Lecture 3 - The Five Basic Equations - Outline

- **Announcements**
  - Webnotes -1. Lecture Outline and Summary; 2. Comments on photoconductivity; 3. Solving the 5 basic equations
- **Review**
  - Photoconductivity: drift and low level injection combined
- **Non-uniform excitation in non-uniform samples**
  - Conditions: $N_d(x)$, $N_a(x)$, $g_L(x,t)$, $n'(X,t)$, and/or $p'(X,t)$ specified
  - Unknowns (5): $n(x,t)$, $p(x,t)$, $J_e(x,t)$, $J_h(x,t)$, $E(x,t)$
  - Continuity and conservation: gen/recomb, flux divergence
  - Diffusion fluxes and currents
  - Poisson's equation
  - The necessary 5 equations
- **General solutions**
- **Special cases we can solve (approximately) by hand**
  - Carrier concentrations in uniformly doped material (Lect. 1)
  - Drift (Lect. 2)
  - Low level uniform optical injection (Lect. 2)
  - Doping profile problems (depletion approximation)
  - Non-uniform injection (flow problems)
- **Using the hand solutions to model devices**

Photoconductivity and photoconductors:

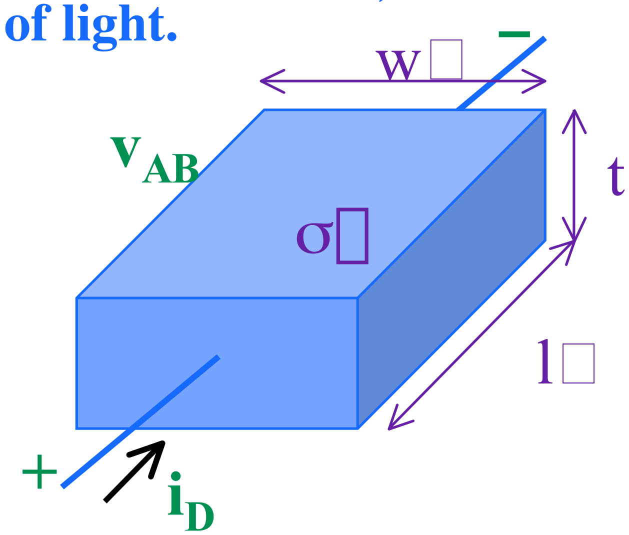
When we shine light on a semiconductor that generated hole-electron pairs we change the conductivity of that material, and this change can be used to sense the presence of light.

Consider steady-state light resulting in:

$$g_L = G \Rightarrow n' = p' = G\tau_{min}$$

This in turn changes the conductivity:

$$\sigma = q[\mu_e(n_o + n') + \mu_h(p_o + n')]$$
$$= \sigma_o + qn'(\mu_e + \mu_h)$$
$$= \sigma_o + \sigma'$$



And if the sample had contacts on either end, and a voltage applied to it, the current through the leads would change in response to the light. This is photoconductivity:

$$i_D = \sigma \frac{w \cdot t}{l} v_{AB} = (\sigma_o + \sigma') \frac{w \cdot t}{l} v_{AB}$$
$$= I_D + i_d \quad \text{with} \quad i_d = \sigma' \frac{w \cdot t}{l} v_{AB} = qG\tau_{min}(\mu_e + \mu_h) \frac{w \cdot t}{l} v_{AB}$$

Photoconductors - quantum well infrared photodetectors QWIPs

See Fig 11.18 from Rosencher, E. and Borge Vinter. Translated by Paul G. Piva. *Optoelectronics.* Cambridge University Press. ISBN 0-251-77813-1.

EBandBV, Fig. 11.18

Above: Schematic illustration of QWIP structure and function.

Right: Energy separation between n = 1 and 2 levels in quantum wells with indicated aluminum fractions and well widths.

See Fig 11.17 from Rosencher, E. and Borge Vinter. Translated by Paul G. Piva. *Optoelectronics.* Cambridge University Press. ISBN 0-251-77813-1.

EBandBV, Fig. 11.17

Lecture 3 - The Five Basic Equations - Summary

- **Review**
  IR imaging video
- **Non-uniform excitation in non-uniform samples**
  The 5 unkowns: $n(x,t)$, $p(x,t)$, $J_e(x,t)$, $J_h(x,t)$, $E(x,t)$
  Continuity and conservation: gen/recomb, flux divergence
  Diffusion fluxes and currents
  Poisson's equation
  The 5 equations
- **Solutions in general**
  5 coupled, non-linear differential equations (A job for a computer!)
- **Special cases we can solve (approximately) by hand**
  Carrier concentrations: (Lect. 1)
  Drift: $J_{drift} = J_{e,drift} + J_{h,drift} = q\,(\mu_e\, n_o + \mu_h\, p_o)\, E = \sigma_o\, E$ (Lect. 2)
  Low level optical injection: $dn'/dt - n'/t_{min} \approx g_L(t)$ (Lect. 2)
  Doping profile problems: the depletion approximation
  Non-uniform injection: flow problems (coming next!)
- **Using the hand solutions to model devices**
  Diodes: two flows and a depl. approx.
  Transistors: three flows and two depl. approx.'s
  MOSFETs: three depl. approx's and one drift