Responses_to_questions

Monday, May 11, 2020 2:37 PM

Q1:

$\eta_a \Phi_B > \frac{n_{th} t}{\tau}$

Is this product just the integrated spectral irradiance or something?

The term on the left hand side of the equation equates to the number of photon generated carriers from a background flux of photons, Φ_B,

$\eta_a \sim \alpha t$ (absorption times thickness)

Consider the figure below:

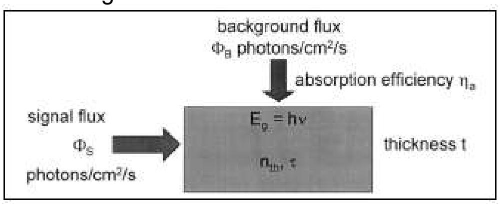

Fig. 1. IR photon detection.

For a Background limited photodetector (BLIP), we want the majority of the noise to be coming from the fluctuations of carriers generated by the background flux (left hand side), and not the thermally generated carriers(right hand side). A slightly deeper discussion can be found in

M. A. Kinch Journ. Electr. Mat. **29**, 809 (2000)

Q2:

$$N_c = \frac{1}{4}\left(\frac{2m_e^* kT}{\pi\hbar^2}\right)^{3/2}$$

This $\frac{1}{4}$ out front doesn't look right

The effective density of states has a two forms, but the number is still the same, this is just using the reduced Planck's constant, $\hbar$, and not ordinary Planck's constant h.

We can make a check:

$$N_c = \frac{1}{4}\left(\frac{2m_e^* kT}{\pi\hbar^2}\right)^{3/2} = \frac{1}{4}\left(\frac{2m_e^* kT}{\pi}\left(\frac{2\pi}{h}\right)^2\right)^{3/2} \quad - expanding\ \hbar = h/2\pi$$

$$\Rightarrow N_c = \frac{1}{4}\left(\frac{8\pi^2 m_e^* kT}{\pi h^2}\right)^{3/2} = \frac{1}{4}8^{3/2}\left(\frac{\pi m_e^* kT}{h^2}\right)^{3/2} \quad - symplifying$$

Now Multiplying $N_c N_v$

$$N_c N_v = \left(\frac{1}{4}\right)^2 8^3 \left(m_e^* m_v^*\right)^{3/2}\left(\frac{\pi kT}{h^2}\right)^3$$

$$\frac{8\cdot 8\cdot 8}{4\cdot 4} = 2\cdot 2\cdot 8 = 32$$

$$\Rightarrow N_c N_v = 32\pi^3\left(m_e^* m_v^*\right)^{3/2}\left(\frac{kT}{h^2}\right)^3$$

This is the same formula that is in Shane's paper that you sent, (eq 7)

I could put it in a form that may be more familiar:

$$N_c = \frac{1}{4}\left(\frac{2m_e^* kT}{\pi\hbar^2}\right)^{3/2} = \boxed{2\left(\frac{2\pi m_e^* kT}{h^2}\right)^{3/2}}$$

Q3: (comment 9)

Here, we will compute the integral by giving an approximate analytic form of the absorption coefficient.

This will be good for new materials whose absorption hasn't been measured, but were you able to get the measured absorption version to work? I'm wondering if it was a problem with limits of integration or something. In any case, if you look at Shane's derivation, it reduces it significantly to where you just need the optical constants at the bandgap

So some groups calculate or measure the absorption coefficient as a function of temperature. But I found that in Shane's paper, he says that the B term is about the same for all temperatures. This was also discussed in other papers as well. ***Would you like me to calculate B for room temp and keep it constant for all other temperatures?*** Since we have InAsSb optical constants at 300 K, we can calculate the B term and use it to approximate B for the superlattices as well.

My problem was with not having a temperature dependent coefficient but calculating G using $\alpha(h\nu, 300\ K)$ at all temperatures, which I think could be the problem. **If you're curious of my code or the integration of our optical constants, you can find it in "calcRadGenRate.m"The code integrates just below the bandgap to some 10kT above the bandgap as well, which should be an okay approximation.**

Q4 (comment 10):

$$G_R = n_i^2 5.8\times 10^{-13}\epsilon_\infty^{1/2}\left(\frac{m_0}{m_e^*+m_h^*}\right)^{3/2}\left(1+\frac{m_0}{m_e^*}+\frac{m_0}{m_h^*}\right)$$
$$\times\left(\frac{300}{T}\right)^{3/2}\left(E_g^2+3kT+3.75(kT)^2\right)$$

Where did this temperature come from? I think we should end up with a kT times exponential to -Eg/kT in the numerator. I think that will become the case after you revise the lower limit of integration to Eg

So we begin with the integral:

$$G_R = \frac{8\pi}{h^3c^2}\int_0^\infty \frac{\epsilon(E)\alpha(E)E^2dE}{\exp(E/kT)-1}$$

and

$$\alpha_{direct} = \frac{2^{3/2}}{3\epsilon_\infty^{1/2}}\frac{m_0e^2\,4\pi^2}{h^2}\left[\frac{m_e^*m_h^*}{m_0(m_e^*+m_h^*)}\right]^{3/2}\left(1+\frac{m_0}{m_e^*}+\frac{m_0}{m_h^*}\right)$$
$$\times\left(\frac{E-E_g}{m_0c^2}\right)^{1/2}$$

So, by approximating the relative dielectric constant $\epsilon(E)$ with the static dielectric constant ϵ_∞

$$G_R = \frac{8\pi\epsilon_\infty}{h^3c^2}\frac{2^{3/2}}{3\epsilon_\infty^{1/2}}\frac{m_0e^2\,4\pi^2}{h^2}\left[\frac{m_e^*m_h^*}{m_0(m_e^*+m_h^*)}\right]^{3/2}\left(1+\frac{m_0}{m_e^*}+\frac{m_0}{m_h^*}\right)\left(\frac{1}{m_0c^2}\right)^{1/2}\int_0^\infty\frac{(E-E_g)^{1/2}E^2dE}{\exp(E/kT)-1}$$

Focusing on the integral

$$\int_0^\infty\frac{(E-E_g)^{1/2}E^2dE}{\exp(E/kT)-1}\Rightarrow\int_{E_g}^\infty\frac{(E-E_g)^{1/2}E^2dE}{\exp(E/kT)-1}\ -\textit{absorption coefficient starts at } E_g$$

Using u-substitution;

$$x=\frac{E-E_g}{kT};\qquad dx\,kT=dE$$
$$\rightarrow xkT=E-E_g;\quad E=(xkT+E_g)$$

so

$$\Rightarrow\int_{E_g}^\infty\frac{(E-E_g)^{1/2}E^2dE}{\exp(E/kT)-1}=(kT)^{3/2}\int_0^\infty\frac{x^{1/2}(xkT+E_g)^2\,dx}{\exp(x+E_g/kT)\ -1}\ -\textit{This is where the } T^{3/2} \textit{ dependence comes from}$$

$$\Rightarrow(kT)^{3/2}\int_0^\infty\frac{x^{1/2}(xkT+E_g)^2\,dx}{\exp(x+E_g/kT)\ -1}=(kT)^{3/2}\int_0^\infty\frac{x^{1/2}(E_g^2+2xkTE_g+x^2(kT)^2)\,dx}{\exp(x+E_g/kT)\ -1}\ -\textit{substitution}$$

$$\Rightarrow\sim(kT)^{3/2}\left[E_g^2\int_0^\infty\frac{x^{1/2}dx}{\exp(x+E_g/kT)}+2kTE_g\int_0^\infty\frac{x^{3/2}dx}{\exp(x+E_g/kT)}\right]-\textit{expanding integral as sum of parts}$$
$$+(kT)^{3/2}\left[(kT)^2\int_0^\infty\frac{x^{5/2}dx}{\exp(x+E_g/kT)}\right]$$

$$\Rightarrow\sim(kT)^{3/2}\exp(-E_g/kT)\left[E_g^2\Gamma(3/2)+2kTE_g\Gamma(5/2)+(kT)^2\Gamma(7/2)\right]$$

Where: $\Gamma(3/2)=\frac{1}{2}\sqrt{\pi},\ \ \Gamma(5/2)=\frac{3}{2}\Gamma(3/2);\ \ \Gamma(7/2)=\frac{5}{2}\Gamma(5/2)$

So

$$\Rightarrow\boxed{\int_{E_g}^\infty\frac{(E-E_g)^{1/2}E^2dE}{\exp(E/kT)-1}=(kT)^{3/2}\exp(-E_g/kT)\frac{1}{2}\sqrt{\pi}\left[E_g^2+3kTE_g+3.75(kT)^2\right]}$$

Plugging the integral back in the original equation

$$G_R = \frac{8\pi\epsilon_\infty}{h^3c^2}\frac{2^{3/2}}{3\epsilon_\infty^{1/2}}\frac{m_0e^2\,4\pi^2}{h^2}\left[\frac{m_e^*m_h^*}{m_0(m_e^*+m_h^*)}\right]^{3/2}\left(1+\frac{m_0}{m_e^*}+\frac{m_0}{m_h^*}\right)\left(\frac{1}{m_0c^2}\right)^{1/2}(kT)^{3/2}\exp(-E_g/kT)\frac{1}{2}\sqrt{\pi}\left[E_g^2+3kTE_g+3.75(kT)^2\right]$$

$$\textit{Now,}\qquad n_i^2=32\pi^3(m_e^*m_v^*)^{3/2}\left(\frac{kT}{h^2}\right)^3\exp(-E_g/kT)$$

Let's try to throw in the intrinsic carrier density and simplify the equation.

$$G_R = 32\pi^3\left(\frac{kT}{h^2}\right)^3(m_e^*m_v^*)^{3/2}\exp(-E_g/kT)\quad h\frac{\epsilon_\infty^{1/2}}{c^2}\frac{2^{3/2}}{3}m_0e^2\left[\frac{1}{m_0(m_e^*+m_h^*)}\right]^{3/2}\left(1+\frac{m_0}{m_e^*}+\frac{m_0}{m_h^*}\right)\left(\frac{1}{m_0c^2}\right)^{1/2}\frac{1}{(kT)^{3/2}}$$

$$\times \frac{1}{2}\sqrt{\pi}\left[E_g^2 + 3kTE_g + 3.75(kT)^2\right]$$

Notice how the temperature dependence is now in the denominator when we include the intrinsic carrier density

$$\Rightarrow \boxed{Bn_i^2 = G_R = n_i^2 \ \frac{(2\pi)^{3/2}}{3}\frac{\hbar e^2}{m_0^2 c^2}\left(\frac{1}{m_0 c^2}\right)^{1/2} \epsilon_\infty^{1/2}\left[\frac{m_0}{(m_e^* + m_h^*)}\right]^{3/2}\left(1 + \frac{m_0}{m_e^*} + \frac{m_0}{m_h^*}\right)\left(\frac{1}{kT}\right)^{3/2}\left[E_g^2 + 3kTE_g + 3.75(kT)^2\right]}$$

Compare this to a formula in literature (which is in this paper)

$$B_{direct} = \frac{(2\pi)^{3/2}}{3}\frac{\hbar e^2}{m^2 c^2}\mu\left(\frac{m}{m_e + m_h}\right)^{3/2}\left(1 + \frac{m}{m_e} + \frac{m}{m_h}\right)\frac{W_g^2}{(kT)^{3/2}(mc^2)^{1/2}}$$

$$= 0\cdot 58 \times 10^{-12}\mu\left(\frac{m}{m_e + m_h}\right)^{3/2}\left(1 + \frac{m}{m_e} + \frac{m}{m_h}\right)\left(\frac{300}{T}\right)^{3/2} W_g^2 \,\mathrm{cm}^3/\mathrm{sec}$$