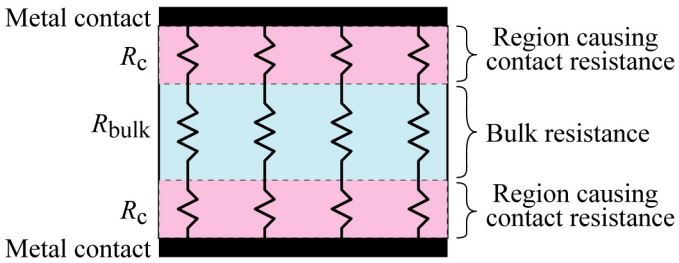
Specific resistance of ohmic contacts

Vertical contact geometry

- Vertical current flow geometry



- Metal-semiconductor contacts can be either Schottky contacts or ohmic contacts. Walter Schottky who worked on metal-semiconductor contacts realized early that such contacts can be resistive, rectifying, and ohmic.
- The figure shows a "region causing contact resistance". What is this region physically?
- Resistances in figure are: Contract resistance, bulk resistance, and again contact resistance.
- Total contact resistance of one contact is R_c.
- The ***specific contact resistance*** is given by

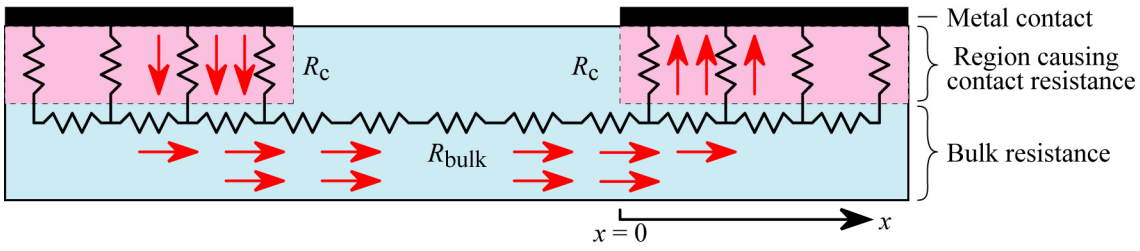
$$\rho_c = R_c A$$

where A is the area of the contact.

- R. H. Cox and H Strack "" *Solid State Electronics* **10**, 1213 (1967)
- S. S. Cohen "Contact resistance and methods for its determination" *Thin Solid Films*, **104**, 361 (1983)
- W. M. Loh et al. "Modeling and measurement of contact resistances", *IEEE Trans. Electron Devices*, **ED-34**, 512 (1987)
- D. K. Schroder "Semiconductor material and device characterization" (Wiley, New York, 1998)

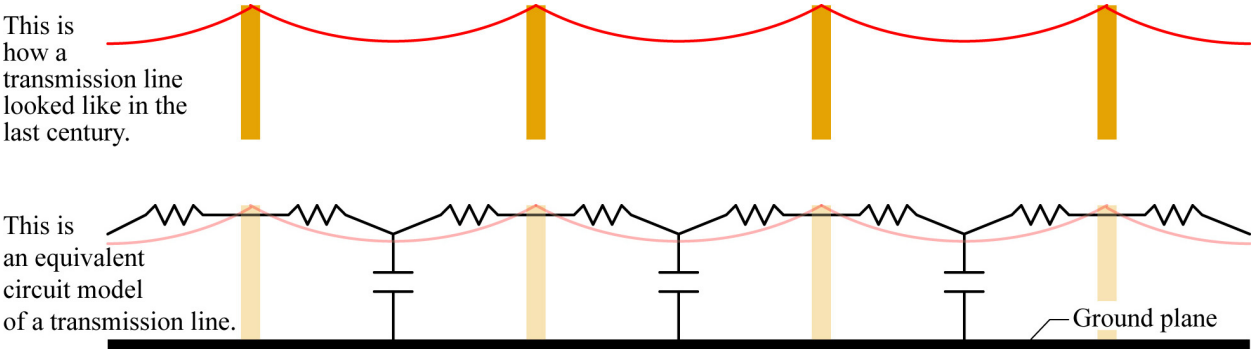
Lateral contact geometry

- Horizontal or lateral current flow geometry

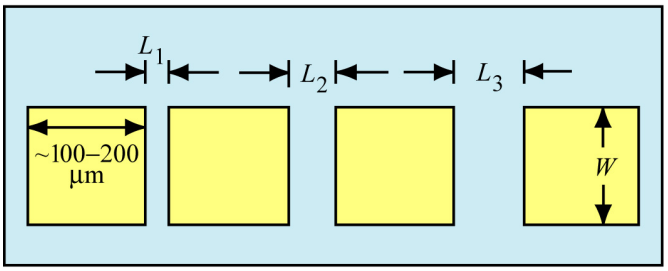


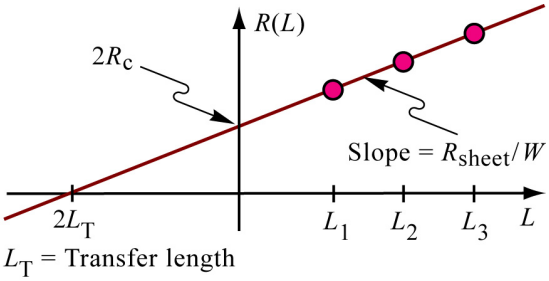
- Current flows non-uniformly through the contact. Why?
- Make a diagram showing the current density in the semiconductor as a function of x.
- Would the above equation ($\rho_c = R_c A$) still be valid? No! Why?

- Therefore a different method is required to measure the contact resistance.
- This different method is called the ***Transmission line method*** (TLM).
- This model was developed by H. H. Berger "Models for contacts to planar devices" *Solid State Electronics* Vol. **15** p. 145 (1972).
- Why this model is called transmission line model?
- The figure shows a transmission line (as it looked like in the last century).



- A transmission line has distributed circuit elements just as shown in the picture.
- The mathematics of transmission line was well known in the 1970s.
- Therefore the transmission line model was applied to electrical contacts in semiconductors.
- It is intuitively clear that the current prefers to flow laterally in the metal contact rather than the semiconductor.
- Thus there is a ***transfer length*** within which the current transfers from the metal to the semiconductor.
- Sketch the current flow in the metal and semiconductor and show the transfer length!
- Explain with your own words the meaning of the "transfer length"?
- The TLM model allows one to extract the specific contact resistance of a contact with lateral current flow.
- The following figure shows TLM measurement.
- TLM measurement uses a series of contact with different spacings
- E.g. L_i = 2, 4, 6, 8, and 10 μm, or L_i = 5, 10, 15, 20, and 25 μm.
- Typical contact lengths and widths (W) are 200 μm.





- The TLM measurement yields values for R_c and L_T.
- Assume that the semiconductor has the sheet resistance R_{sheet}.

- The TLM analysis yields the following relations:

$$R(L) = \frac{R_{\text{sheet}}}{W}(L + 2L_{\text{T}})$$

$$R(L=0) = 2R_{\text{c}} = \frac{R_{\text{sheet}}}{W} 2L_T$$

Solving equation for R_{sheet} yields:

$$R_{\text{sheet}} = \frac{R_{\text{c}} W}{L_T}$$

Specific contact resistance:

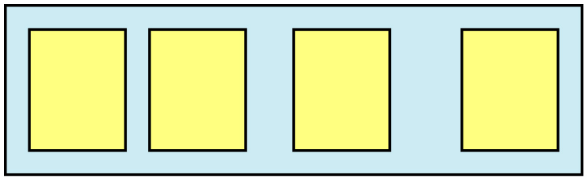
$$\rho_{\text{c}} = R_{\text{sheet}} L_{\text{T}}^2$$

- The potential distribution under the contact is such that the voltage is highest near the contact edge and drops nearly exponentially with distance. The "1/e" distance of the voltage curve is defined as the transfer length L_{T}, given by:

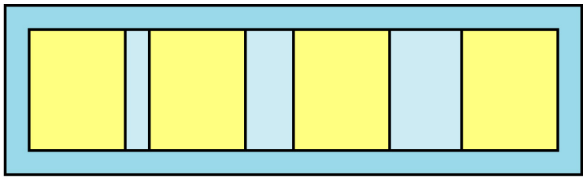
$$L_{\text{T}} = \sqrt{\rho_{\text{c}} / R_{\text{sheet}}}$$

- Thus the TLM model provides a way to assess the specific contact resistance for a lateral current flow geometry.
- What does the TLM model teach us about the minimum length of a contact?
- What should the minimum length of a contact be? Contact length should be > L_{T}.
- In FETs, a figure of merit is contact resistance × gate width, i.e. R_{c} W.
- The name "Transmission line model" has limited meaning to the younger generation (Why?). The method to evaluate contact resistances is also known under the name "***Transfer length method***" which has the same acronym, TLM.

Mesa etching required?



TLM pattern without mesa etching



TLM pattern with mesa etching

- What does "mesa" mean? (Etymologically, "mesa" comes from the Latin word "mensa" which means "table"). What is a mesa mountain (or table mountain)? What is a mesa etch?

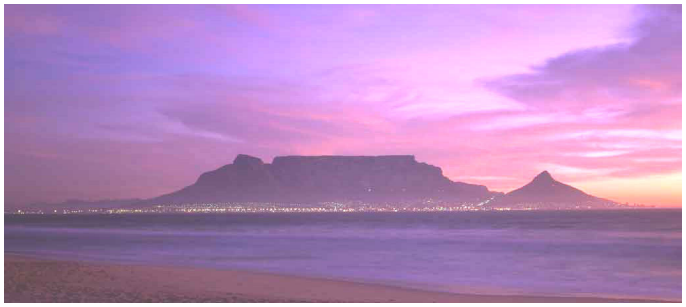
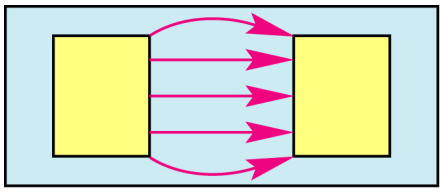
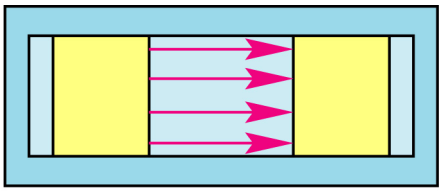


Table Mountain (Mesa Mountain) near Cape Town, South Africa.

- Show current flow in TLM pattern with and without having a mesa etch.



Current flow without mesa



Current flow with mesa

- Discuss differences and effect on TLM measurement.
- Which measurement would be more accurate – with or without mesa pattern?
- Are there conditions under which a mesa pattern is not needed?

Recipes

- Ohmic contact to n-type GaAs
  AuGe/Ni/Au — 50 nm/40 nm/60 nm
  AuGe = eutectic = 88% Au 12% Ge — Annealing: 425 °C for 30 s in forming gas
  Explanation: Eutectic: A eutectic evaporates in theeutectuic ratio so that the composition of the source material does not change. The eutectic of a compound AB has a lower melting point than that of either element A or element B.
  Ge acts as dopant; Ni has low surface tension and therefore prevents balling-up; Au is protective coating
- Ohmic contact to n-type GaAs
  SnAu — 50 nm
- Ohmic contact to p-type GaAs
- Zn/Au (Zn acts as Acceptor)
- Ohmic contact to p-type GaAs
  ZnAu — 50 nm
  10 % Zn 90 % Au — Annealing: 420 °C for 30 s in forming gas
- Ohmic contact to n-type GaN
  Ti/Al/Ni/Au — 15 nm/60 nm/20 nm/ 20 nm
  Annealing: typically 850 °C for 30 sec.
  Explanation: Ti on GaN forms TiN by extracting N from the GaN. This causes accumulation of N vacancies near the metal-semiconductor interface, which act as donors.
  Al prevents an out-diffusion of Ga from the metal-semiconductor interface to the top Au layer. Together with Ti, it prevents also the in-diffusion of excess Ni and possibly Au from the top layer to the metal-semiconductor interface.

- Ohmic contact to p-type GaN
  Ni/Au 20nm/ 20nm
  Annealing: 530 °C for 5 min in dry air

  Explanation: Ni has a high work function.

Wire bonding

- Additional thick Au layer required (frequently deposited by plating)