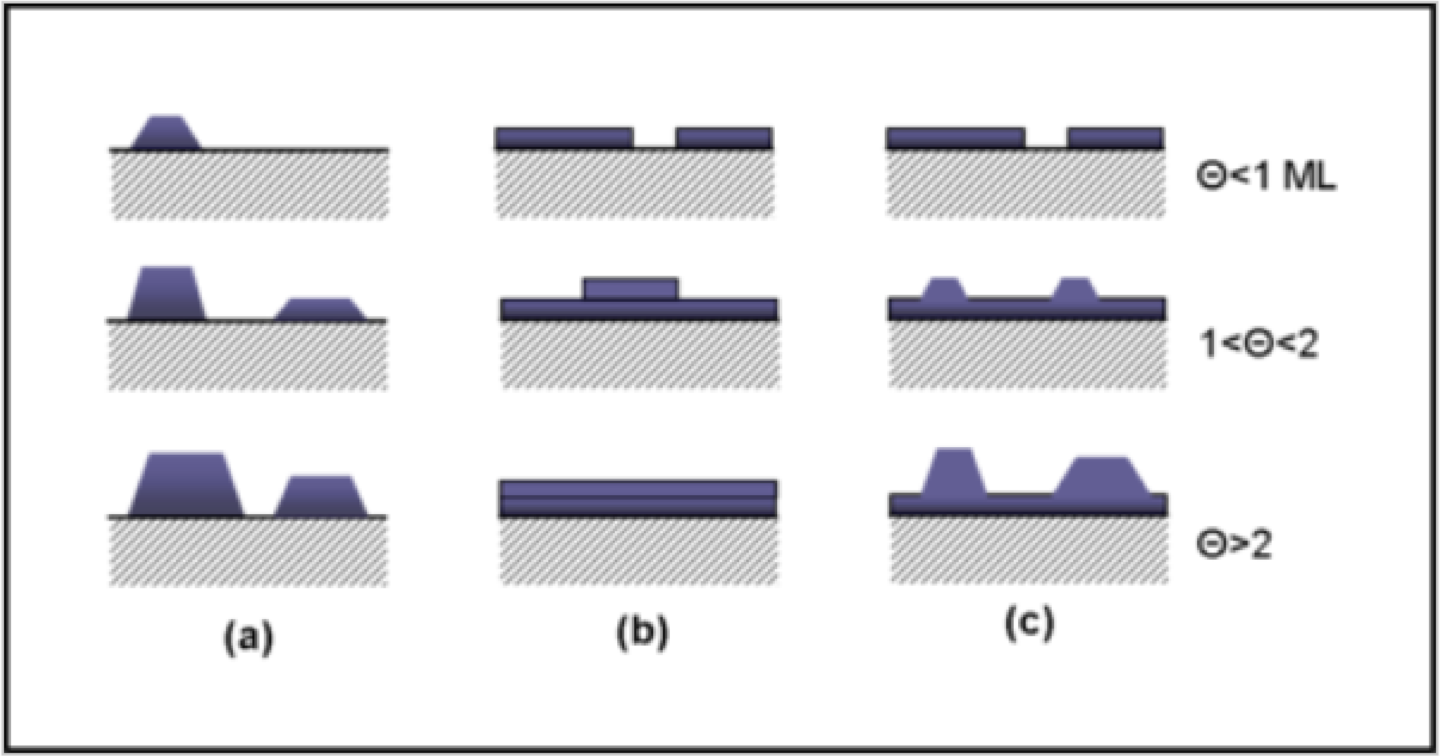
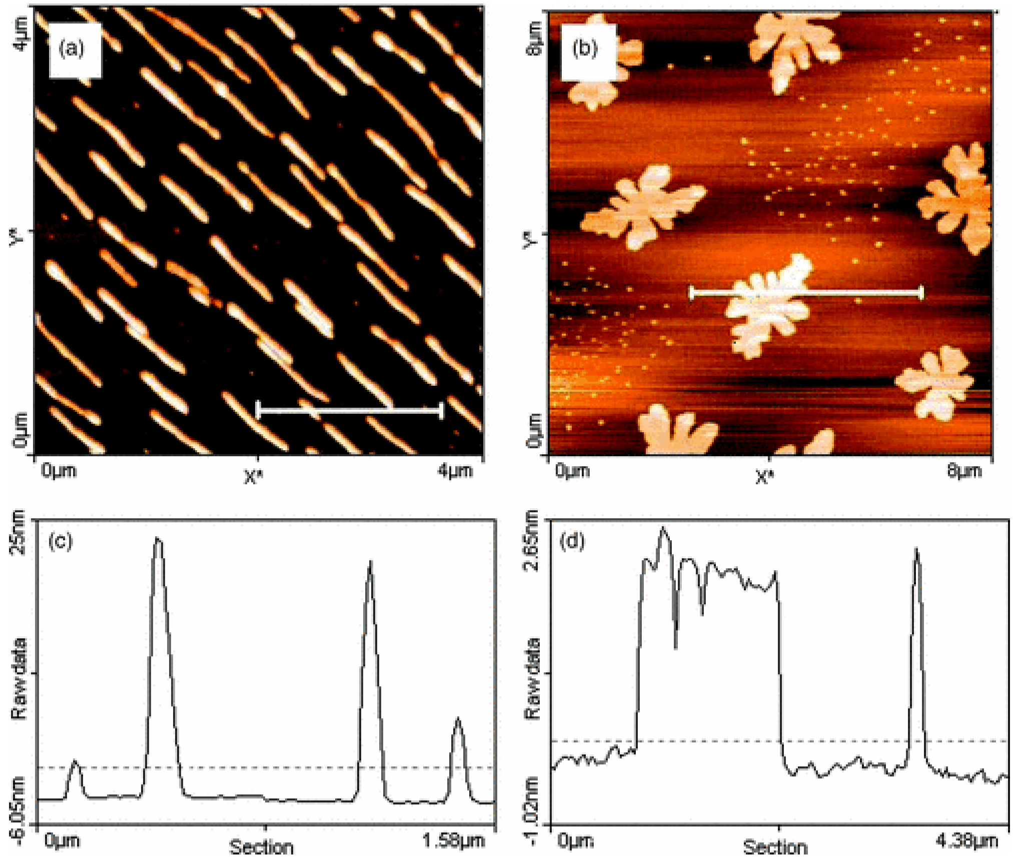


Figure 1. Cross-section views of the three primary modes of thin-film growth including (a) Volmer–Weber (VW: island formation), (b) Frank–van der Merwe (FM: layer-by-layer), and (c) Stranski–Krastanov (SK: layer-plus-island). Each mode is shown for several different amounts of surface coverage, Θ.

http://en.wikipedia.org/wiki/Stranski%E2%80%93Krastanov_growth

Origin of the bimodal island size distribution in ultrathin films of *para*-hexaphenyl on mica

L. Tumbek, C. Gleichweit, K. Zojer, and A. Winkler
Phys. Rev. B **86**, 085402 – Published 1 August 2012



Evaporated atoms or molecules may form layers, needles, or clusters.

Heteroepitaxy

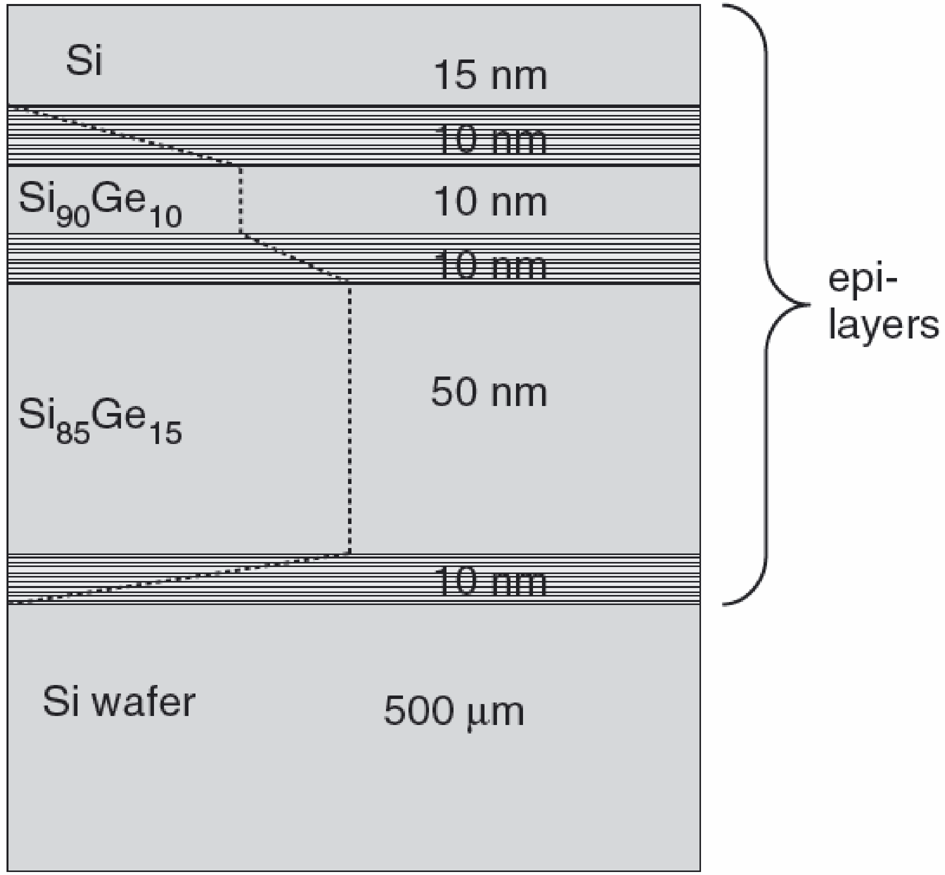
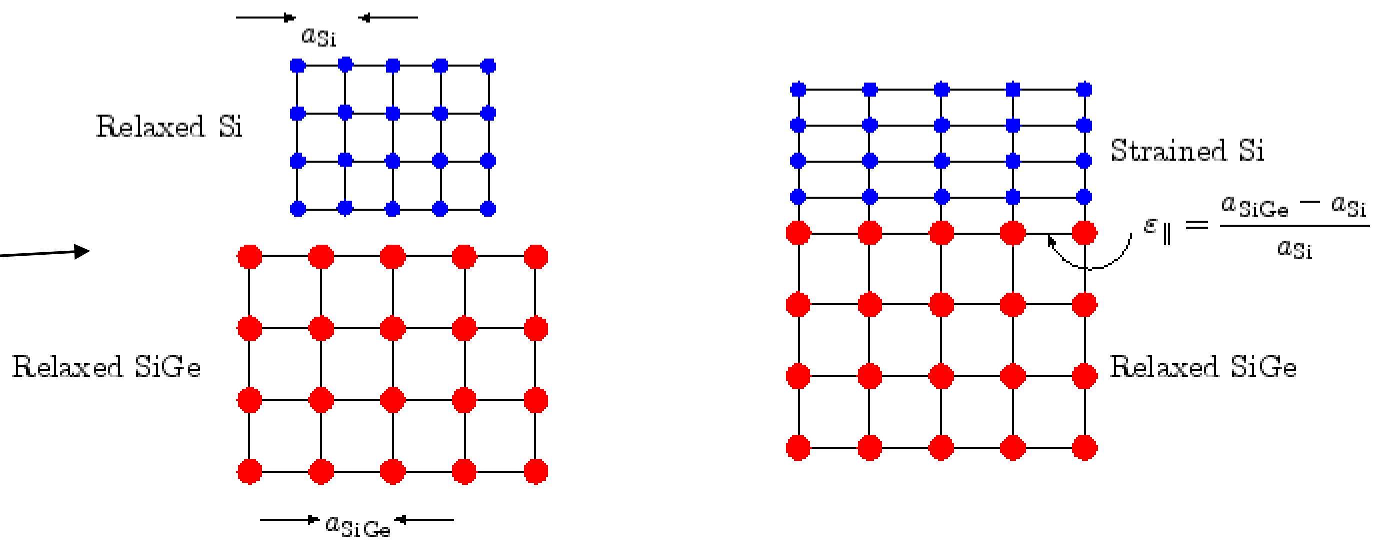


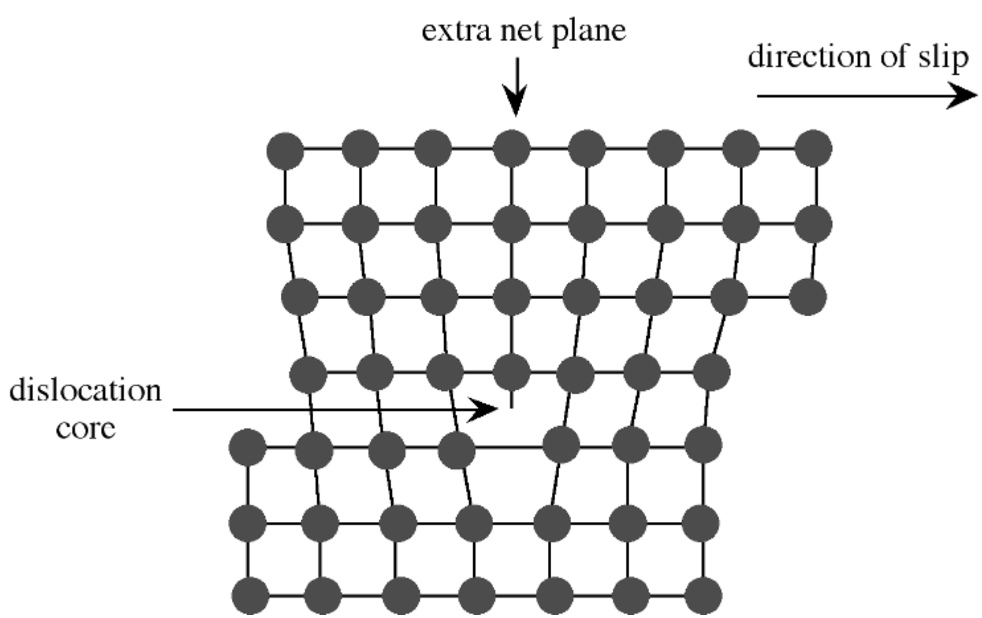
Figure 6.6 Thin heteroepitaxial $Si_{1-x}Ge_x$ layers for high-speed bipolar transistors. The hatched layers are graded epilayers with constantly changing germanium content

Fransila

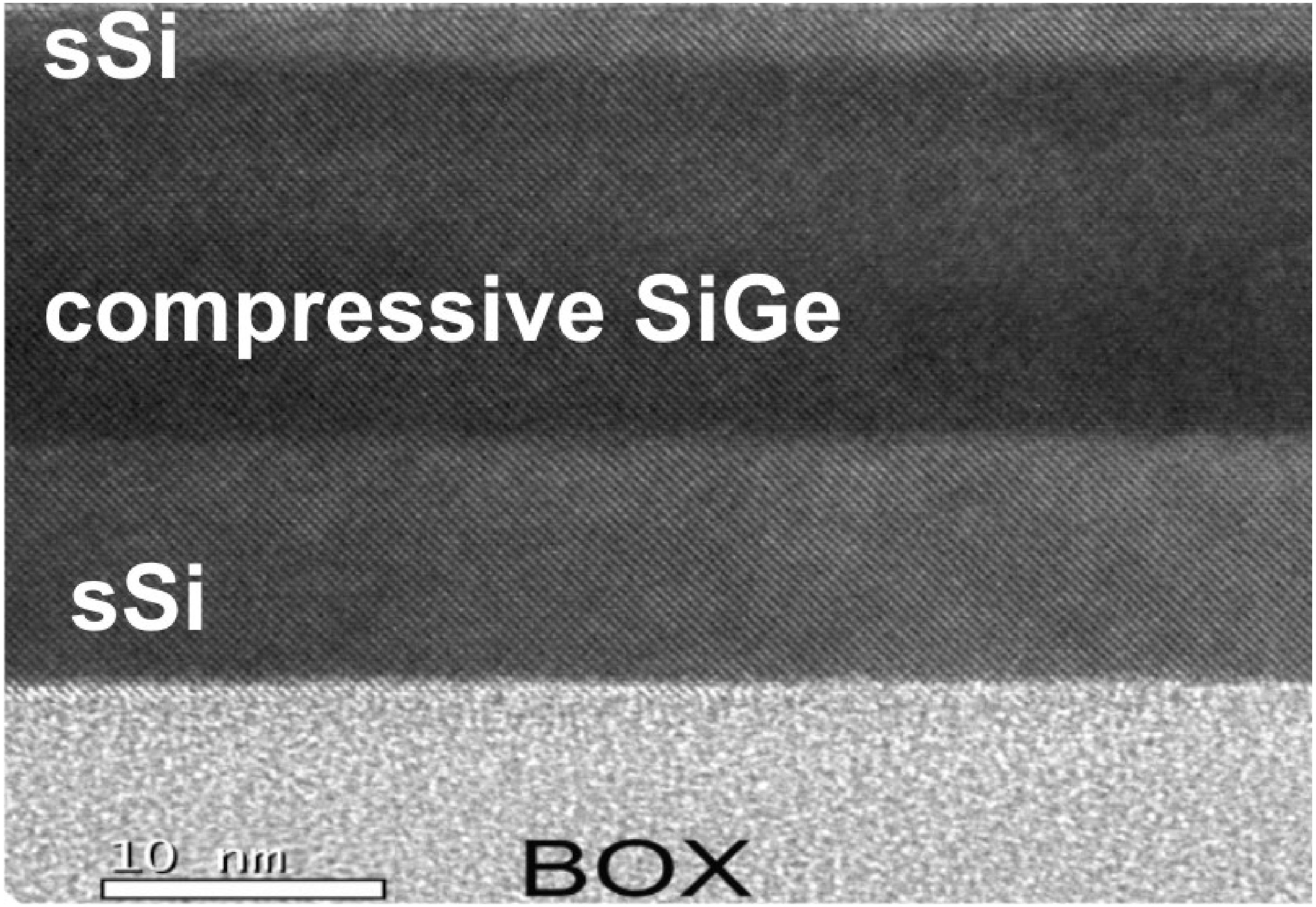
Strain induced by lattice mismatch

http://www.iue.tuwien.ac.at/phd/dhar/node12.html





http://cnx.org/contents/e90d5161-66b0-4214-bd6c-9f1d20a35bae@10/Crystal_Structure

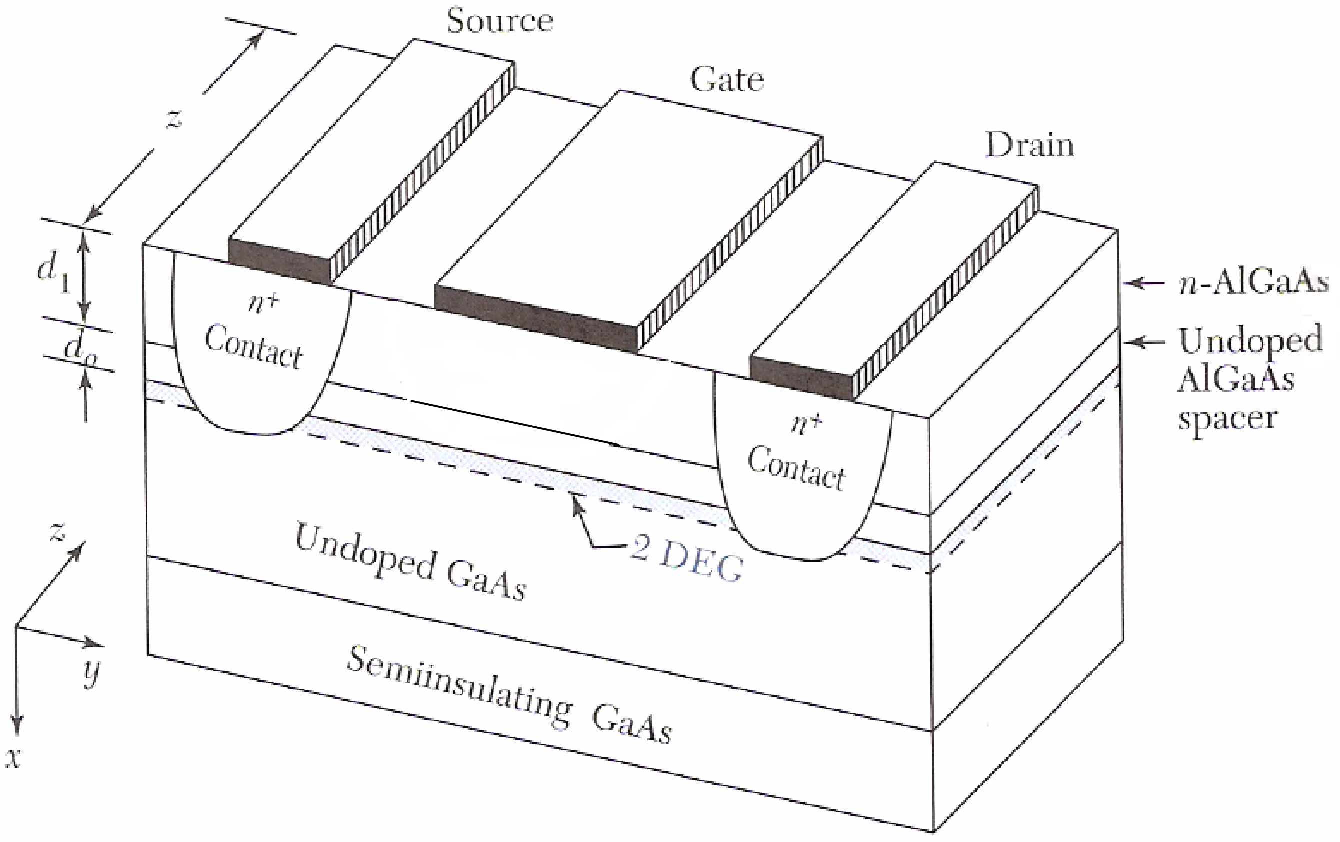


TEM image of a 3 nm Si cap/ 15 nm SiGe 50% /10 nm strained SOI structure grown at CEA-Leti and used for p-SiGe MOSFET fabrication.

http://www.fz-juelich.de/pgi/pgi-9/EN/Forschung/08-strained%20silicon/04_Biaxially%20strained%20Si_SiGe_%28S%29SOI%20heterostructure/_node.html

MODFET (HEMT)

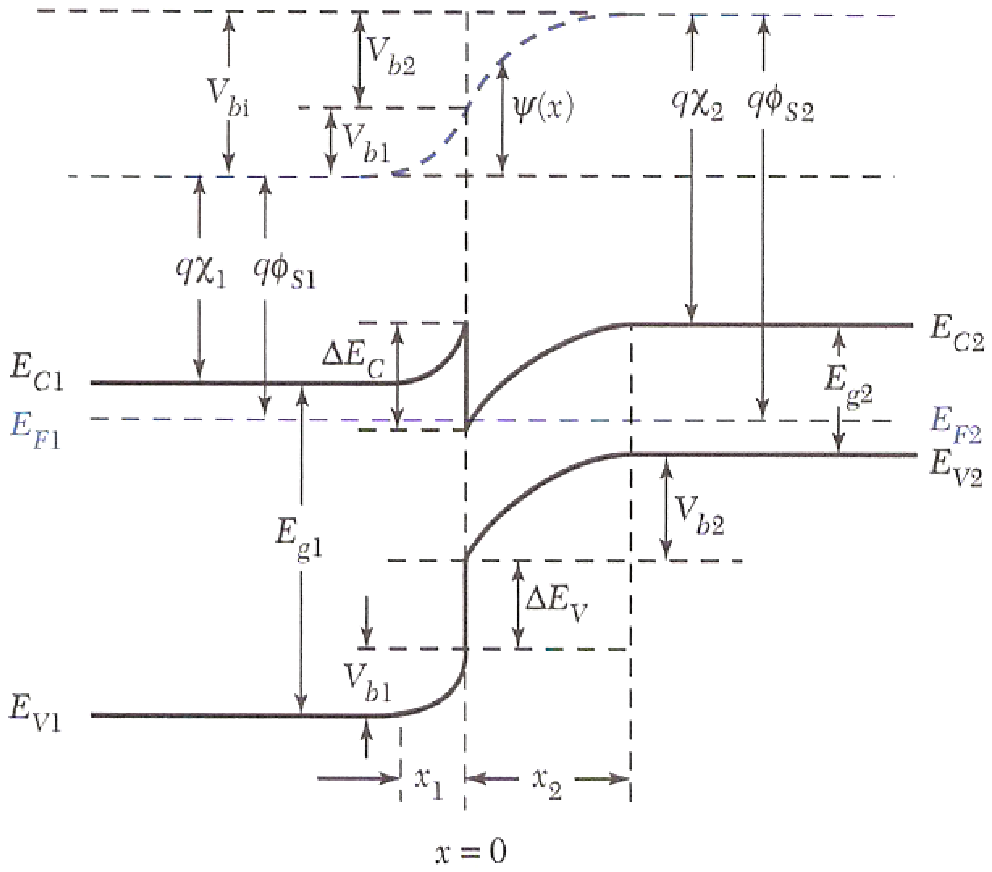
Modulation doped field effect transistor (MODFET)
High electron mobility transistor (HEMT)



V_T = Threshold voltage = voltage where charge is depleted

Heterostructure

pn junction formed from two semiconductors with different band gaps



MODFET/HEMT

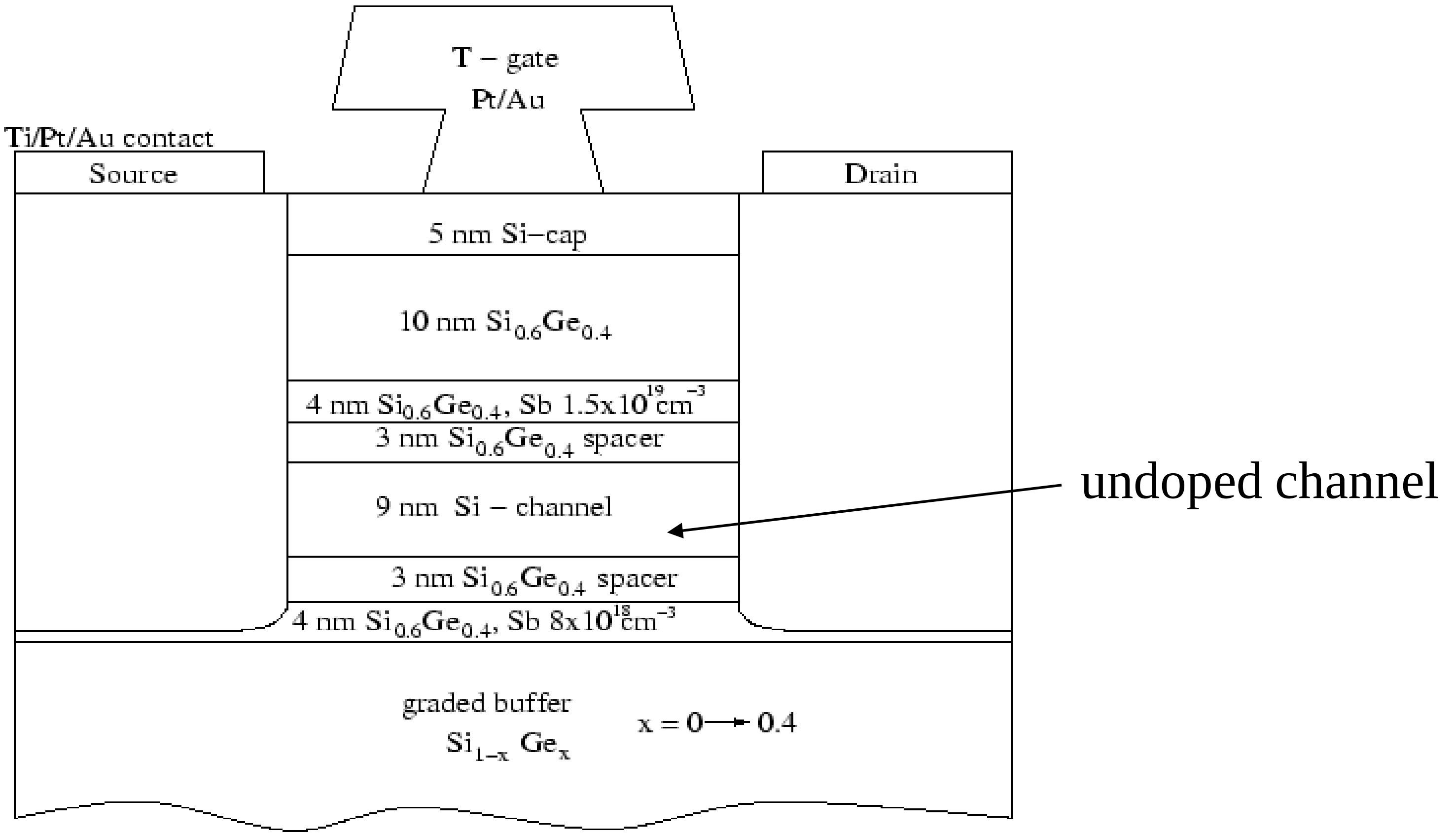


Figure 3.3: S-MODFET structure.

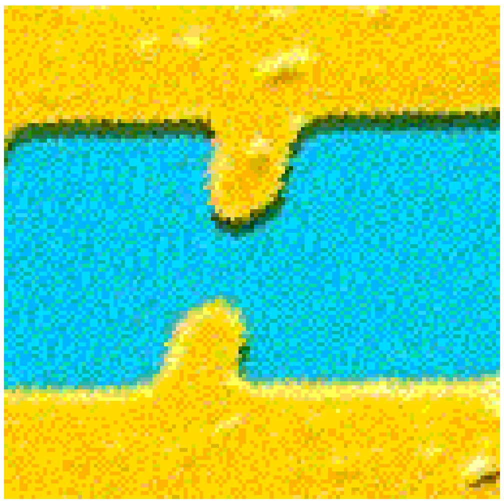
HEMT: HEMT devices are found in cell phones, electronic warfare systems, microwave and millimeter wave communications, radar, and radio astronomy.

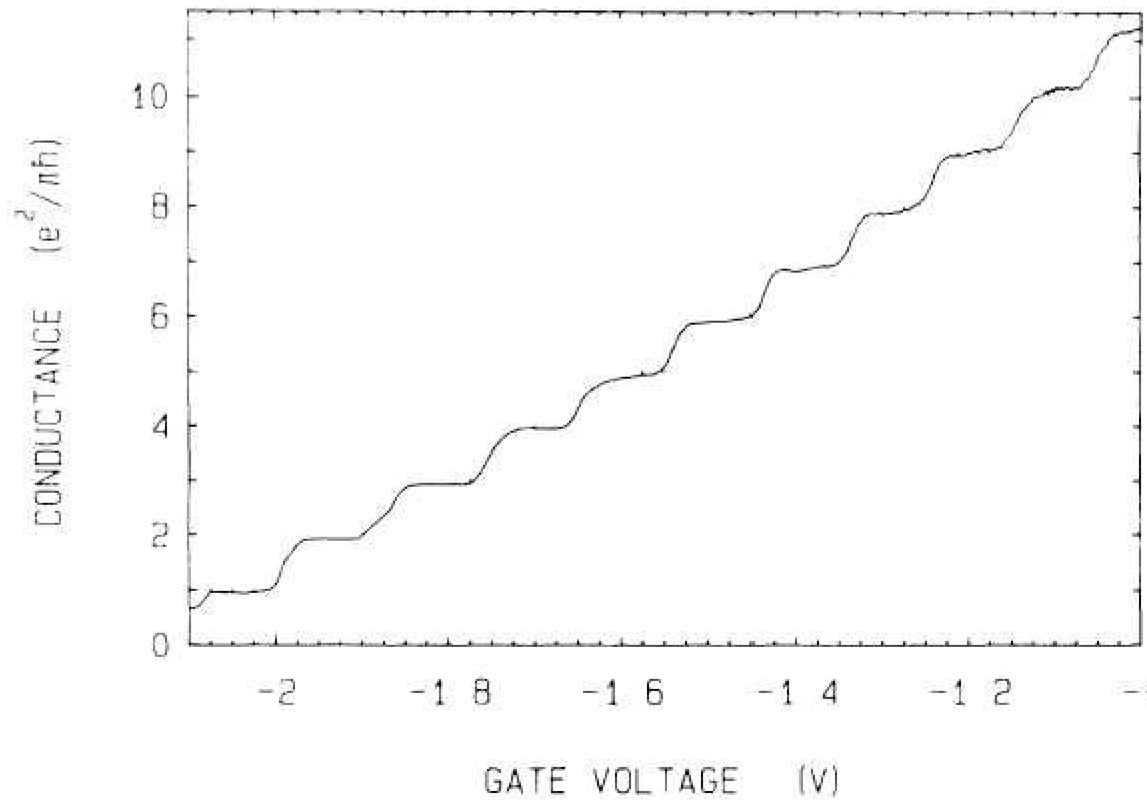
PhD Thesis Sergey Smirnov

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

Quantized conduction

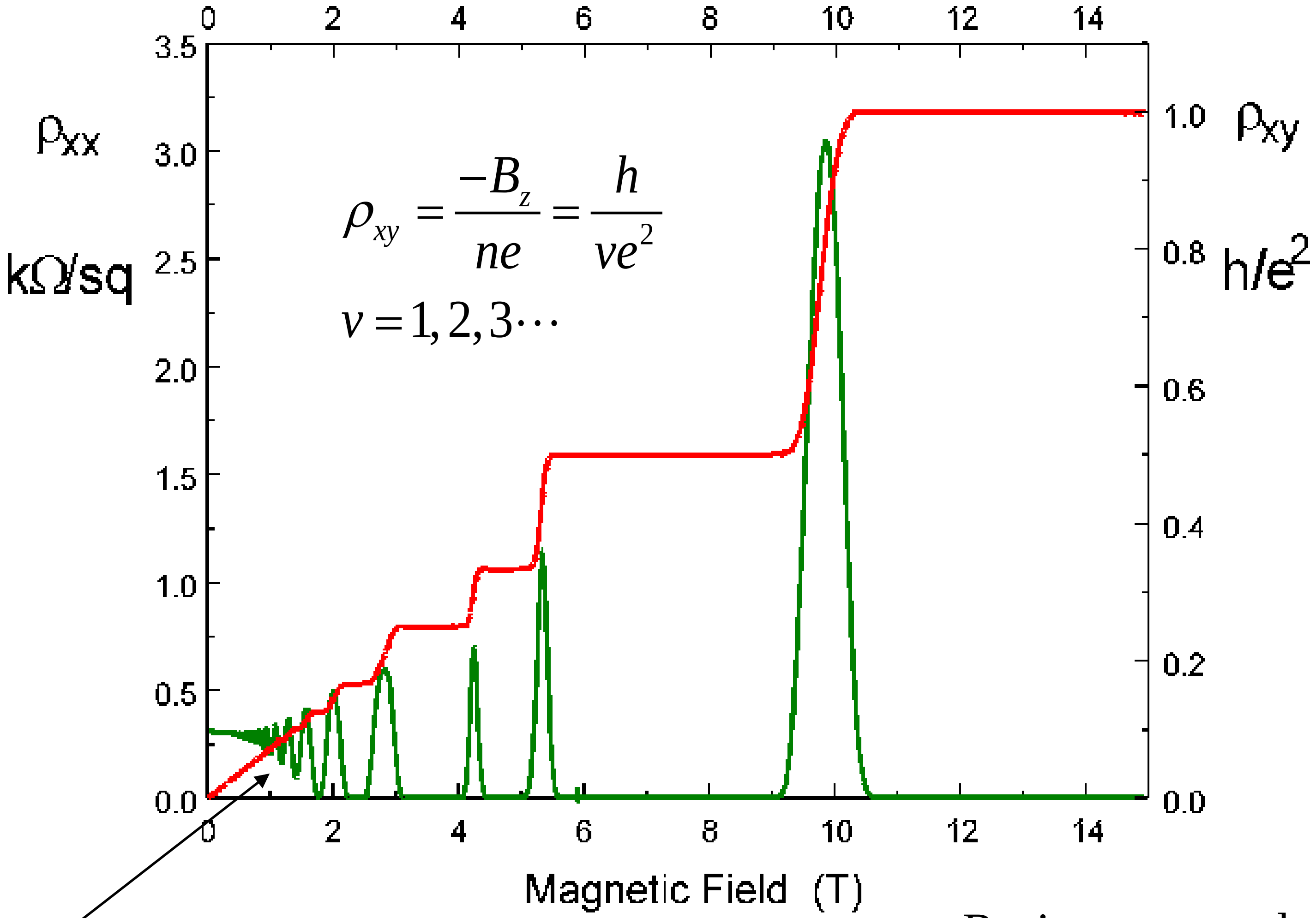
$$R_K = h/e^2 = 25812.807557(18)\ \Omega$$





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).

Quantum Hall Effect



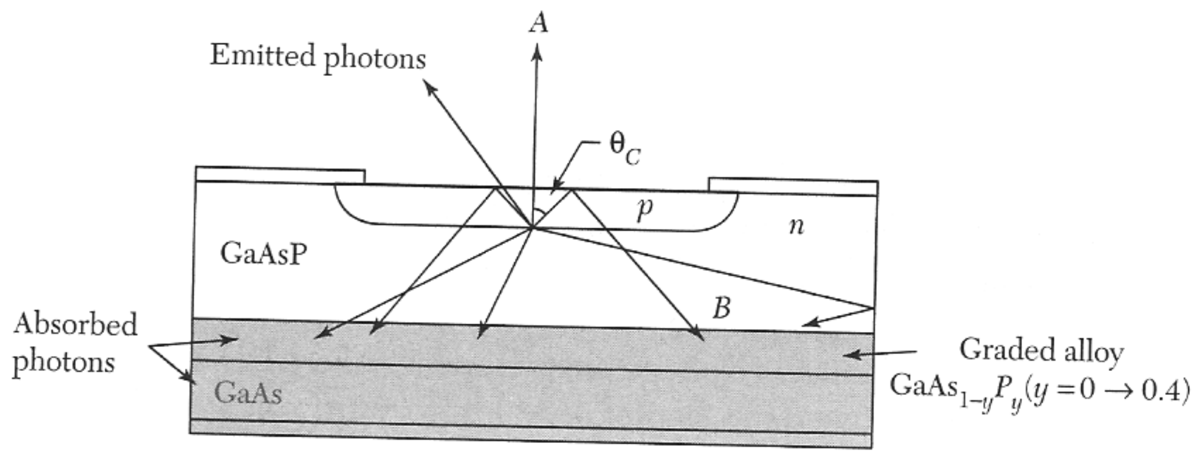
$$\rho_{xy} = \frac{-B_z}{ne} = \frac{h}{ve^2}$$

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

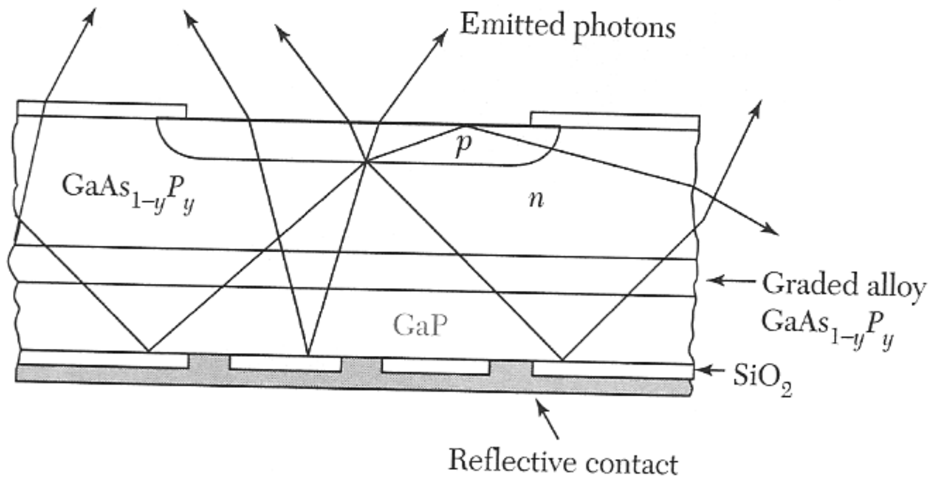
Shubnikov-De Haas oscillations

Resistance standard
25812.807557(18) Ω

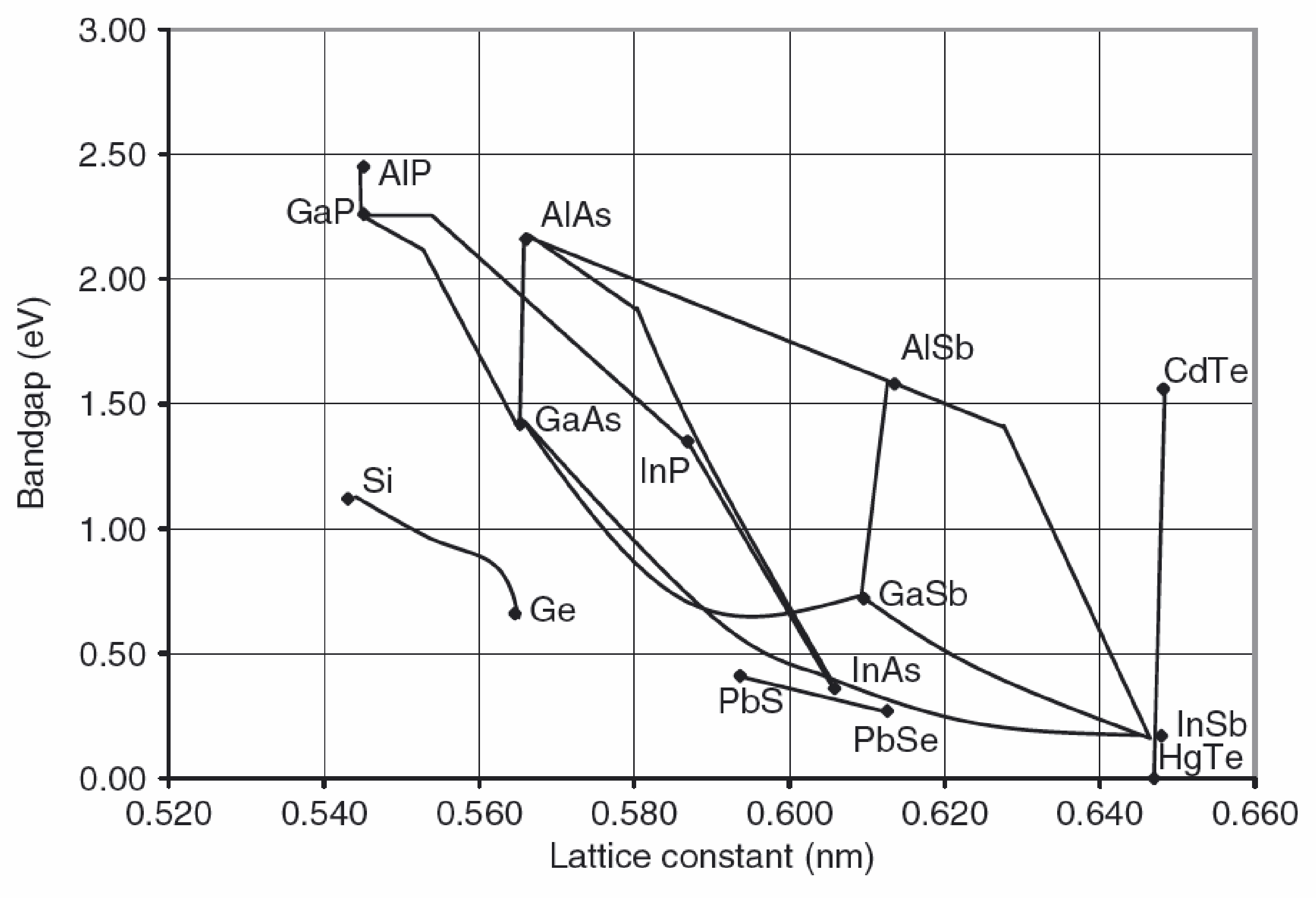
Light emitting diodes



absorption
reflection
total internal reflection

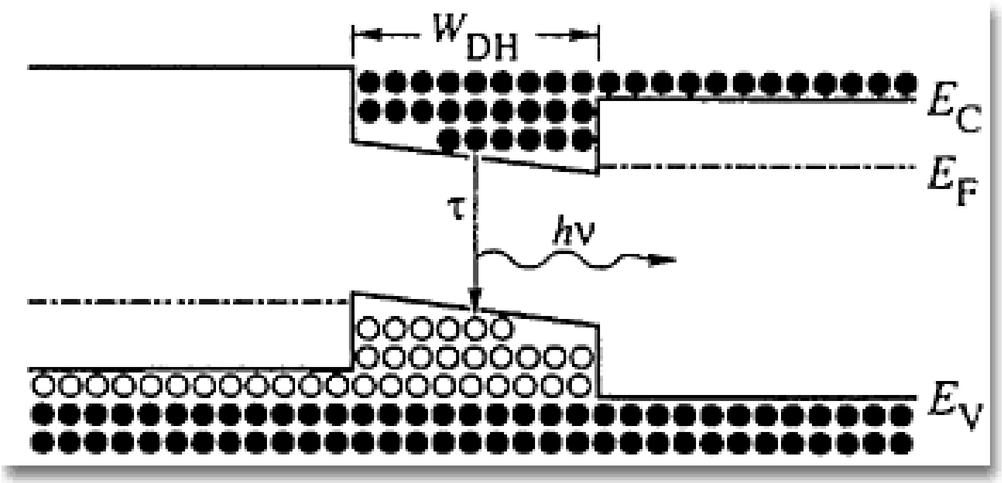


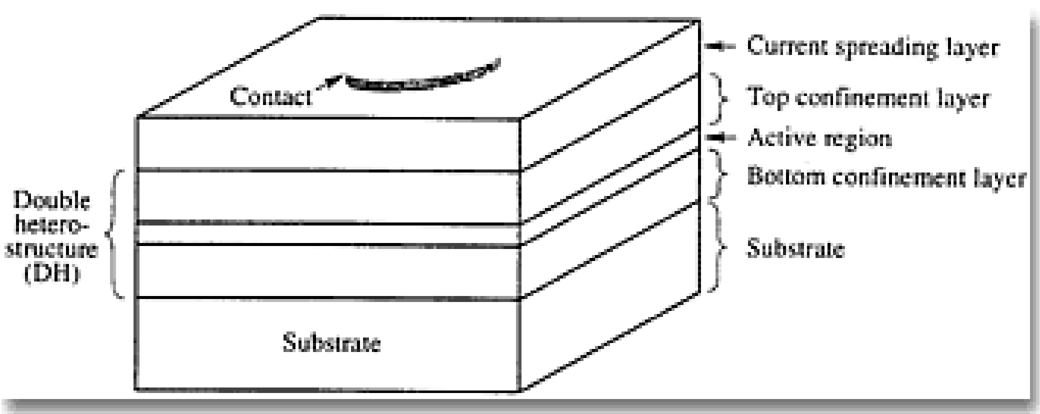
Bandgaps



3.00
2.50
2.00
1.50
1.00
0.50
0.00
Bandgap (eV)
0.520
0.540
0.560
0.580
0.600
0.620
0.640
0.660
Lattice constant (nm)
AlP
GaP
AlAs
AlSb
CdTe
GaAs
InP
Si
Ge
GaSb
InAs
PbS
PbSe
InSb
HgTe

Double Heterojunction lasers





http://spie.org/x18854.xml