Impurities issue -Ionization rate

Chih-Hsiang Yeh

9/13

Issues

- As the report before, we can shed the light on “the ionization rate” to figure out the “Gain”.
- ➔ Note! We only discuss about the signal now.

- Upon the knowledge of the Ge ionization rate
- ➔ Based on them and build the similar structure to see
- ➔ Reminder: We found that “Mobility” is the key to this issue
- ➔ We need to know the exact processes affecting it.

Just in case

- $\frac{\mu \times m*}{e} = \tau$
- $\tau \times v_d = MFP(L)$

$$\alpha_s = \frac{a_s}{z} \exp\left(-\frac{b_s}{E(x)}\right) \quad \text{with} \quad s = \{n, p\} \quad (20a)$$

and

$$z(x) = 1 + \frac{b_n}{E(x)} \exp\left(-\frac{b_n}{E(x)}\right) + \frac{b_p}{E(x)} \exp\left(-\frac{b_p}{E(x)}\right) \quad (20b)$$

and

$$a_s = \gamma_s = \frac{1}{L_s} \quad \text{and} \quad b_s = \frac{U_c^s \gamma_s}{q} \quad (20c)$$

Important point: (1) Mean free path (2)Ionization energy

How to know?

- Mobility
- ➔ More the scatterings happens, less the mobility will be.
- First of all, due to the complicated processes, we need to cut them into many pieces to see it clearly!
- Then, we need to sum them up for getting the “total mobility”!

Total Mobility

Other good question:

We always said “Low-concentration”
Is it possible for it to be too low to produce the process?

- Use the empirical formula
- ➔ $\frac{1}{\mu} = \frac{1}{\mu_1} + \frac{1}{\mu_2} + \frac{1}{\mu_3} + \cdots$

- All of them need to be summed up and see.

- Go finding out the exact processes now!
- -Note: I won’t list all of the calculations but the one related to the “charge concentration”
- ➔ We want to check if the concentration is ok or not.

Note!

The cases as follows are "No electric field"

I will tell you when going to the "Saturation cases"

Ionized impurities scattering

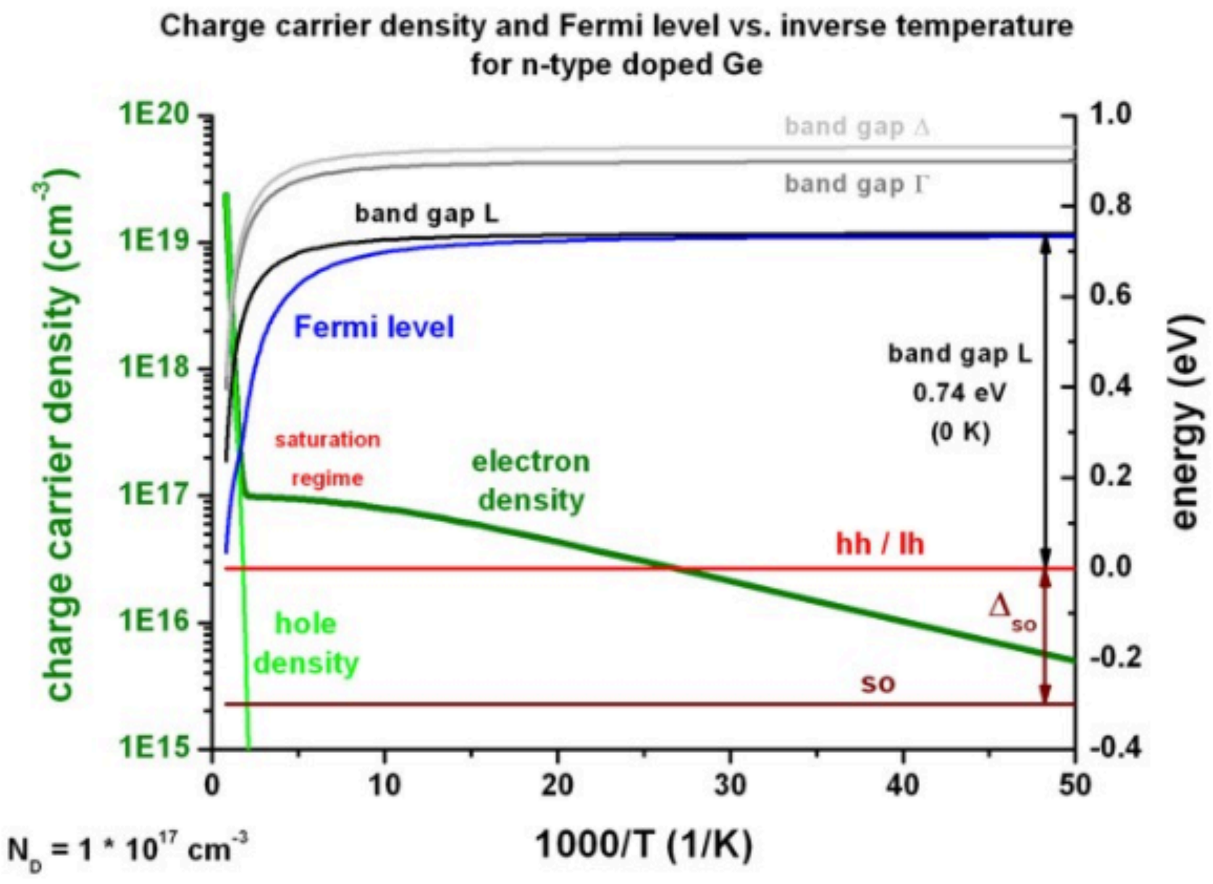
- Charged impurities ➔ The issue of the temperature!
- Highly depend on the temperature
- CW model ➔ Well describe the phenomenon!

$$\mu_I = \frac{128\sqrt{2}\pi^{1/2}(\varepsilon_r\varepsilon_0)^2(k_B T)^{3/2}}{m^{*1/2} N_i Z^2 q^3} \Big/ \ln \frac{24 m^* \varepsilon_r \varepsilon_0 (k_B T)^2}{N_i q^2 \hbar^2}. \qquad \propto \frac{T^{\frac{3}{2}}}{\ln T^2}$$

$$\mu_I = ((\mu_l)_I + 16.05(\mu_h)_I)/17.05$$

$$= \frac{1.59\times 10^{20}}{N_i}\left[\ln \frac{2.8\times 10^{20}}{N_i}\right]^{-1} + \frac{1.02\times 10^{21}}{N_i}\left[\ln \frac{3.44\times 10^{18}}{N_i}\right]^{-1} \quad \times \frac{\ln 77^2}{77^{\frac{3}{2}}} \times \frac{T^{\frac{3}{2}}}{\ln T^2}$$

Charged concentration density



Temperature-dependent
charged concentration density

Lower than "ionization energy"
120K
Density of the charged concentration will get smaller since the insufficient fluctuation.

$$\propto \frac{1}{e^{\frac{1}{k_B T}}}$$

$$1 : \frac{1}{e^{\frac{1}{k_B * 120}}} = x : \frac{1}{e^{\frac{1}{k_B T}}}$$

We can get the charged concentration correlated with the temperature!

Acoustic phonon scattering

- “Quantized” energy package (vibration)
- Related to the temperature

$$\mu_A = 7.77 \times 10^7 \cdot T^{-3/2},$$

Obviously, it only depends on the temperature.

Neutral impurity scattering

- Basically, since we have already known the concentration of the neutral impurity, we assumed the value of it is $2{\times}10^{15}/cm^3$
- We have the formula:

$$(\mu_N)_E = \frac{2.31\times10^{18} + 2.36\times10^{20}}{N_n}$$

$$\mu_N = (\mu_N)_S = 0.82(\mu_N)_E\left[\frac{2}{3}\left(\frac{k_B T}{E_N}\right)^{1/2} + \frac{1}{3}\left(\frac{E_N}{k_B T}\right)^{1/2}\right],$$

$$\mu_N = (\mu_N)_S = 9.76\times10^4(0.228T^{1/2} + 0.976T^{-1/2}),$$

It depends on the temperature.

Note!

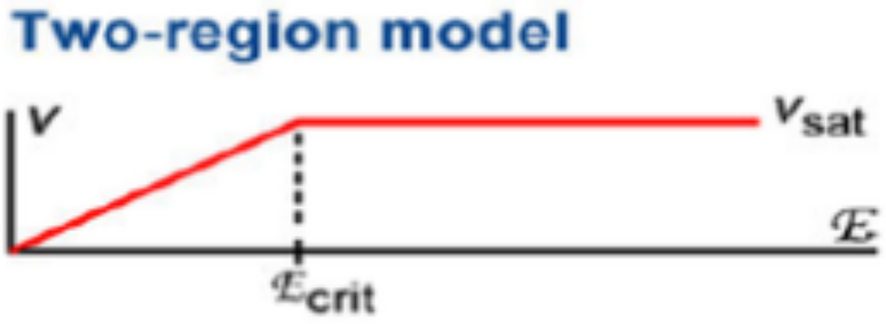
The cases as follows are “Induced electric field”

High-electric-field approximation

- Since in the high electric field
- ➔ It can make the electrons accelerated to “Saturation” cases.

- Why? After the calculation
- ➔ You can find that $10^7/cm^3$ is the enough velocity for electron to ionize other electrons ~0.01eV

Two-region model approximation

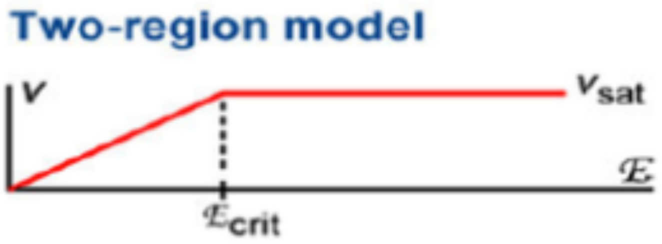


What's the real mobility of the electrons under this condition?

- The first region - Normal region
- ➔ We will have a constant for the mobility
- ➔ Since the formula of that is $\frac{v_d}{E} = \mu$ (Supposed to be a constant)
- The second region – Saturation region
- ➔ Empirical formula

$$v_d \approx \frac{\mu E}{1 + \dfrac{E}{E_{sat}}}$$

Two-region model approximation



What’s the issue now?

- We want to discuss whether the concentration of the charged impurity is enough for the signal to have the avalanche process.
- ! First, we need to find out the ionization rate
- Correlated to the concentration and the temperatures (4,77K)

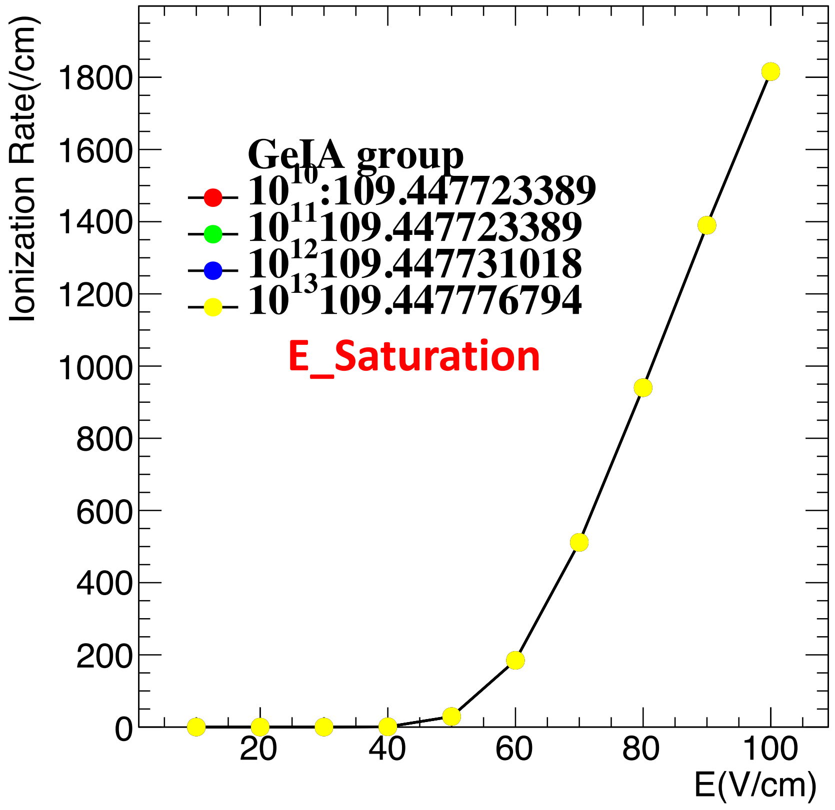
- But…..
- I found that it is not so related to that….
- Check this issue with Prof. Dongming first, since it will directly influence the gain factor.

Because….

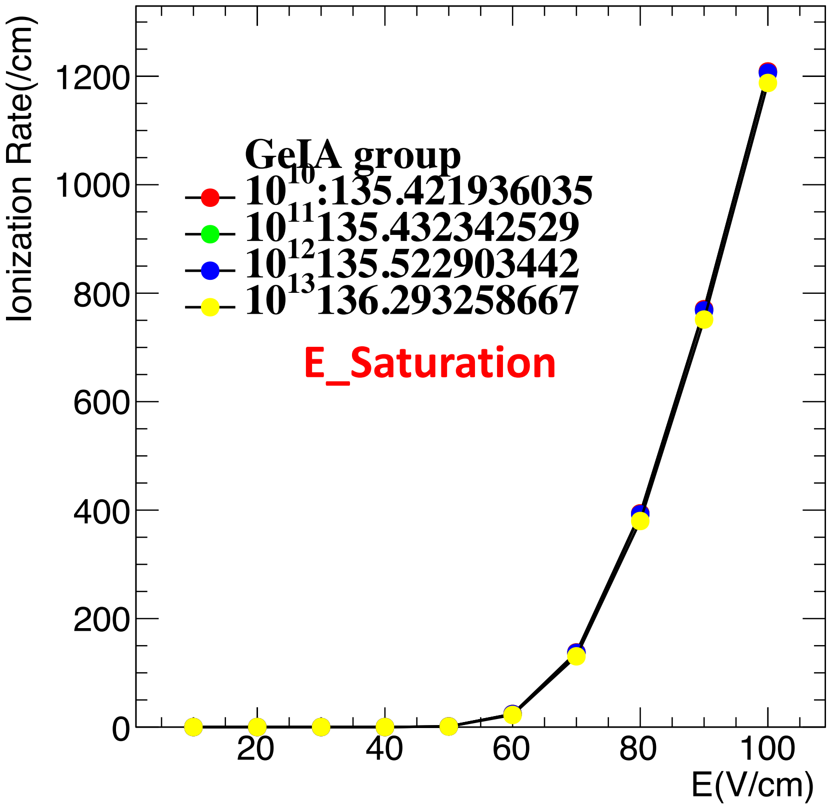
- 1. The same temperature
- ➔ For the phonon and neutral impurity, they have the same mobility

- 2. The different “charged impurities concentration”
- ➔ It can only affects “ionized impurity scattering”
- ➔ When the temperature goes down
- ➔ The mobility will be bigger.
- ➔ The effect of it will be smaller for the total mobility!

My results (Not sure)



4K
The same



77K
Very little difference

Next Step

- Will discuss with Prof. Dongming tomorrow first.
- After figuring it out, and we just finish paving the way for getting out the “pure” gain without the noise.
- Then I will have a chat on this issue with Prof. Henry Wong, and see the next step of the project.
- ➔ I think the next step is to take the leakage current into account.