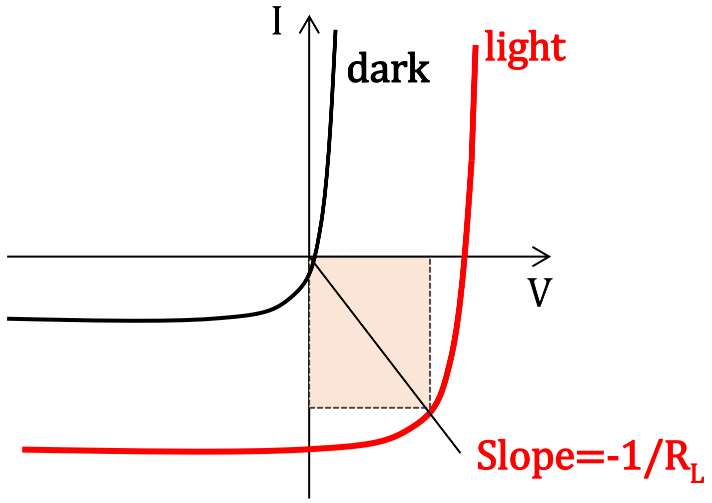
Sample solution 2016

1.



a) a full sketch and labels

To achieve high absorption, a PERL solar cell has

- Inverted pyramid: Sunlight incident on a side slope is partially transmitted into the cell and partially reflected to the other slope, increasing the probability of light being absorbed.
- Antireflection oxide layer: Designed to minimise reflection of incident sunlight.
- Si-Oxide-Aluminium: Act as mirror to reflect light (particularly at long wavelengths) back into the cell.

To maximise the photocurrent

- Surface passivation: Oxide layer passivates the surface to minimise surface recombination so that photogenerated carriers are not lost.
- Metal-semiconductor area (defined by the small Boron diffused p+ region) is small to minimise surface recombination loss.
- p-region: Should have long minority carrier diffusion length to ensure high output current. Minority carrier lifetime in ms is routinely achieved.
- p-region: Should have low background doping to increase the depletion width that will improve the quantum efficiency

b) InGaAs has a cutoff wavelength of 1.65μm. Therefore it absorbs a significantly larger portion of the solar spectrum than Si solar cell.

The intrinsic carrier concentration,

$$n_i^2 = N_c N_v \exp\left(-\frac{E_g}{kT}\right)$$

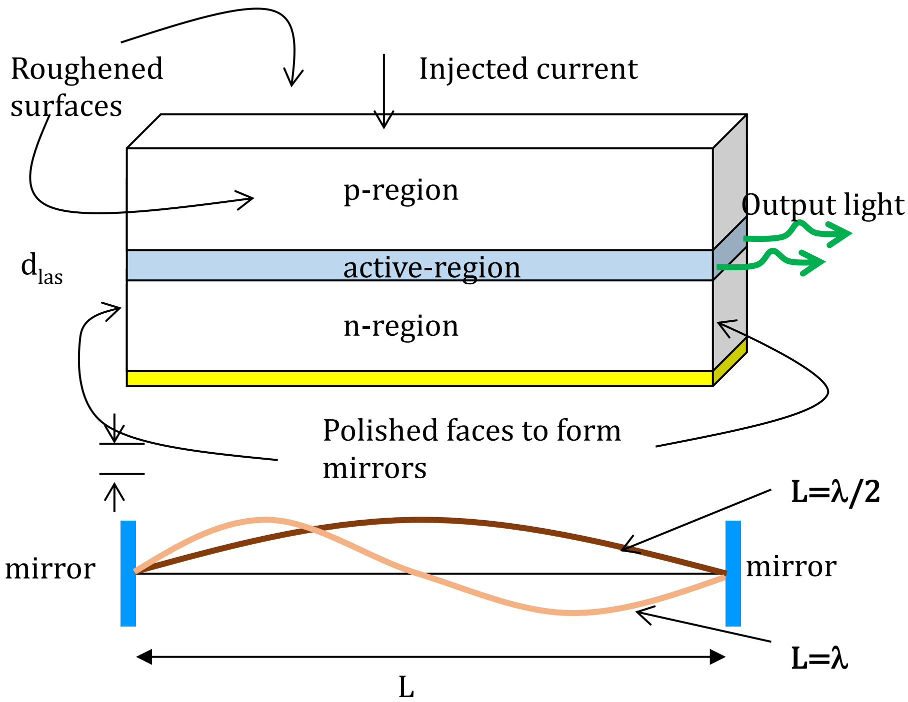
is higher in InGaAs. Therefore the dark current is significantly higher than Si solar cell. Consequently the open circuit voltage is reduced.

c) i) The cost of low defect crystalline Si is too high for large solar panel production. Therefore amorphous Si thin film, which can be deposited on glass, has been developed. Unlike crystalline Si, amorphous Si has a short range order and hence does not have to be lattice matched to the substrate.

ii) The lack of perfect crystal structure, leads to reduced carrier mobility and hence reduced output from the solar cell. The bandgap of amorphous Si is also larger than crystalline Si, leading to lower conversion efficiency.
iii) Adding a micro-crystalline Si, which has small regions with crystalline Si within the amorphous material, can provide a smaller bandgap, 1 eV, thin film. Using this a tandem solar cell with higher efficiency can be produced. The amorphous Si absorbs the UV and visible wavelengths while the micro-crystalline absorbs the near infrared wavelengths.

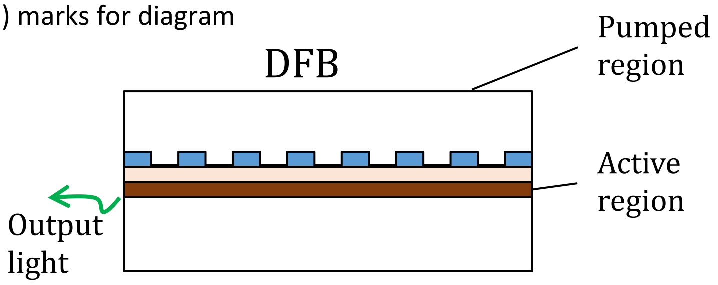
2. a) To achieve lasing, it is necessary to achieve population inversion and to have feedback mechanism to allow the photon intensity to build up.
b) Key features are
- Polished faces to form mirrors, which will reflect the photon at the wavelength that matches the resonant modes defined by the length of the cavity.
- Roughen surfaces on the side to prevent build up of photons at other wavelengths.
- Use of lower refractive index in the p and n regions to form a waveguide that confines light in the active region.
- Highly doped p and n regions to reduce series resistance so that heating is minimised.

marks for the diagram



c) i) In a simple stripe laser, the cavity length can support resonant modes for wavelengths that satisfy the condition $L=N\lambda/2$. Therefore these wavelengths will be emitted leading to an emission spectra that is too broad to achieve a high channel number in WDM.

ii) marks for diagram

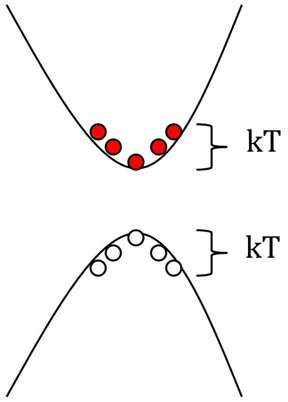


In a DFB structure, a periodic grating shown above is incorporated. The period of the grating is fabricated such that it will enhance the reflection at the chosen wavelength. This leads to a much narrower emission spectra of ~1Å compared to ~20Å in Fabry Perot laser.

Key disadvantages: The process involves etching of the grating, followed by regrowth of the top layers. The fabrication cost is therefore much more expensive than the simple Fabry Perot laser.

Key advantages: The emission wavelength is less sensitive to temperature. Single mode emission required for telecommunication is easily achieved.

3. a) marks for diagram



$$\hbar\Delta\omega \approx kT$$

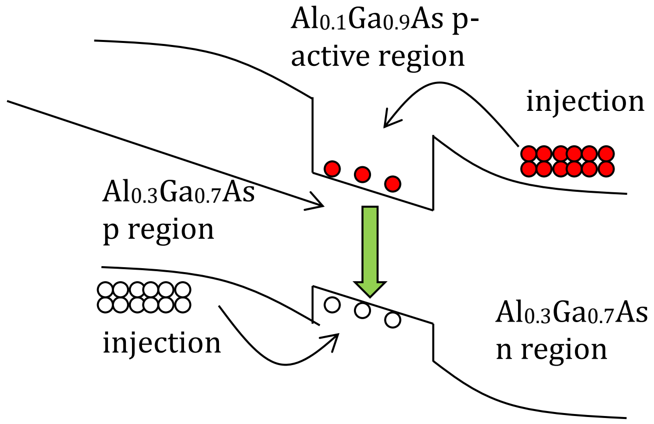
$$\Delta\lambda \approx \frac{kT\lambda^2}{hc}$$

Because of thermal energy distribution, carriers are distributed in CB and VB. Recombination processes corresponding to different energies leads to a broad emission spectrum. In addition there is no wavelength selection features such as gratings or filters in a simple LED.

b) The light is emitted through spontaneous recombination, which has a lifetime typically of a few hundred picoseconds. Therefore the modulation speed is normally limited to below GHz.

c) To emit a wavelength of 800 nm, the bandgap required is 1.24/0.8μm = 1.55 eV. The Al composition required is therefore (1.55-1.424)/1.247=0.10. To achieve high brightness, a double heterostructure LED should be used. In this case the $Al_{0.1}Ga_{0.9}As$ active region is sandwiched between two wider bandgap, for example $Al_{0.3}Ga_{0.7}As$. Since electrons and holes are confined within the active region, the recombination process is enhanced. In addition the widebandgap p and n regions are transparent to 800 nm, such that there is no re-absorption of the emitted light.

A band diagram is shown below.



d) i) to reduce $J_h = \frac{qD_h p_n}{L_h}\exp\left(\frac{qV}{kT}\right)$, the minority hole concentration pn should be reduced by increasing the doping in the n region. Improving the crystal quality such that L_h increases will also reduce J_h.

ii) increasing the doping in i-region will reduce the depletion width. This will lead to lower J_{GR}. $J_{GR} = \frac{qn_iW}{2\tau}\left[\exp\left(\frac{qV}{2kT}\right)-1\right]$.

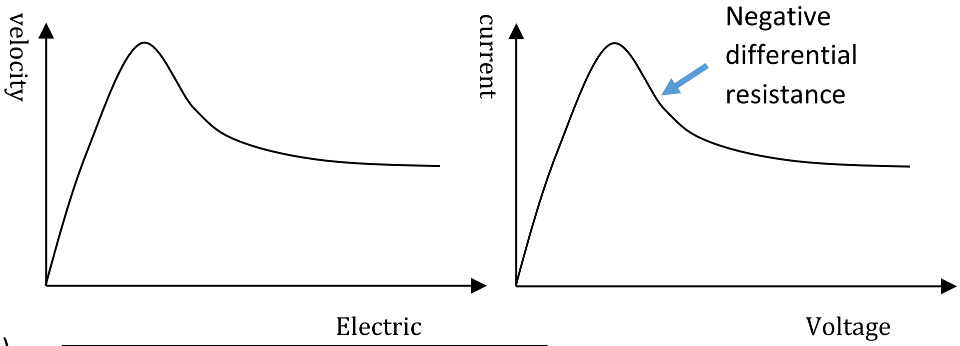
Therefore high doping in the i-region leads to an increase in the injection efficiency.

iii) Note that ni, pn and np all increase with temperature. This is stronger than the effect of exp(qV/kT). Hence an increase in temperature will increase J_h, J_e and J_{GR}, leading a reduced injection efficiency and reduced output from the LED.

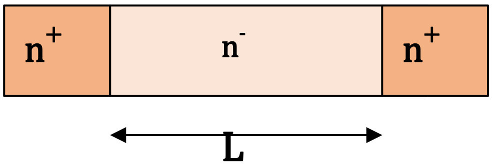
4. a) Provide one example: An obvious example of where the negative differential resistance is used is to provide a negative resistance to control the response of an RLC circuit. Using the negative resistance, a perfect LC circuit can be obtained.

b) In the absence of electric field electrons should be in the bottom of the conduction band (in the Γ valley) with a small effective mass. Under influence of electric field the electron drift velocity increases with the electric field until the point where the electron is transferred to a satellite valley such as L valleys, which have higher effective masses. Consequently the electron drift velocity drops. This drop in velocity leads to a drop in current, although the field is increasing. This produces the negative differential resistance.

marks for velocity vs E diagram.



c) i)

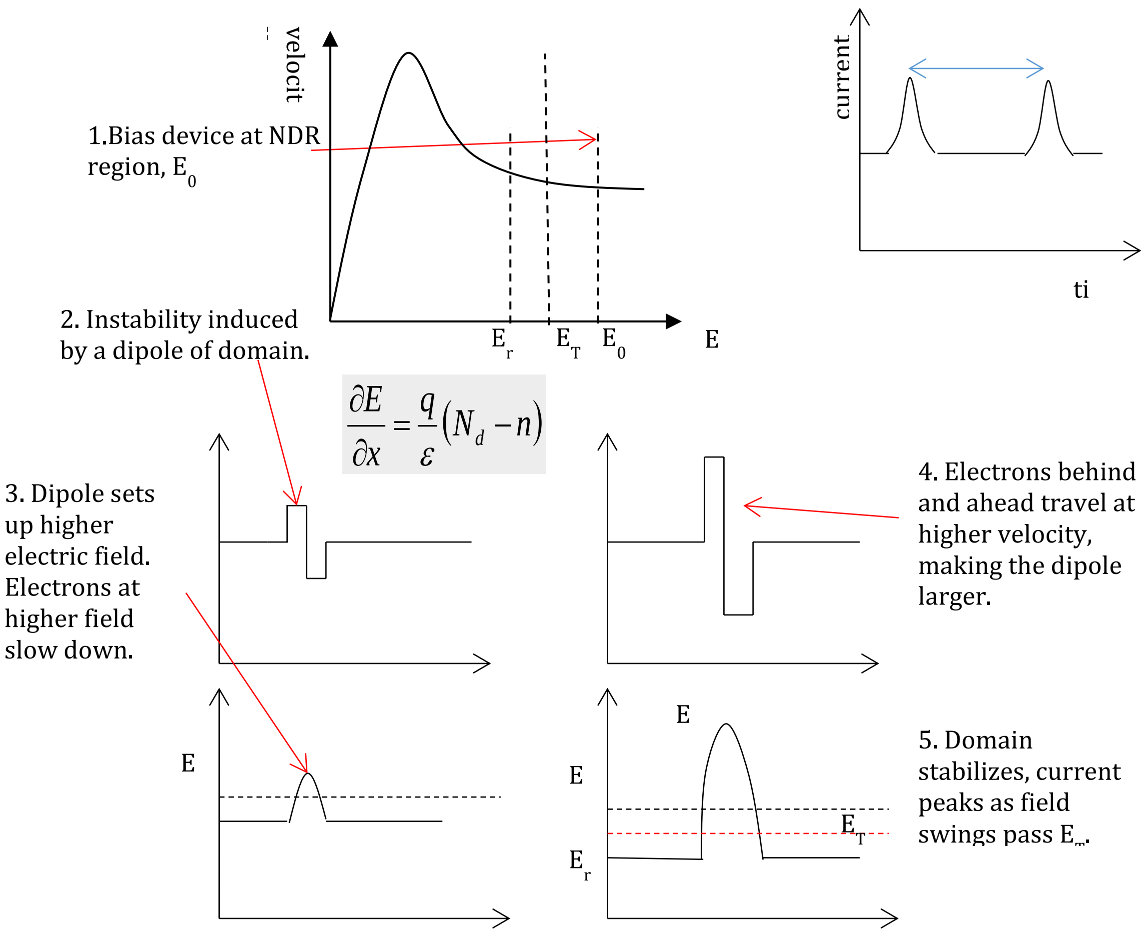


A simple Gunn diode is constructed using a lowly doped n region sandwiched between two highly doped n+ region.

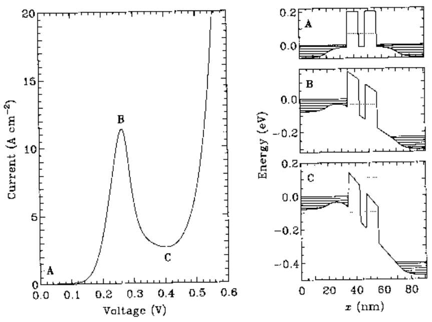
ii) Using diagram to explain how the formation of domain changes the electric field and hence the velocity to create lead and lag in velocity. (5 steps listed).

The current pulse which collapses when the electrons exit the device. When engineered properly a periodic current pulse is produced as shown below.

marks for diagrams.



d). A resonant tunnel diode can achieve much higher oscillation frequency than the Gunn diode.



The energy band diagram of a double barrier RTD is shown above.

A) At 0V, the current is low as electrons are blocked by the barrier.

B) As the bias is increased, the band is tilted. Electrons from the left can tunnel to the state in the quantum well and then to the empty states on the right. Current increases.

C) At higher bias, the state in the quantum well is no longer aligned with the occupied states, so tunnelling reduces and the current drops.

Description of a conventional tunnel diode is also acceptable.