Section 14
Doping

14.4 Multiple doping, co-doping, and heavy-doping

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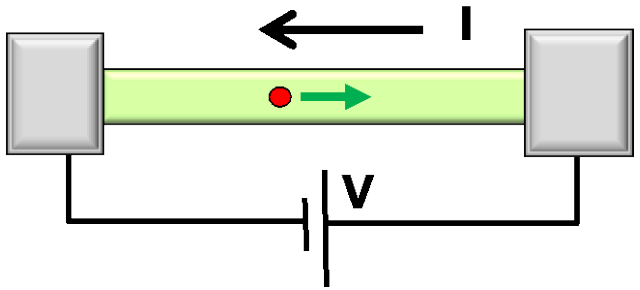
PURDUE UNIVERSITY

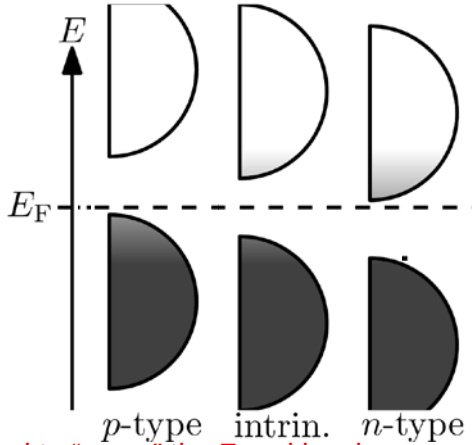
School of Electrical and Computer Engineering

Section 14
Doping



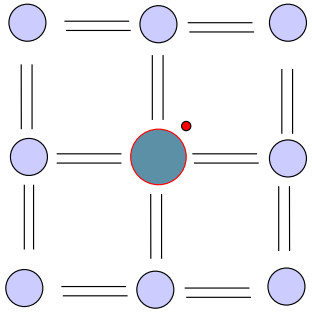
$$I = G \times V$$
$$= q \times n \times v \times A$$

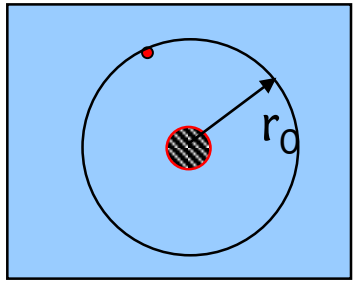
charge density velocity area



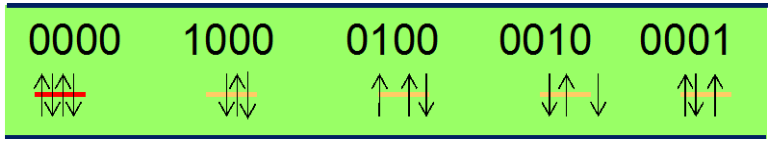
» Need to "move" the Fermi level
» "add" electrons – n-type doping – E_F close to E_c
» "add" holes – p-type doping – E_F close to E_v

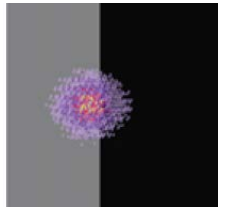
- 14.1 Basic concepts of donors and acceptors

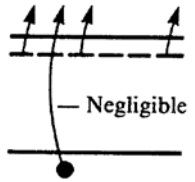


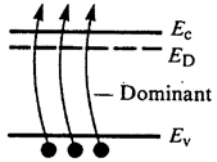


- 14.2 Statistics of donor and acceptor levels

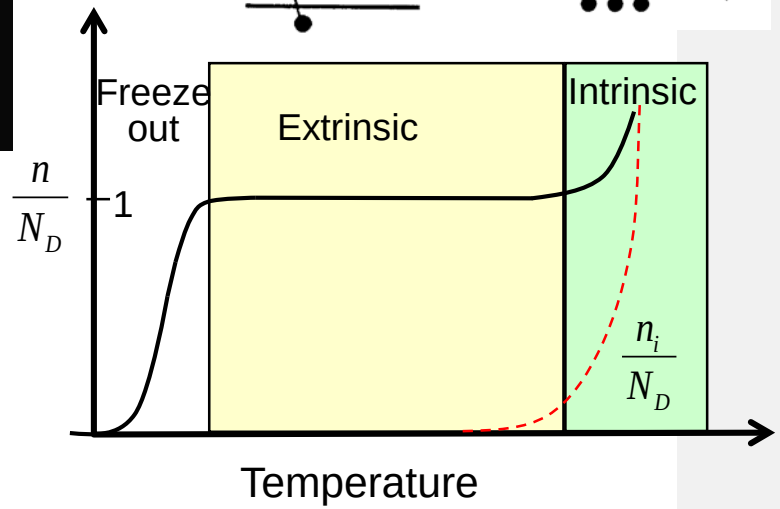








$$N_V e^{-(E_F-E_V)/k_BT} - N_C e^{-(E_C-E_F)/k_BT} + \frac{N_D}{1+2e^{(E_F-E_D)/k_BT}} - \frac{N_A}{1+4e^{(E_A-E_F)/k_BT}} = 0$$



- 14.3 Temperature dependence of carrier concentration
- 14.4 Multiple doping, co-doping, and heavy-doping

Video
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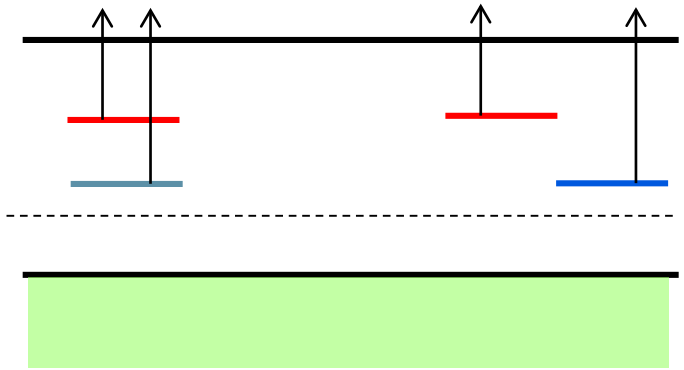
Multiple Donor Levels



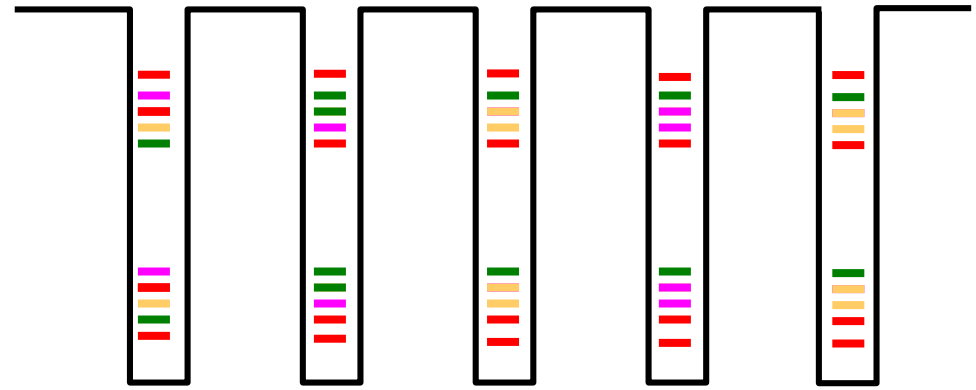
Multiple levels of same donor …

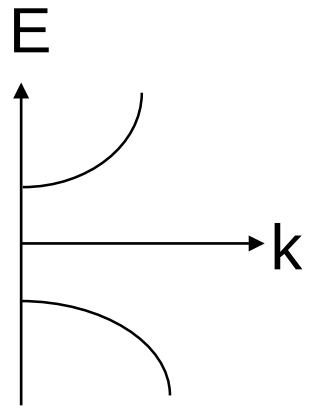
$$p - n + \frac{N_D}{1 + 2e^{(E_F - E_{D1})/k_B T}} + \frac{N_D}{1 + 2e^{(E_F - E_{D2})/k_B T}} - \frac{N_A}{1 + 4e^{(E_A - E_F)/k_B T}} = 0$$

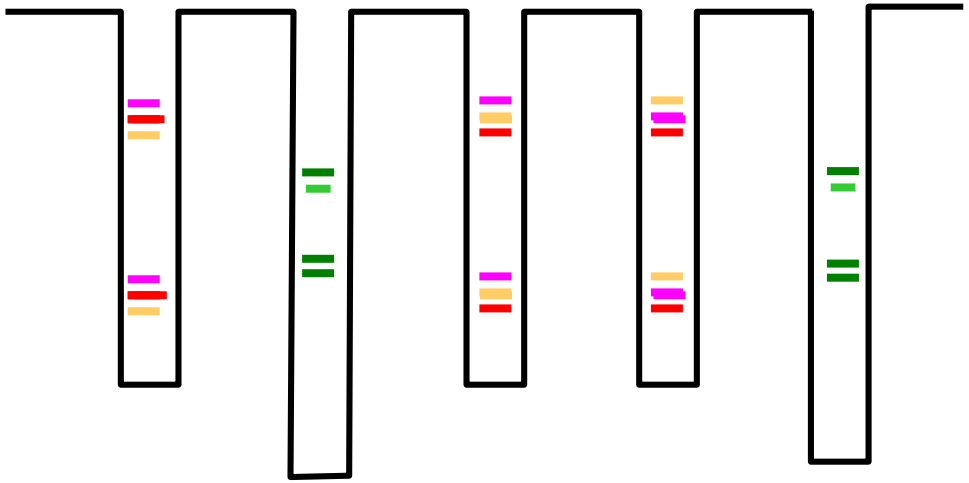
Codoping…

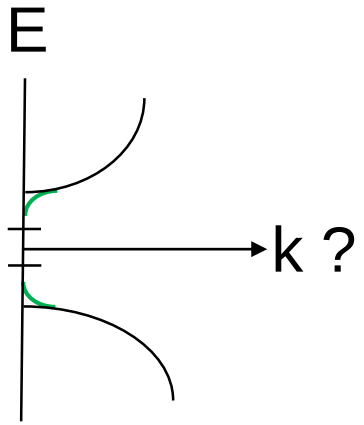
$$p - n + \frac{N_{D1}}{1 + 2e^{(E_F - E_{D1})/k_B T}} + \frac{N_{D2}}{1 + 2e^{(E_F - E_{D2})/k_B T}} - \frac{N_A}{1 + 4e^{(E_A - E_F)/k_B T}} = 0$$

Heavy Doping Effects: Bandtail States

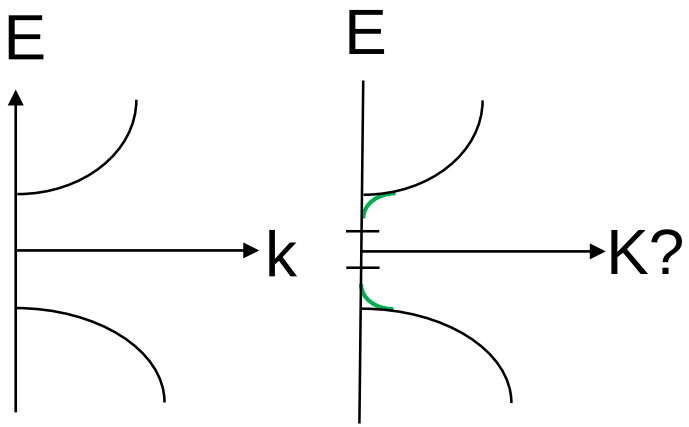








Heavy Doping Effects: Hopping Conduction



Bandgap narrowing

$$p \times n = N_C N_V e^{-\beta E_G^*}$$

e.g. Base of HBTs

Band transport
vs.
hopping-transport

e.g. a-silicon, OLED

Conclusions

$$N_V e^{-(E_F - E_V)/k_B T} - N_A e^{-(E_C - E_F)/k_B T} + \frac{N_D}{1 + 2e^{(E_F - E_D)/k_B T}} - \frac{N_A}{1 + 4e^{(E_A - E_F)/k_B T}} = 0$$

1. Charge neutrality condition and law of mass-action allows calculation of Fermi-level and all carrier concentration.

2. For semiconductors with field, charge neutrality will not hold and we will need to use Poisson equation.

3. Heaving doping effects play an important role in carrier transport.

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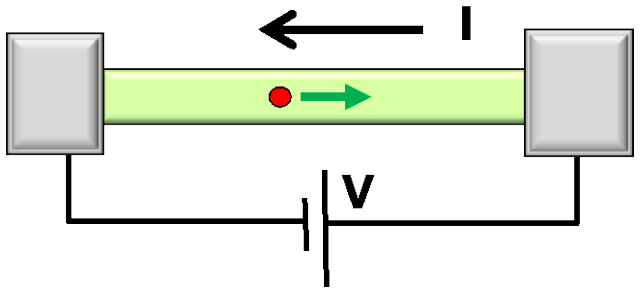

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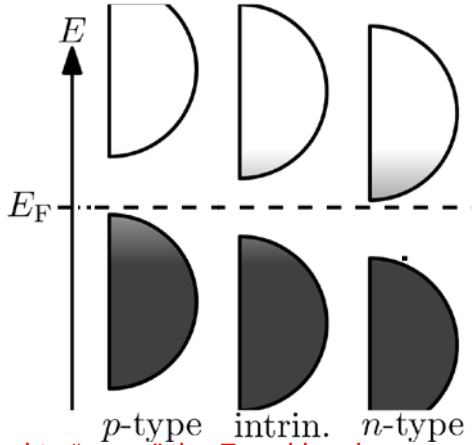

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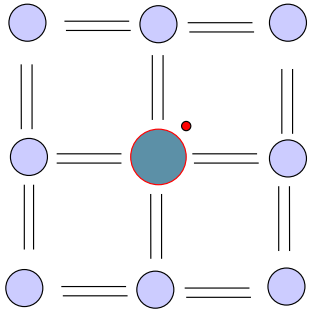

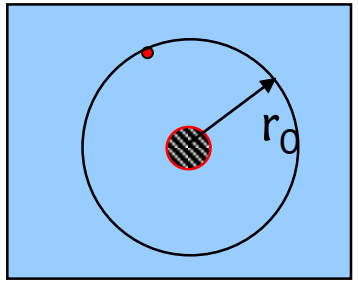

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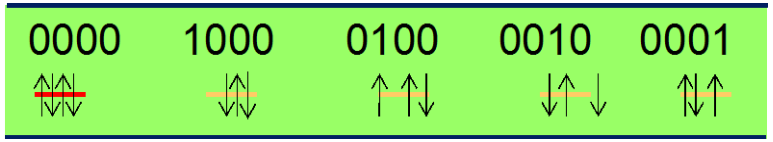

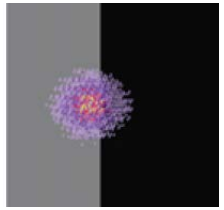

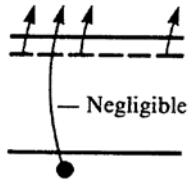

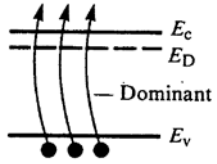

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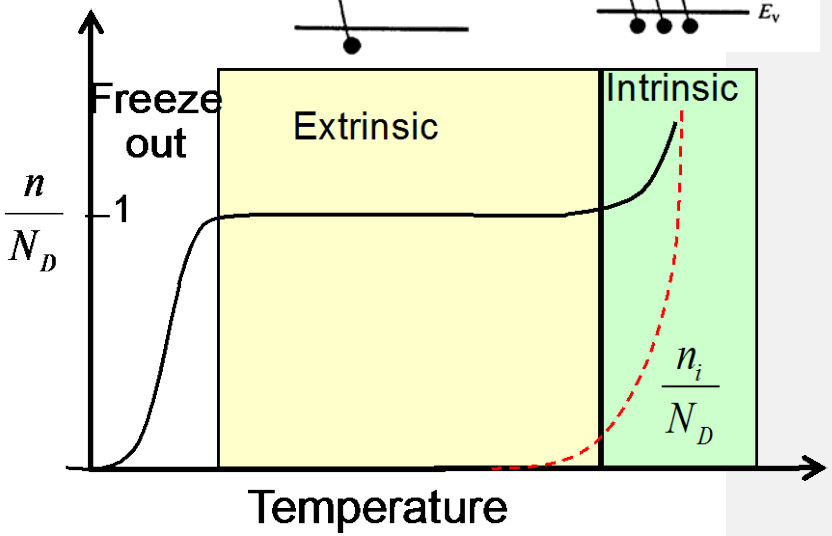

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