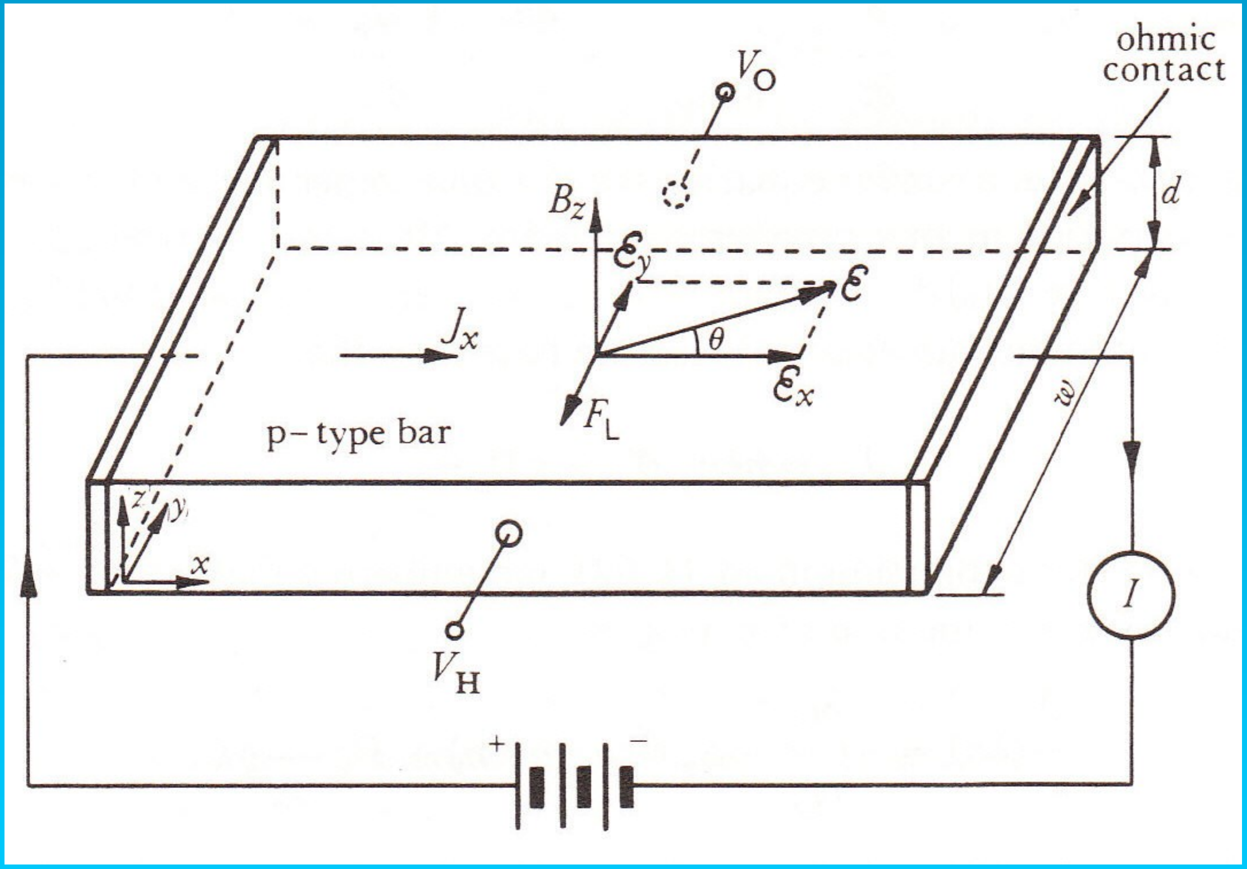
Hall effect

If a current is passed through a semiconductor and a magnetic field B is applied at right angles to the direction of current flow, an electric field is induced in a direction mutually perpendicular to B and the direction of current flow. This phenomena is known as the Hall effect. A Hall measurement confirms experimentally the validity of the concept that it is possible for two independent types of charge carrier, electrons and holes, to exist in a semiconductor.


ohmic
contact
V_O
B_z
d
$\mathcal{E}_y$
$\mathcal{E}$
J_x
θ
$\mathcal{E}_x$
w
F_L
p- type bar
z
y
x
I
V_H
+
−

- Consider a bar of p-type material, carriers to be positive holes, of charge e, only. Assume that a current density J_x is produced in the bar by application of an electric field E_x and that a magnetic field of flux density B_z is applied in the z-direction. Since the holes are flowing with some drift velocity v_{Dx} under the influence of the applied field, they experience a Lorentz force:

$$F_L = ev \times B$$

Of magnitude

$$\left| F_L \right| = ev_{Dx} \times B_Z$$

And direction in the negative y-direction. This force tends to drive holes towards the front face of the block; there is an excess of holes there and a deficiency of holes at the back face. Since there can be no net flow in the y-direction, the movement of holes to front and back creates an electric field in the positive y-direction, E_y. This electric field produces a force on the holes which exactly compensates for the Lorentz force field and prevents transverse current flowing.

Hence, in equilibrium:

$$eE_y = F_L = ev_{Dx}B_z \qquad (1)$$

Also the current density is given by:

$$J_x \approx pev_{Dx}$$

Which can be substituted into (1) to give

$$E_y = \frac{J_x B_z}{pe} \qquad (2)$$

Thus, if voltage probes are attached to front and back faces, assumed separated by a distance w, a voltage

$$V_H = E_y w$$

May be measured.

The Hall coefficient, R_H and from (2) is

$$R_H = \frac{E_y}{J_x B_z} = \frac{1}{pe}$$

Alternatively, if the current through the bar of thickness d is I:

$$R_H = \frac{V_H}{wIB_z}.wd = \frac{V_H d}{IB_z} = \frac{1}{pe}$$

It will be verified easily that for n-type material where the current is carried by majority electrons, the polarity of the hall voltage, V_H, is reversed and

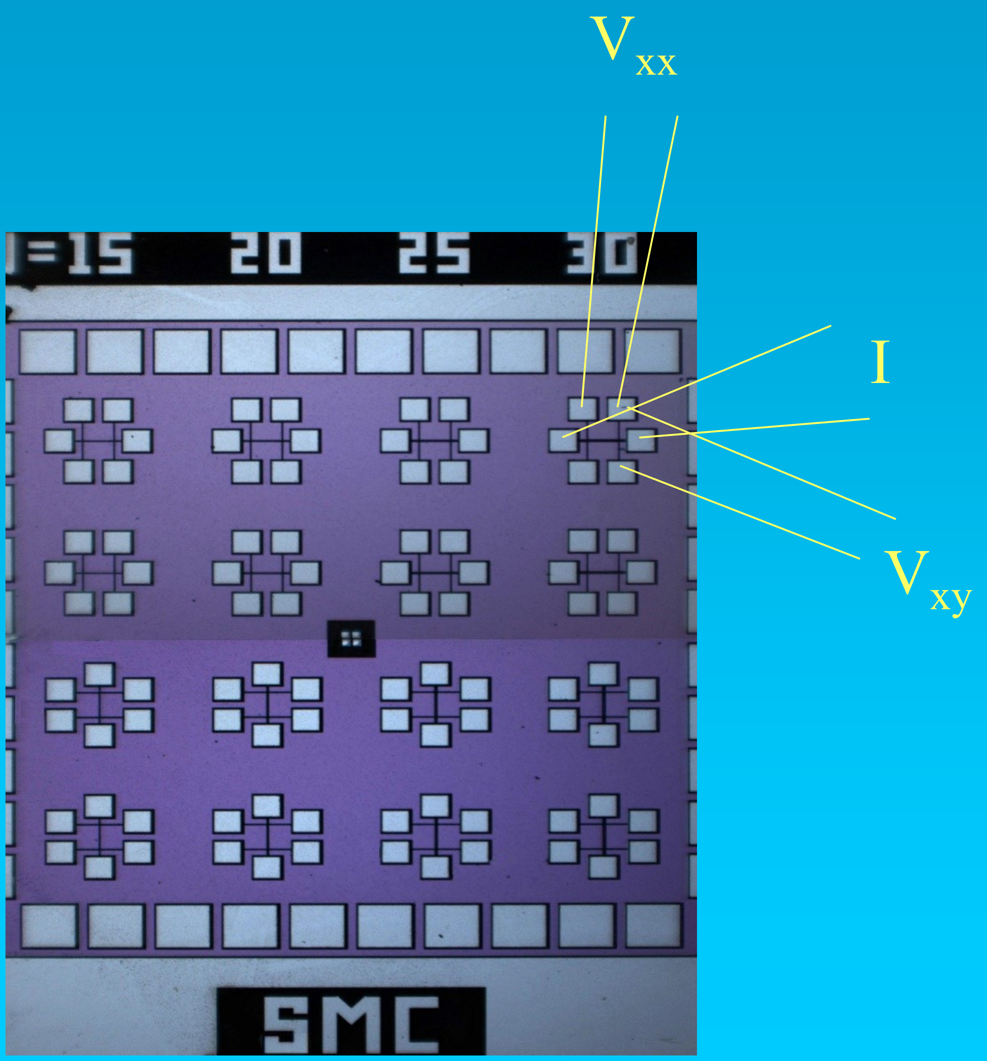
$$R_{He} = -\frac{1}{ne}$$

- We see that the measurement of current and magnitude and sign of the Hall voltage for any given magnetic flux density gives the sign of the charge carriers, that is, it shows whether the doped semiconductor is n- or p- type, together with the density of the majority carriers.

- The Hall mobility is given by:

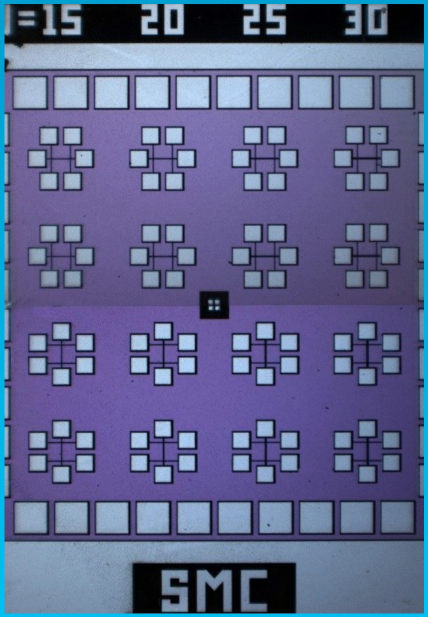
$$\mu_H = R_H \sigma$$

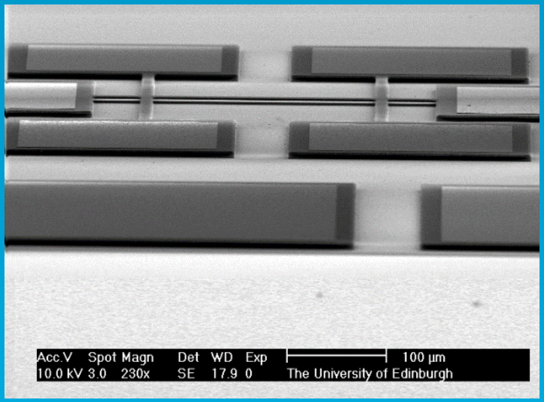
Typical Hall bar structure

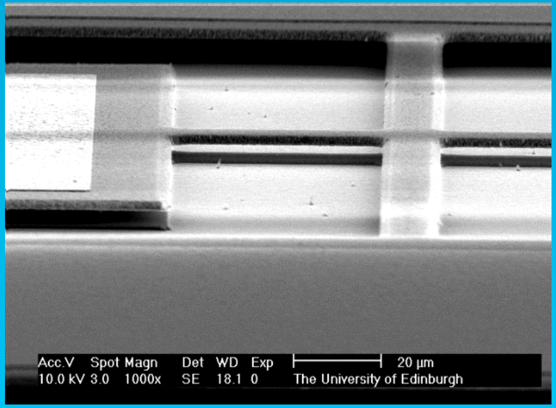


Bridge width between 15 - 30 microns
Bridge length 340 microns

Towards electronics





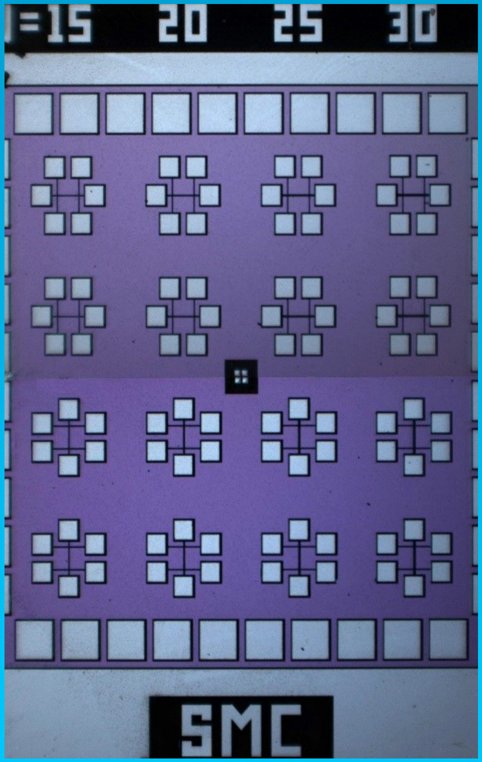


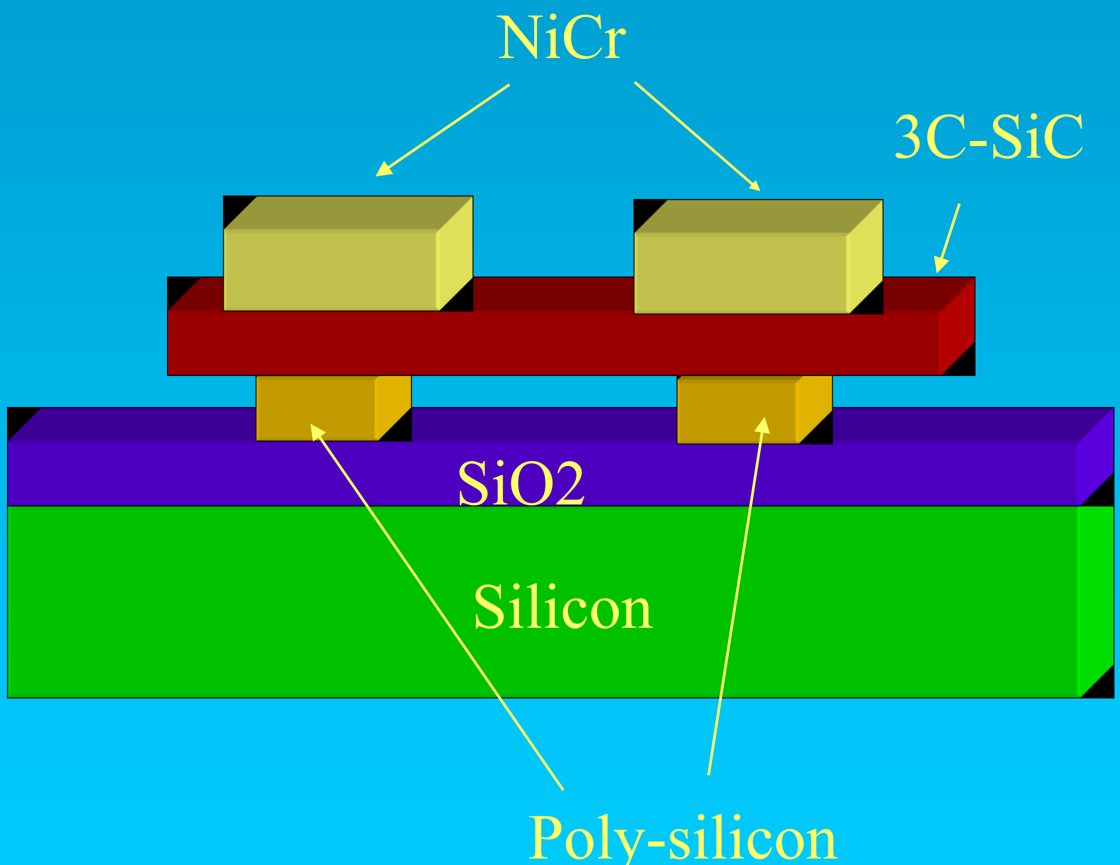
Hall bar structures in 3C-SiC

4 - 6 x 10^{20} /cm^3; 2 cm^2/Vs

Microelectronic Engineering, 83, pp 1396-1399, (2006)

Our Hall bar structures





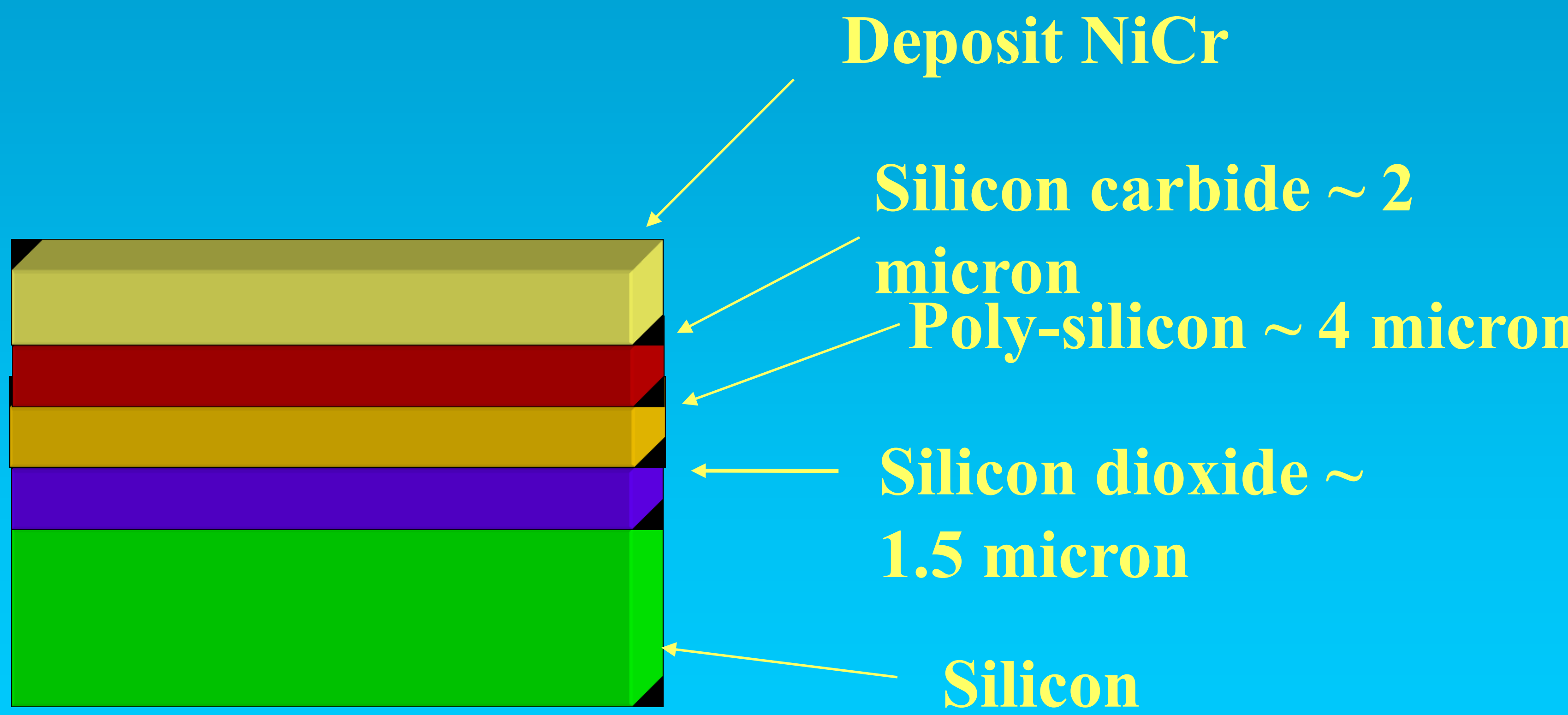
Bridge width between 15 - 30 microns

Bridge length 340 microns

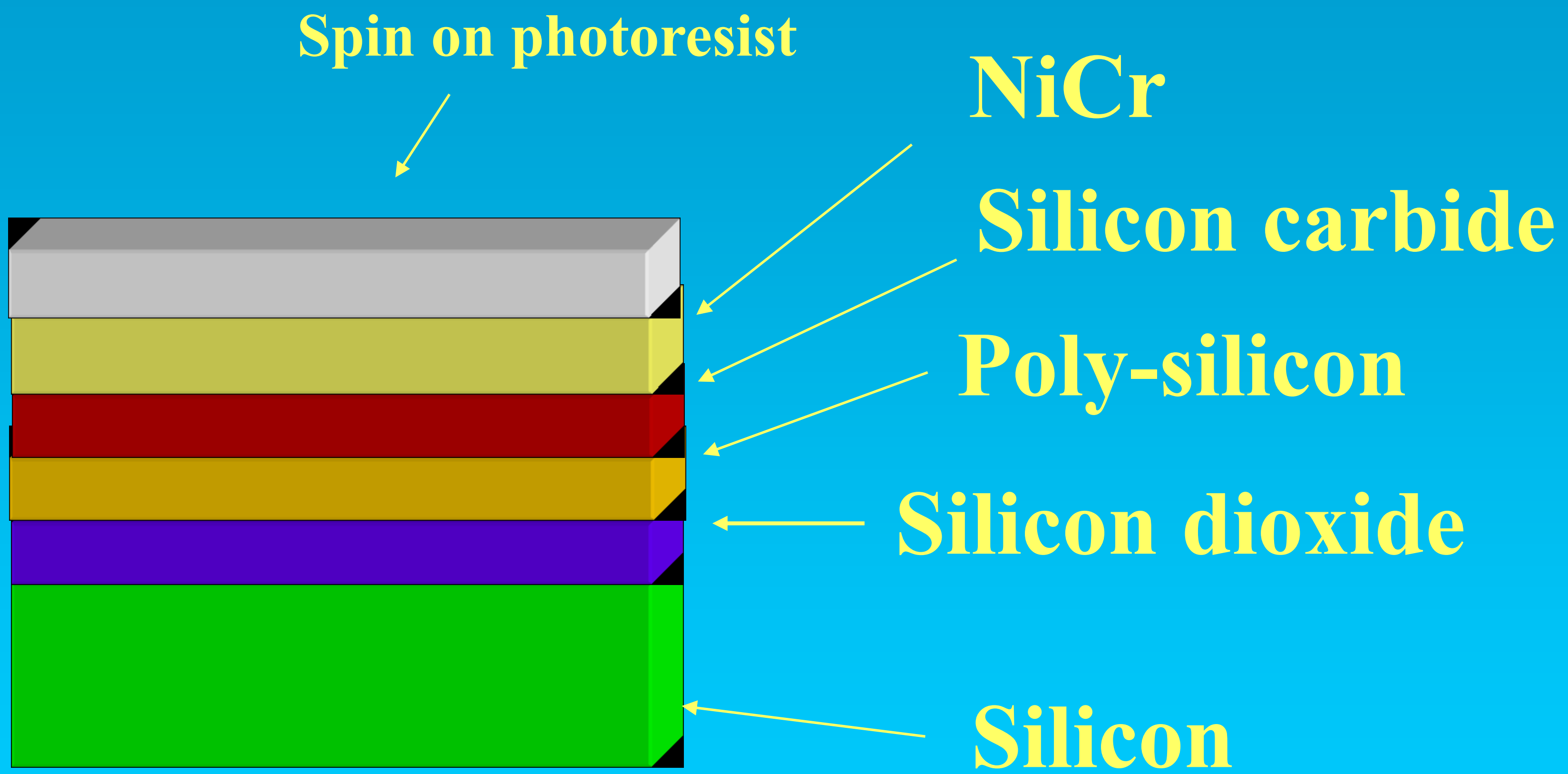
- **Advantages of our process procedures**
  - Optimised process can combine etching and release into one step
  - Suitable for batch processing
  - Can be included during MEMS design and fabrication to enable electrical characterisation of the material

Fabrication Procedures

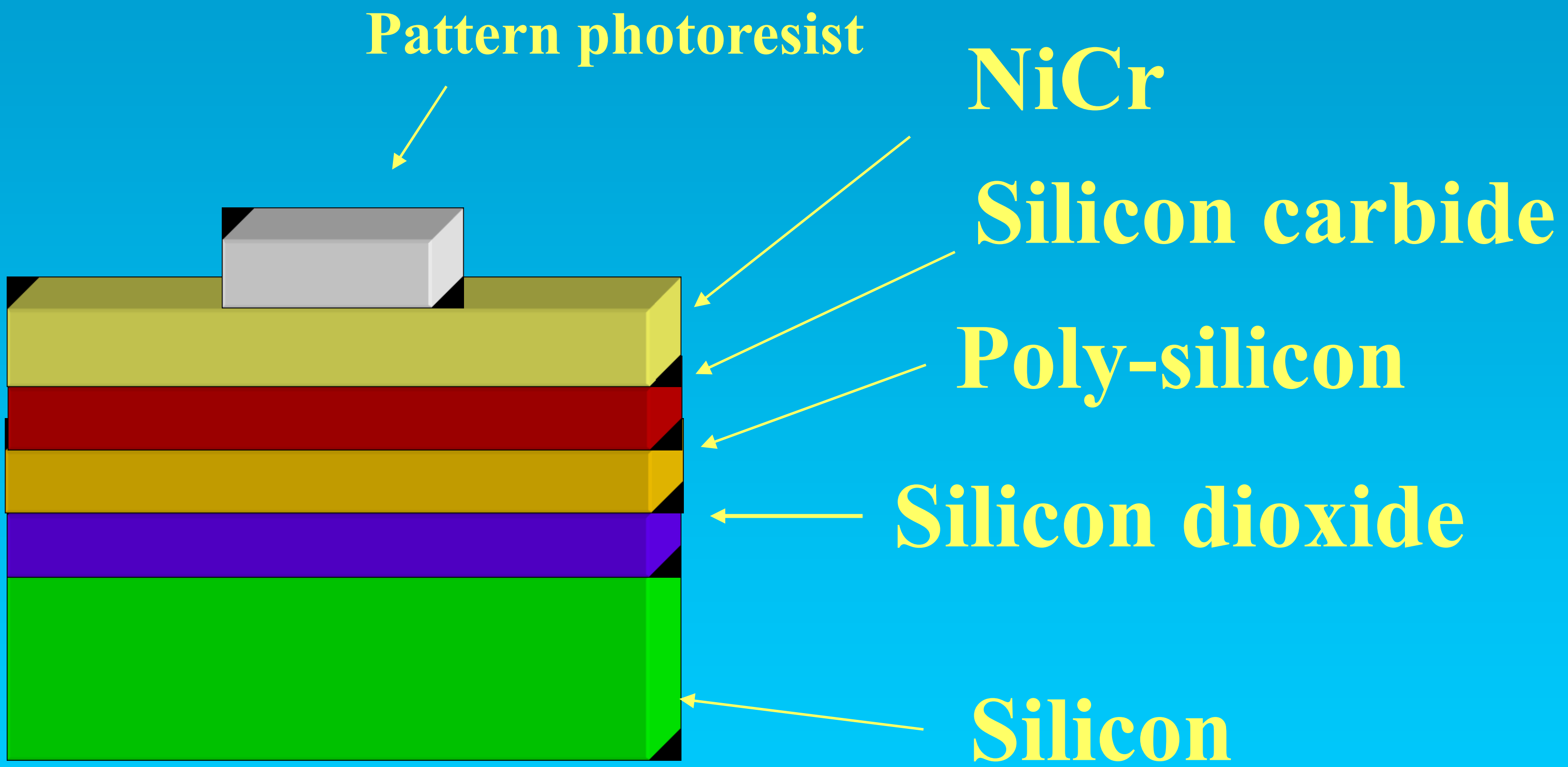
NiCr deposition



Pattern contacts

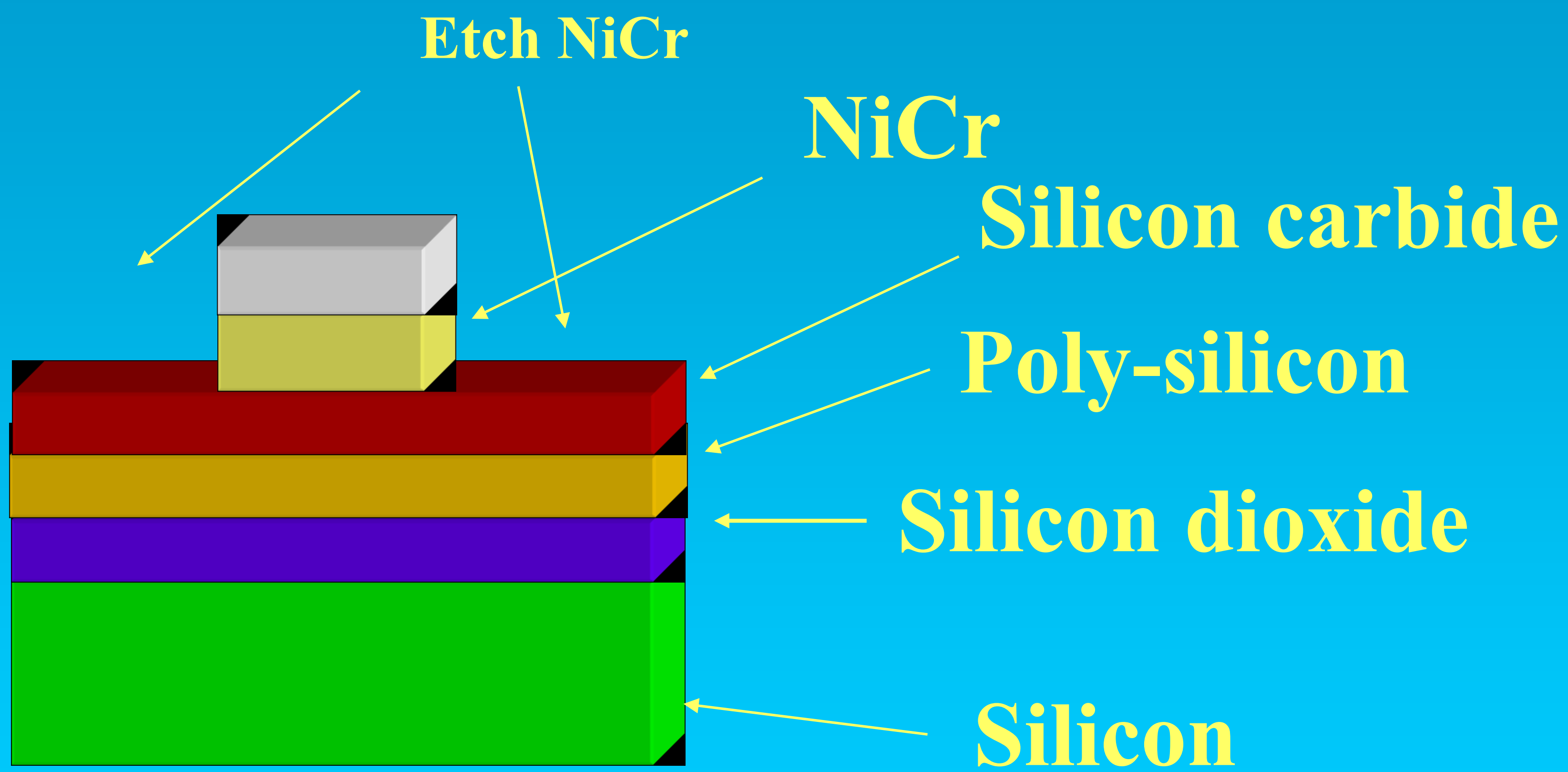


Pattern contacts

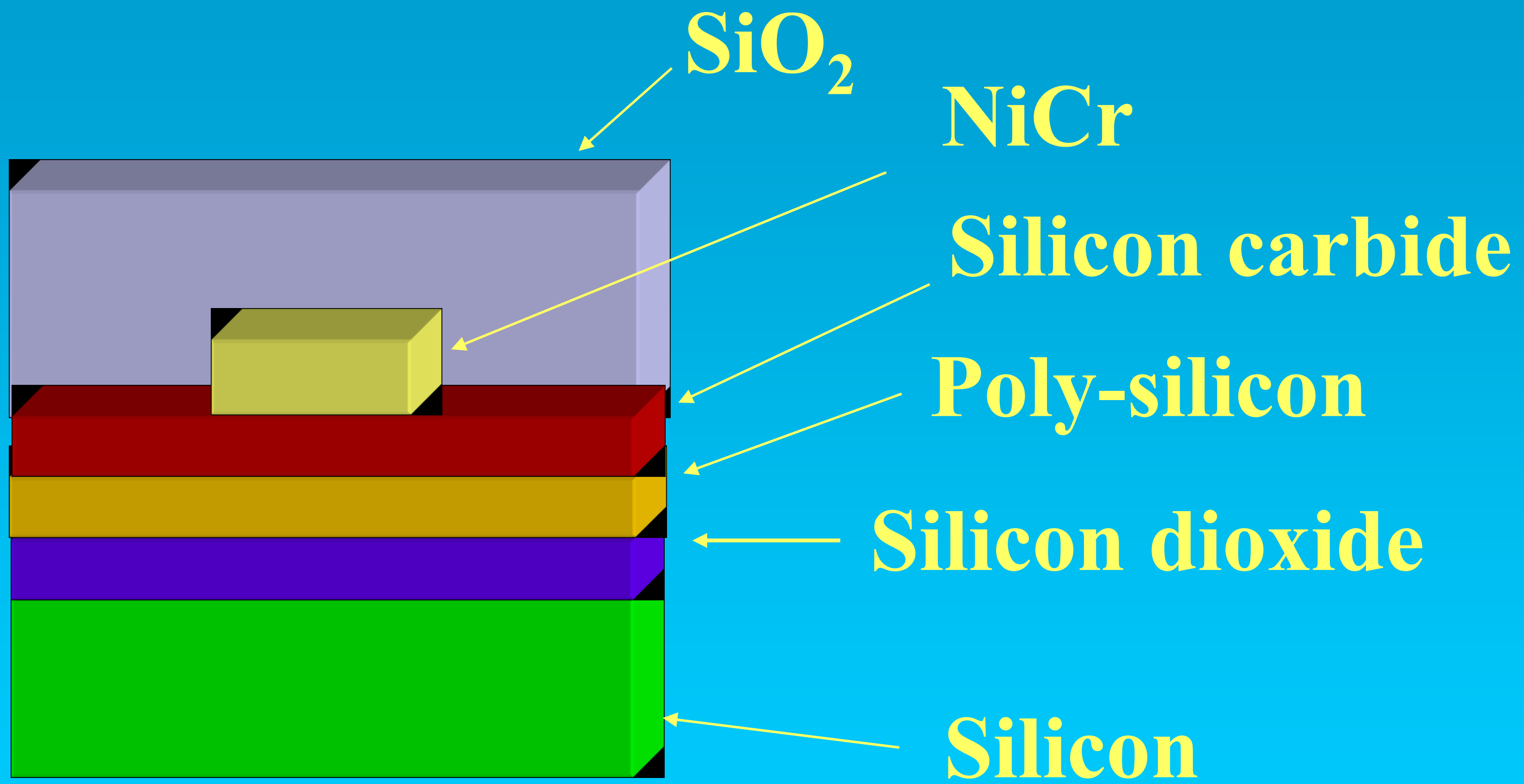


After optical lithography

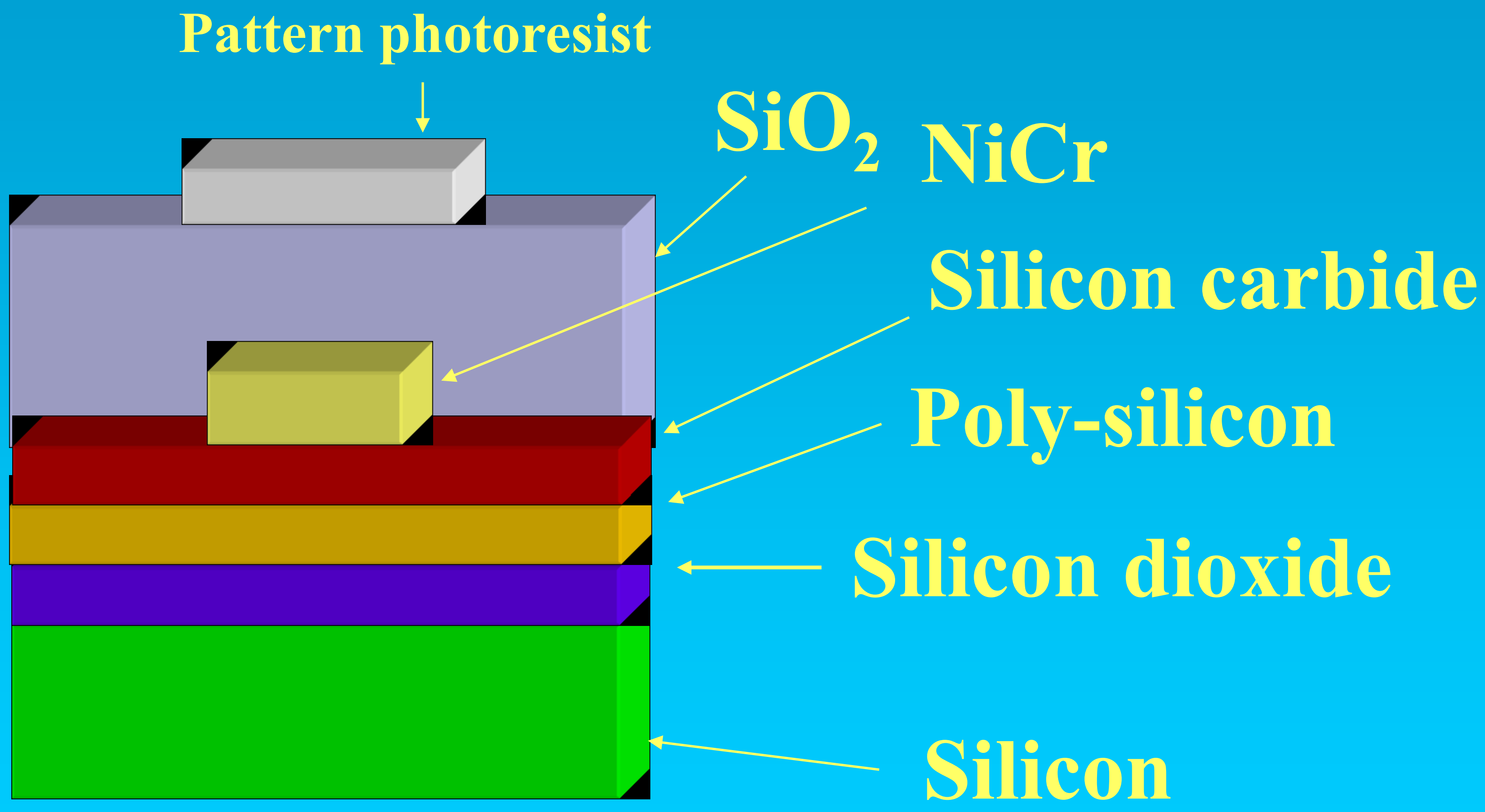
Pattern contacts



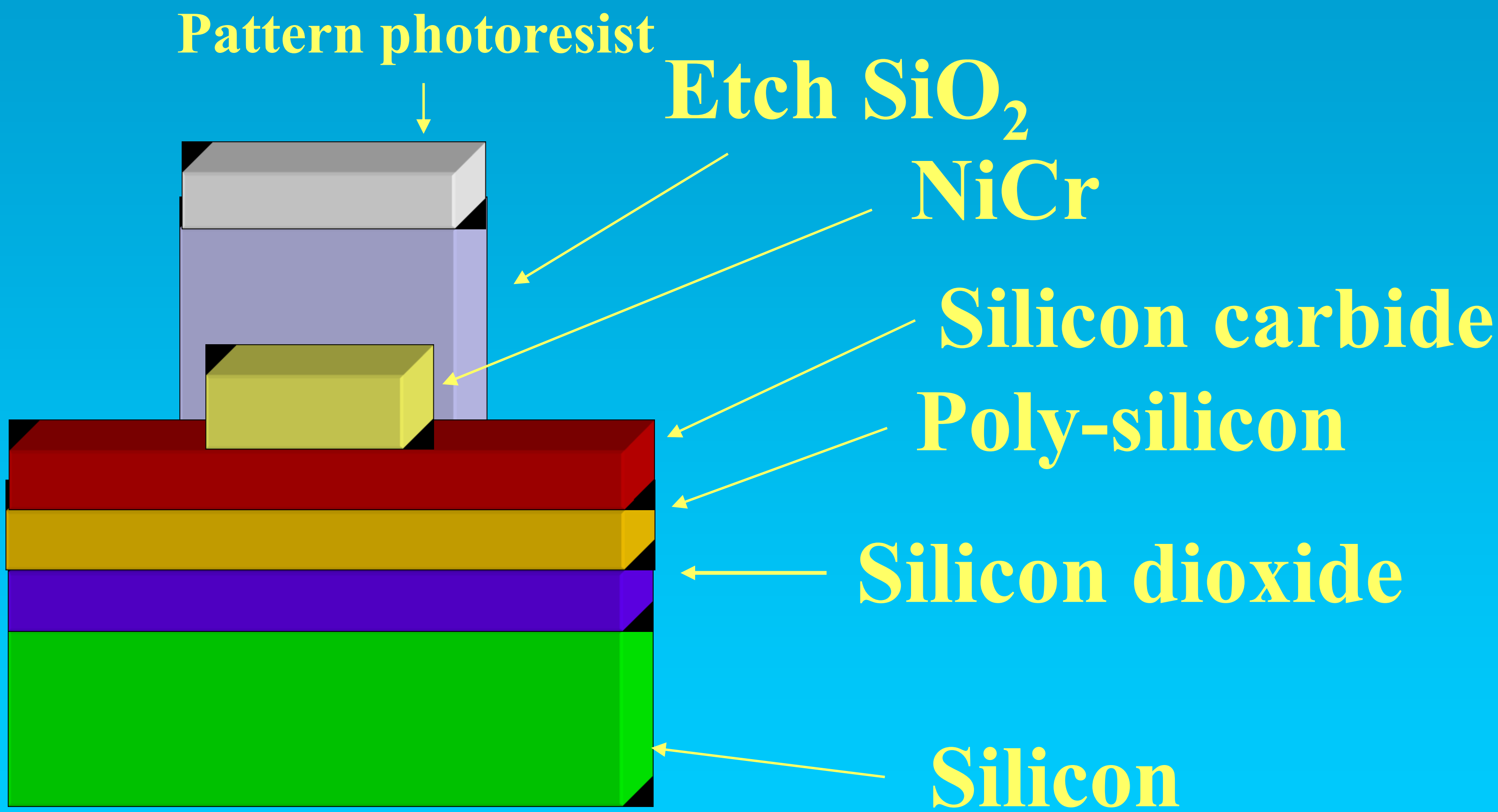
Deposit SiO_2 using PECVD



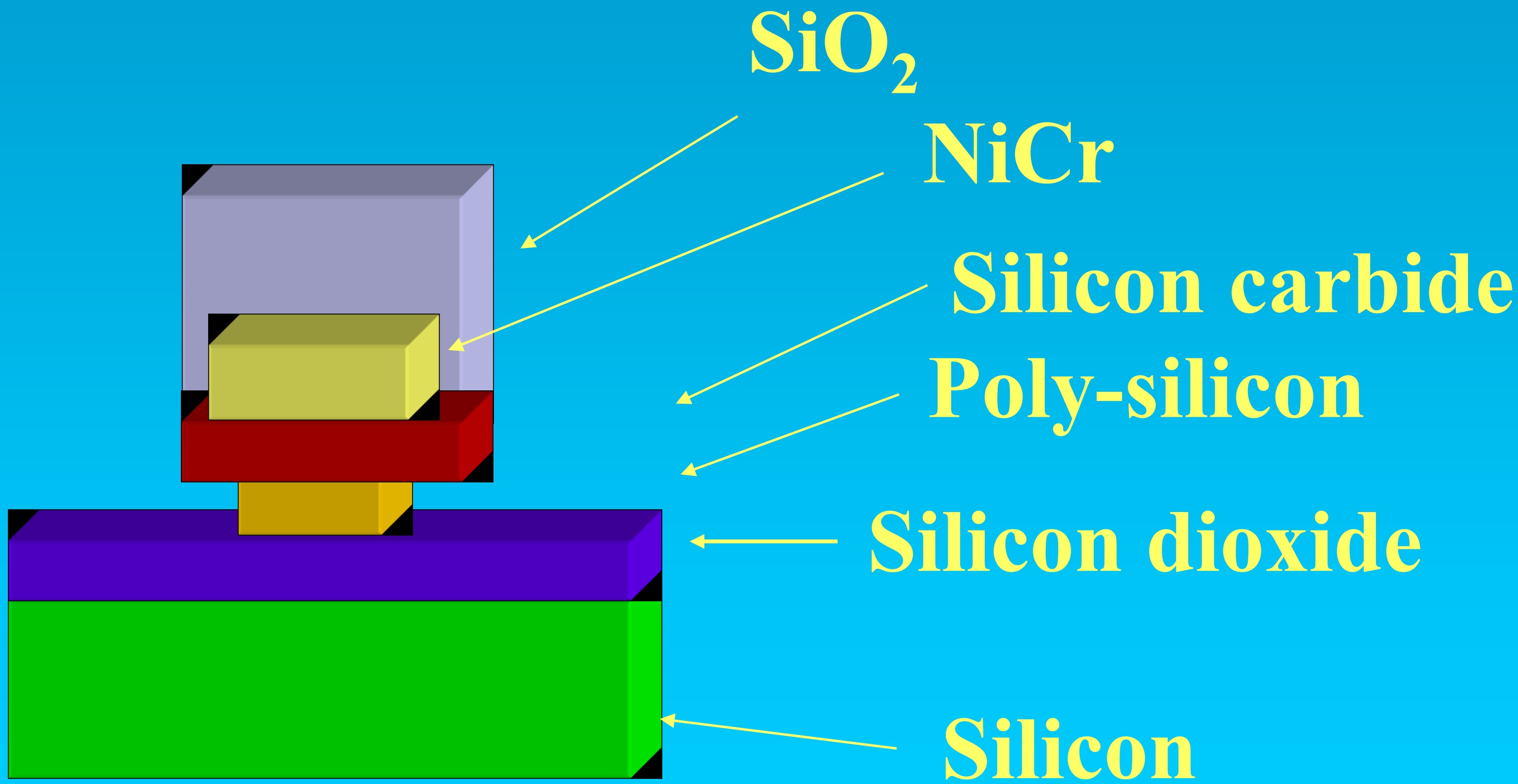
Pattern Hall bar device



Pattern Hall bar device

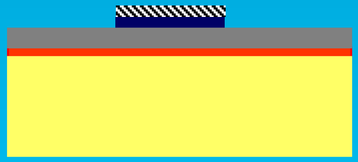


One step etch and release process

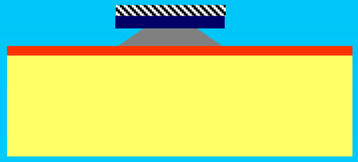


One-step dry etch and release

SF_6/O_2 ICP etch SiC

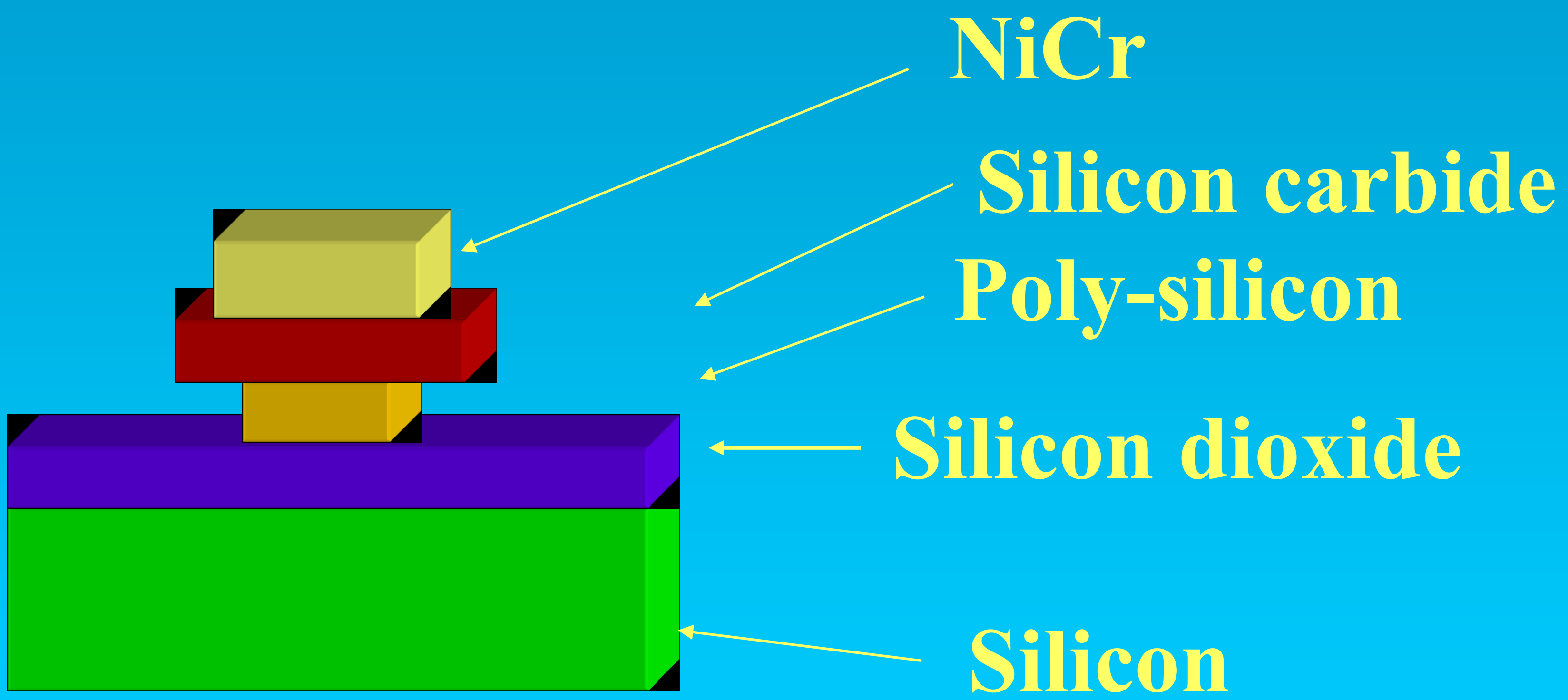


SF_6/O_2 ICP etch and undercut poly-Si sacrificial layer

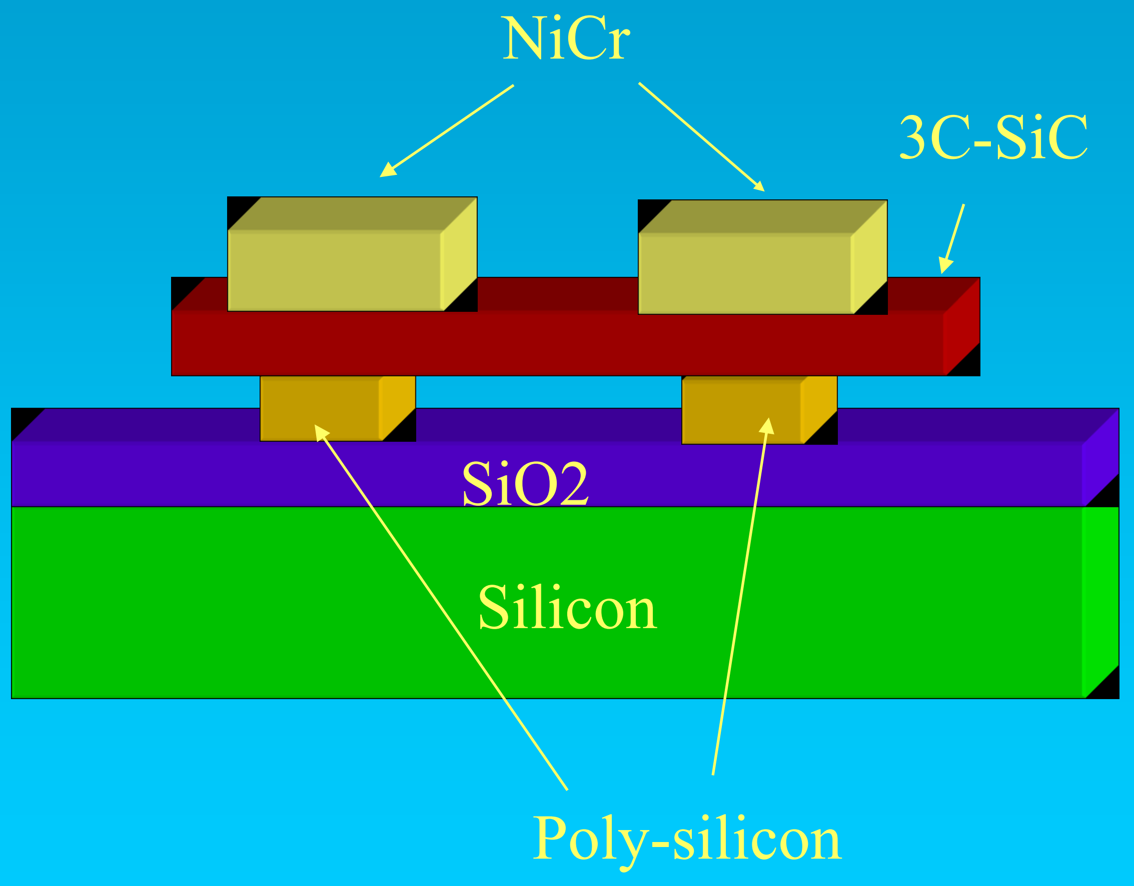


- Process conditions: SF_6 flow=40sccm; O_2 flow=10sccm; work pressure=5mT, ICP coil power=1kW, chuck power=50W, dc bias=100V
- Patterned SiO_2 has been used as a hard mask
- High etch rate selectivity of ~15 has been achieved between poly-Si to SiC: a single recipe has been used to pattern and release of SiC bridge

Remove SiO_2

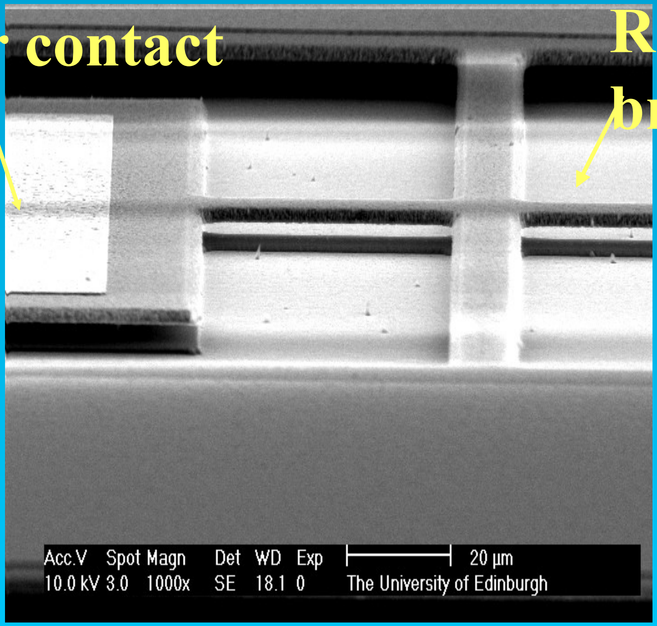

NiCr
Silicon carbide
Poly-silicon
Silicon dioxide
Silicon

Hall Device Structure

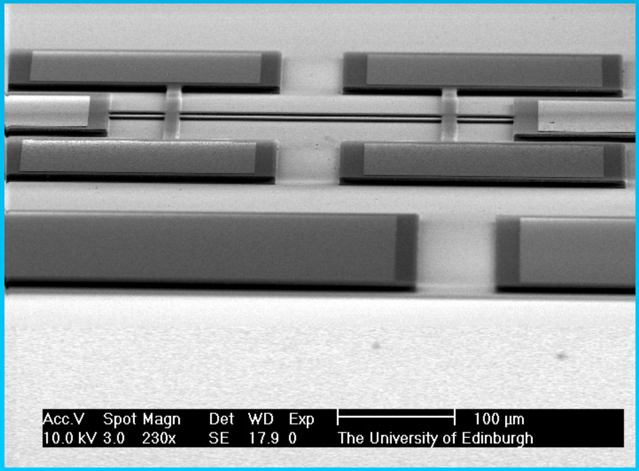


Picture of Hall bar

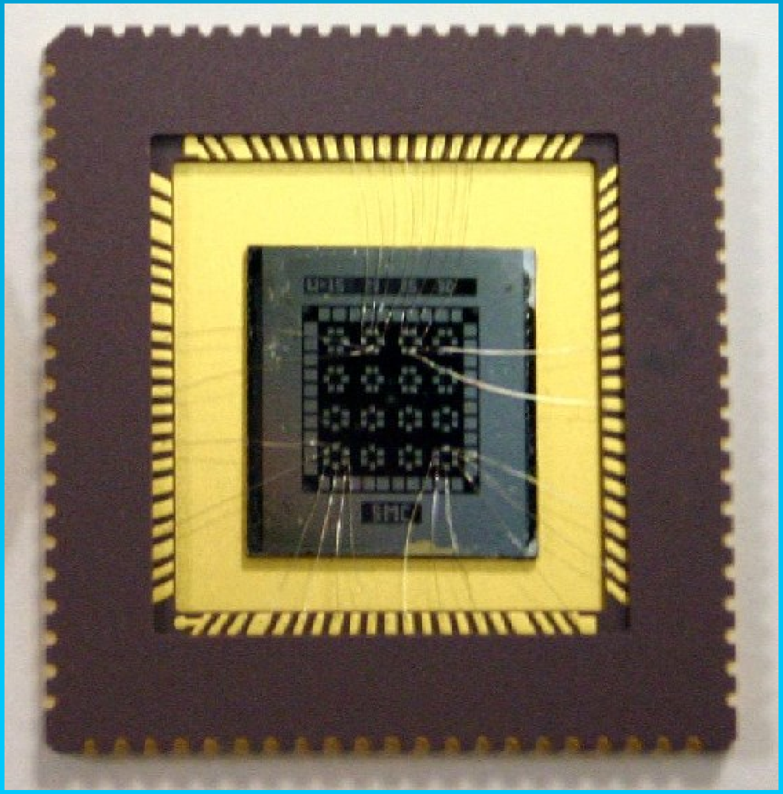
NiCr contact



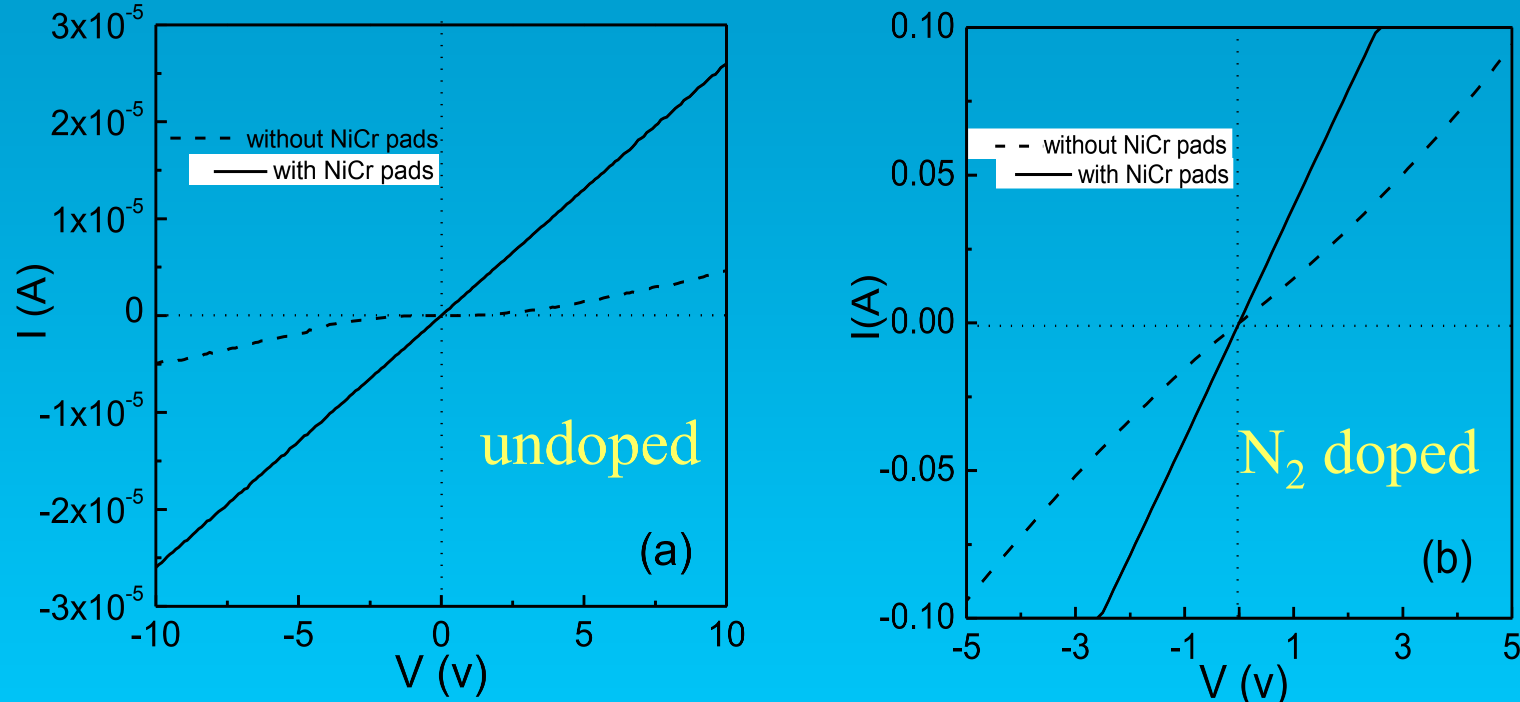
Released bridges



Picture of bonded chip

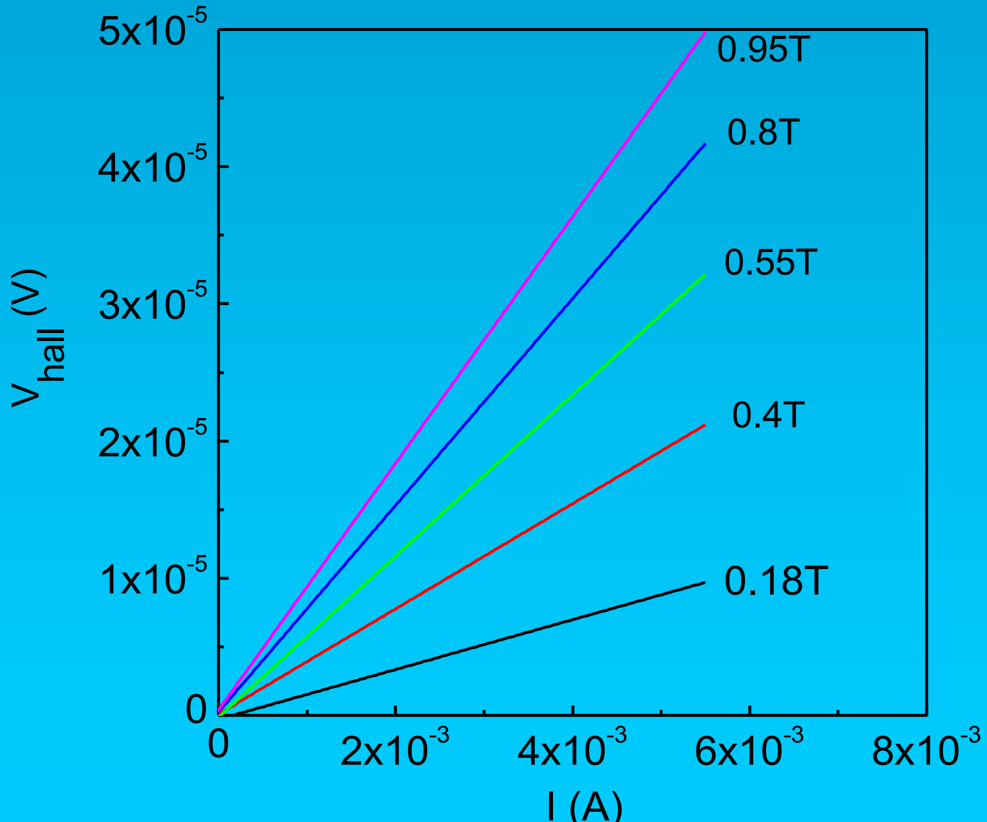


NiCr contacts on undoped and nitrogen doped 3C-SiC films



- Improvement of resistance and linearity of contacts after NiCr evaporation
- 5 orders of magnitude improvement in the resistivity for N_2 doped 3C-SiC films compared to undoped films

Hall voltage versus current up to 1Tesla for nitrogen doped 3C-SiC films



- Carrier concentration of 4-6 x 10^{20} /cm^3
- Mobility of ~ 2 cm^2/Vs

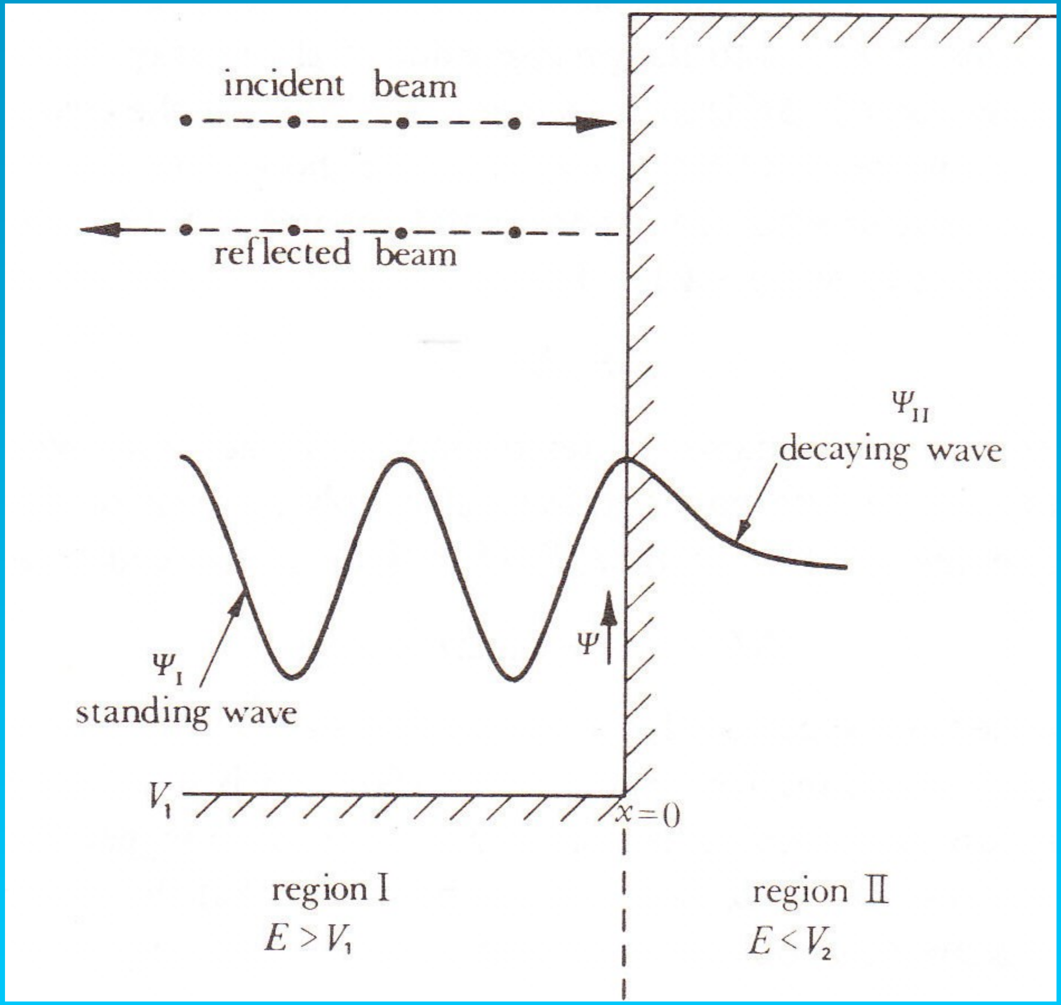
Hall question

- A bar of n-type germanium 10mm x 1mm x 1mm is mounted in a magnetic field of 0.2 Tesla. The electron density in the bar is 7 x $10^{21}m^{-3}$. If one mV is applied across the long ends of the bar, determine the Hall coefficient and the Hall resistance (voltage measured between the Hall electrodes placed across the short dimensions of the bar). Assume $\mu_e = 0.39$ m^2/Vs
- Answer 8.9 x 10^{-4} m^3/C, 0.178 ohms

Answer

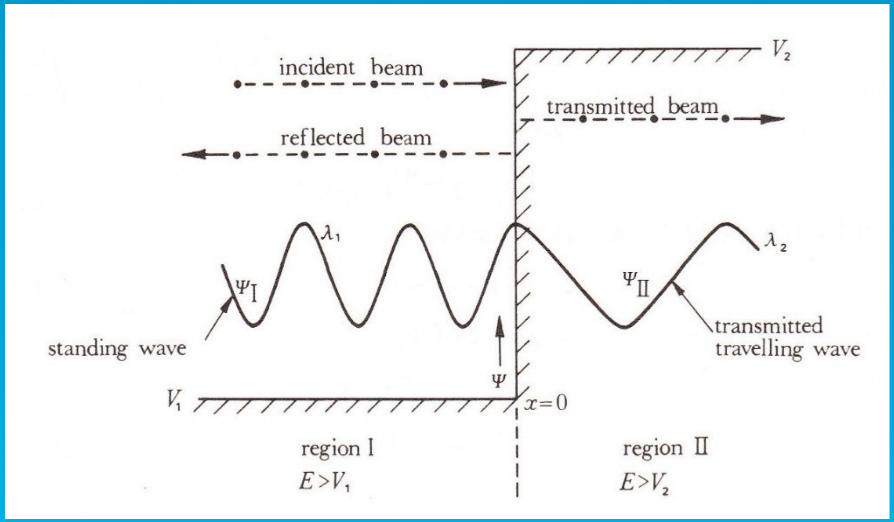
- $R_H = 1/ne = 1/(7 \times 10^{21} \times 1.6 \times 10^{-19}) = 8.9 \times 10^{-4}\ m^3/C$

- $V_H/I = (R_H\ B_Z)/d = (8.9 \times 10^{-4} \times 0.2)/10^{-3} =$ 0.178 ohms



Tutorial 1

1st case

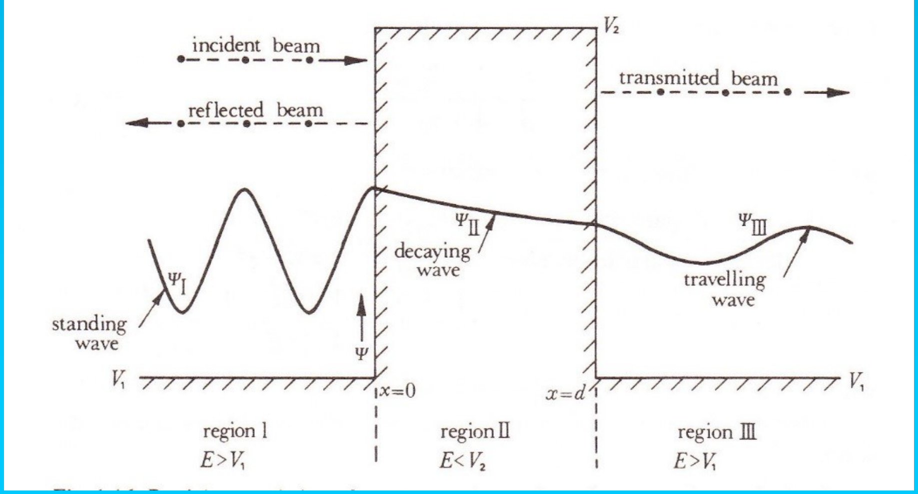


Tutorial 2

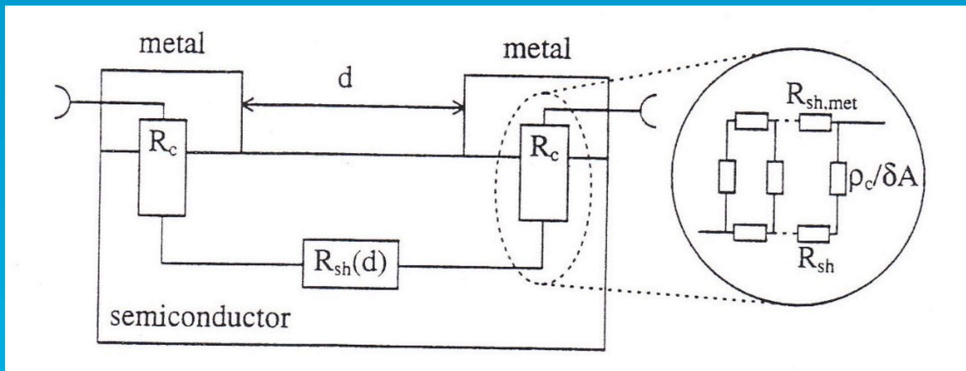
2[nd] case

Tutorial 2

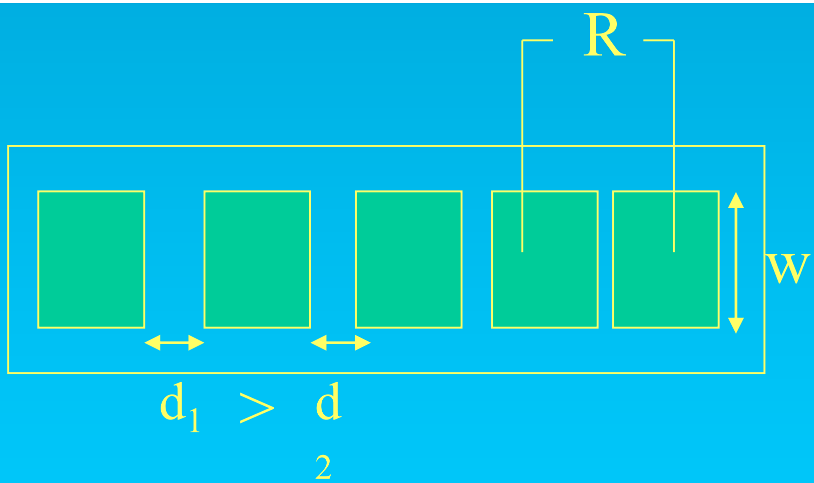
3rd case

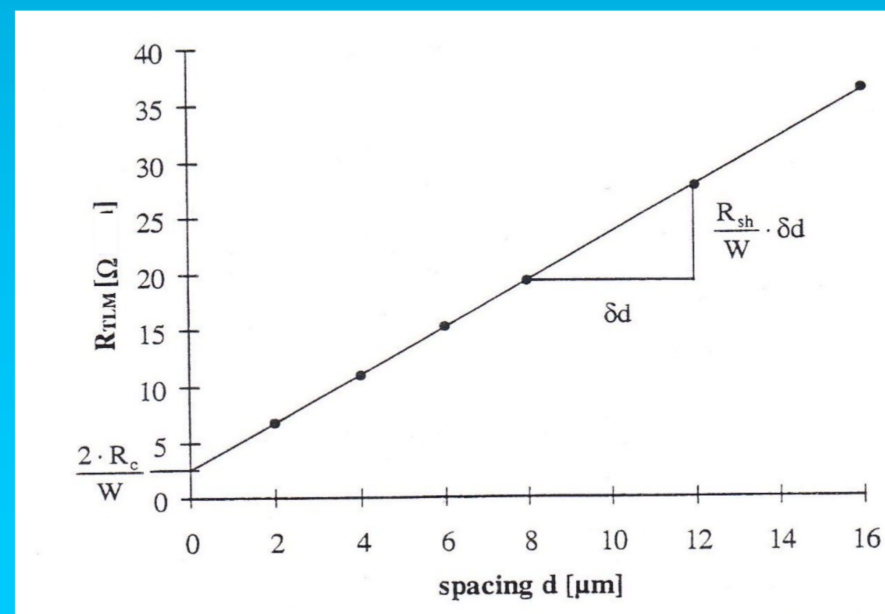


Transmission Line Model (TLM) technique



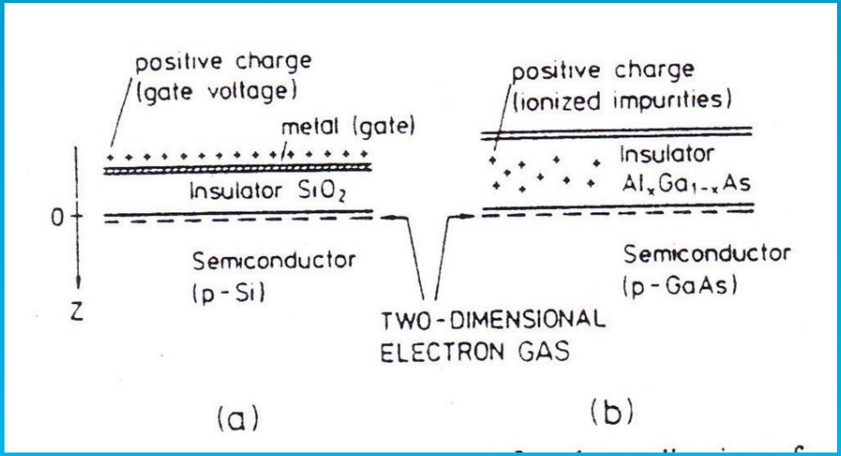
Contact (R_c) and sheet resistance (R_{sh}) measurements

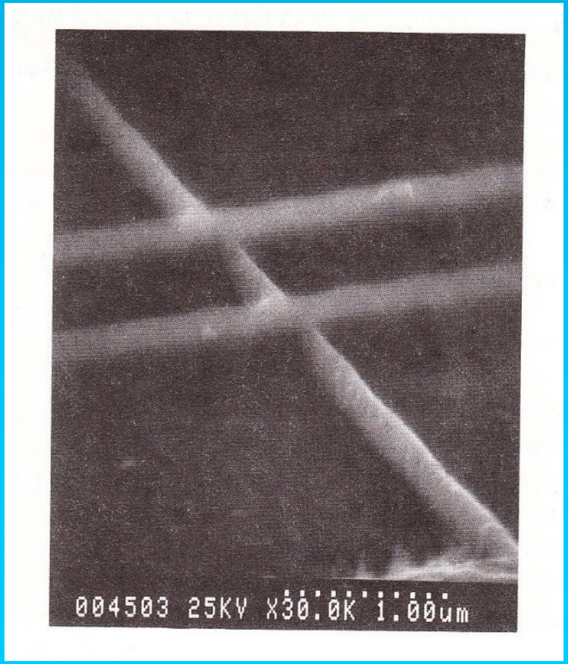


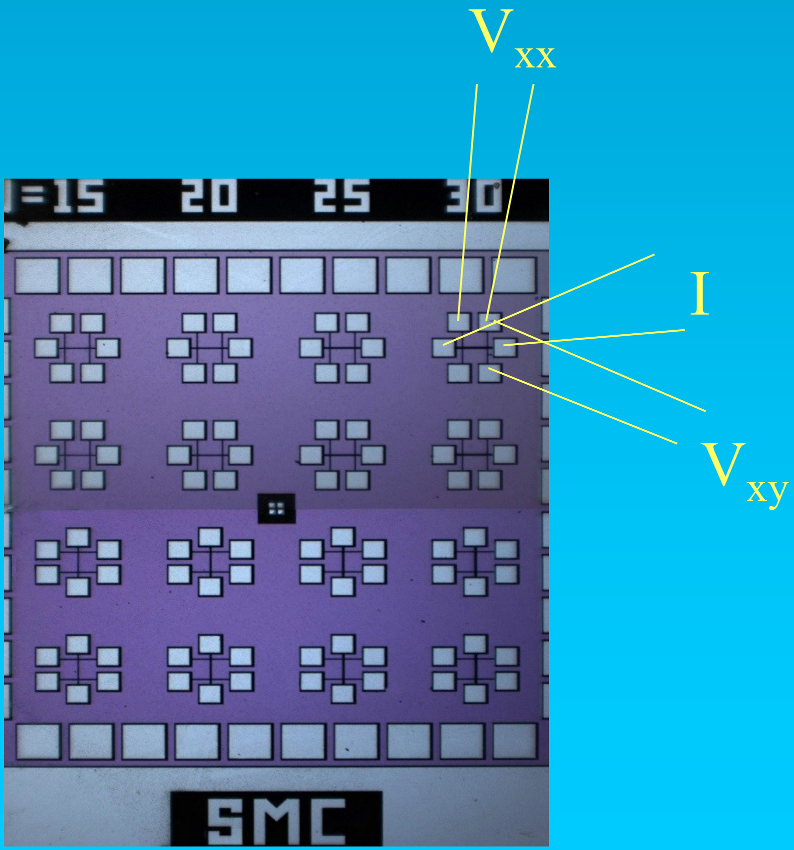


$$R_{TLM}(d) = \frac{2R_C}{w} + \frac{R_{sh}}{w} d$$

Quantum Hall Effect



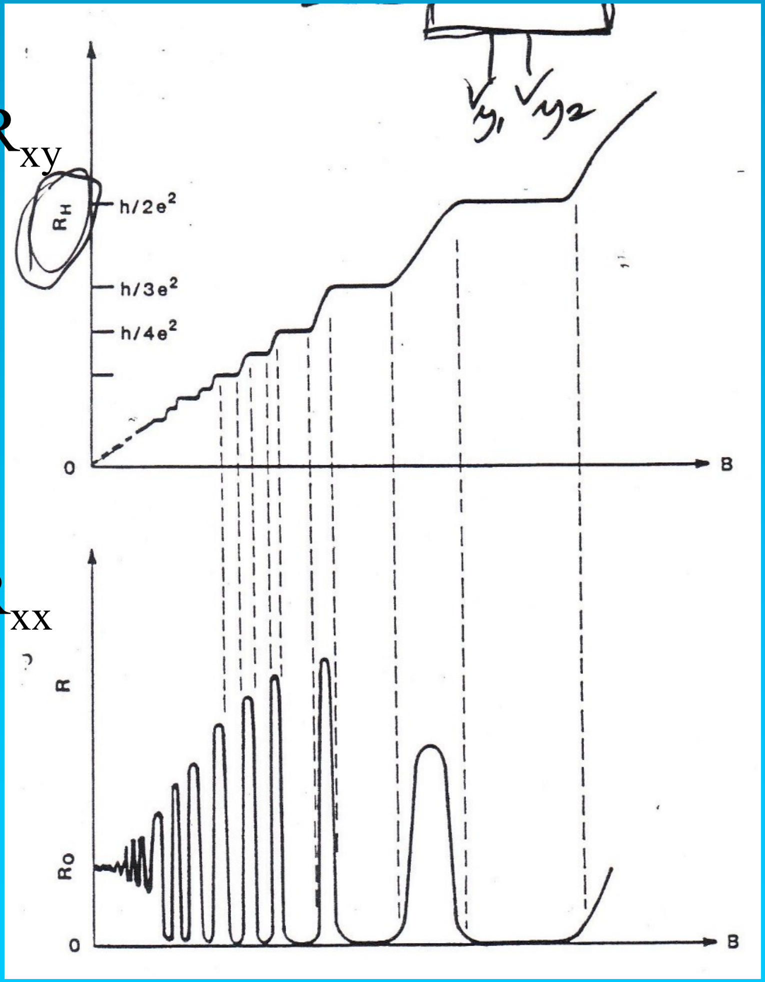




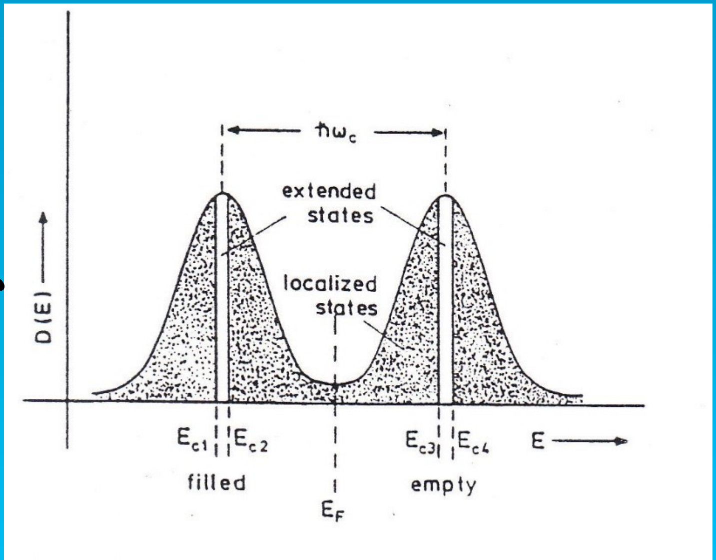
Quantum Hall Effect

R_{xy}

R_{xx}



Density of states



Resistance as a function of magnetic field at low temperatures