Exercise 1: Charge carrier statistics in thermodynamic equilibrium

The aim of this exercise is to acquire charge carrier densities and the chemical potential in semiconductors for an arbitrarily constructed density of states. Despite the wealth of analytical relationships given in the textbooks, one hast to keep in mind that these expressions typically hold for particularly shaped DOS or special cases. Only for such situations, simplifying assumptions allow to analytically evaluate the defining expressions. To explore a more general situation and to scrutinize the validity of the simplified relations, a numerical treatment is in order.

The following tasks will be pursued, for each of which a MATLAB script has to be provided. To that purpose, you will be provided with a library of functions (**Appendix B**). A short overview on these functions (**Appendix B,D**) and a sample script (**Appendix E**) based on these functions are given. For each task, the MATLAB script, the plots (scientifically sound), and a written discussion have to be returned.

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(1) Temperature-dependent occupation

(a) Consider p-doped crystalline silicon. Plot the chemical potential μ, the concentration of holes p, and the concentration of ionized acceptors N_A^- as a function of temperature.

$N_A = 10^{21}$ m^{-3}, $E_A = E_V + 0.1$ eV, T = 10 .. 800 K

(b) Compare the obtained values for μ and n with the values, μ and n would adopt in the intrinsic semiconductor.

(c) Compare these relations with the situation in Ge and GaAs.

(d) Considering the peculiar evolution of μ(T): Which characteristic regions can be discerned? How are these regions affected by the bandgap, how by the the effective mass? Create your own, artificial semiconducting material 'MyMt' in the routine AssignSemiconductor.m so that you can freely modify the effective masses and the bandgap.

(e) In which temperature region are the simplified expressions for the charge carrier density in semiconductors valid? (cf. **Appendix C**)

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(2) Relation between chemical potential and doping density

(a) Consider an n-doped crystalline semiconductor. Plot the chemical potential μ as a function of the donor density.

$N_D = 10^{13}$ .. 10^{25} m^{-3} , $E_D = E_C - 0.1$ eV, T = 300 K

(b) Introduce a Gaussian-shaped distribution of trap states 100 meV below the midgap position. Plot again the chemical potential μ as a function of the donor density.

$N_T = 10^{22}$ m^{-3}, width of Gaussian function σ = 50 meV, traps become negatively charged upon filling with electrons. What changes in μ are observed? Why?