Exercise 0519 for “Semiconductors”

Problem setting:	28/04/2021	出題	2021 年 4 月 28 日
Solution submission deadline:	19/05/2021	解答提出期限	2021 年 5 月 19 日

General notes / 一般的注意

The text part in the answer should be typed (not handwriting) in English or Japanese. The scoring does not depend on the language. It doesn’t matter if you are good at grammar, vocabulary, or sentences, but if I cannot catch the meaning, the scoring will get deducted regardless of English or Japanese. The answer sheet should be in small-sized (hopefully less than 1 MB) PDF format, which can be appropriately displayed by Adobe Reader. The file of the answer should be submitted through ITC-LSM.

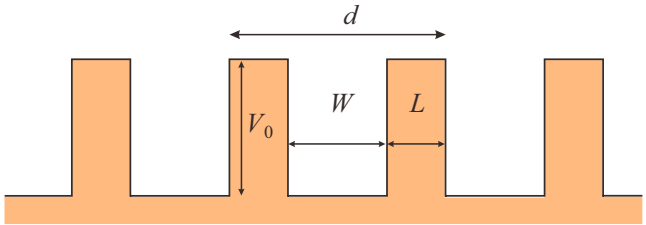
解答のテキスト部分は手書きでないようにお願いします．英語，日本語のどちらでも良く，採点は言語に依存しません．文法や語法，文章の上手下手は問題にしませんが，意味が取れない場合は，英語日本語にかかわらず，減点します．解答は，ファイルサイズのできるだけ小さな (1 MB 以下が目安)，Adobe Reader できちんと表示できる PDF ファイルにまとめ，ITC-LSM を通して提出してください．

As for these problems / 今回の問題について

We have three problems this week as the time for submitting the solutions is three weeks. For your answers, you can select two of them. Giving the solutions for all of the three is of course OK. In that case, I take the top two scores from the results.

今回は，解答提出まで 3 週間もあることから，3 問出題します．2 題を選んで答えてください．無論，3 問全部お答えいただいても結構です．その場合，点の良い方から 2 問分を登録します．

0519-1 Effective mass

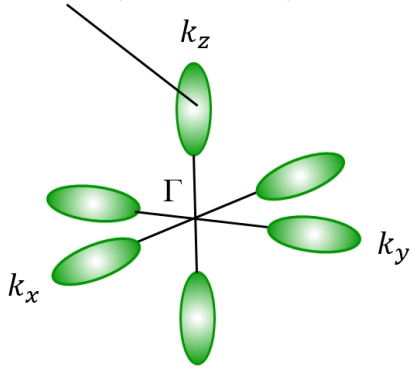


a. Consider the Kronig-Penny potential drawn above. Numerically calculate the lowest four bands in energy and obtain the effective masses. You can assume the ratios between L, W, and V_0 at your convenience.

b. Explain why the effective mass of the electrons in crystals can be lighter than that of electrons in vacuum. Use the equation of motion for the explanation.

0519-2 Carrier statistics

$$E_0 = \frac{\hbar^2}{2}\left(\frac{k_x^2 + k_y^2}{m_t} + \frac{k_z^2}{m_l}\right)$$



In the conduction band, Si has six valleys, each position of which places the point slightly inside the first Brillouin zone edge from an X-point to Γ-point (see the figure). They are degenerate having a spheroid shape.

The anisotropic effective mass is determined form the cyclotron resonance to be $0.19m_0$ for transverse mass m_t and $0.97m_0$ for longitudinal mass m_l.

The top of the valence band is at Γ-point. The constant energy surfaces have warping and the averaged effective mass for heavy hole is m_{hh}=$0.49m_0$, and for light hole m_{lh}=$0.16m_0$.

a. Obtain the conduction band effective density of states N_c for the temperature T.
b. Obtain the same (symbol N_v) for the valence band.
c. Si has the energy gap of 1.1 eV at 300 K. Find the np product at 300 K.

0519-3 Exciton

a. Calculate the binding energy and radius of the n = 1 and n = 2 free excitons in ZnS, which has m_e^*=$0.28m_0$, m_h^*=$0.5m_0$ and ϵ_r=7.8. Would you expect these excitons to be stable at room temperature?
b. Calculate the difference in the optical wavelengths for the absorption peaks of the n = 1 and n = 2 excitons in InP, which has Eg = 1.424 eV, m_e^*=$0.077m_0$, m_h^*=$0.2m_0$ and ϵ_r=12.4.
(optical wavelength: wavelength of light in the vacuum)