Aprēķini

3. Aprēķināt dotā pusvadītāja aizliegtās zonas platumu dzesēšanas posmam

$$\Delta E_{\searrow \text{sāk.}} = 2k\frac{\ln(R_p^{-1}) - \ln(R_1^{-1})}{T_1^{-1} - T_p^{-1}} = 2 \cdot 1{,}381 \cdot 10^{-23} \cdot \frac{-5{,}7138 - \ln(\frac{1}{342})}{\frac{1}{35+273{,}15} - 0{,}0031} \approx$$
$$\approx 1{,}3633 \cdot 10^{-20}\ \text{J} \approx 0{,}0851\ \text{eV}$$

$$\Delta E_{\searrow \text{beig.}} = 2k\frac{\ln(R_7^{-1}) - \ln(R_p^{-1})}{T_p^{-1} - T_7^{-1}} = 2 \cdot 1{,}381 \cdot 10^{-23} \cdot \frac{\ln(\frac{1}{270}) + 5{,}7138}{0{,}0031 - \frac{1}{71+273{,}15}} \approx$$
$$\approx 3{,}3797 \cdot 10^{-20}\ \text{J} \approx 0{,}211\ \text{eV}$$

4. Kļūdu aprēķini

$t_1, t_p, t_2, R_{t_1}, R_p$ un R_{t_2} ir tiešo mērījumu kļūdas
ΔE ir netiešo mērījumu kļūdas

$$\Delta t_1 = \Delta t_{\searrow p} = \Delta t_{\nearrow p} = \Delta t_7 = \Delta t = \sqrt{\Delta t_s^2} = \frac{\delta_t}{3} \cdot t_{0{,}95}(\infty) = \frac{0{,}5}{3} \cdot 1{,}96 \approx 0{,}3266$$

$$\varepsilon(t_1) = \frac{\Delta t}{t_1} = \frac{0{,}3266}{35} \approx 0{,}9331\%$$

$$\boxed{t_1 = (35 \pm 0{,}3266)\ {}^\circ\text{C pie } \beta = 0{,}95 \text{ un } \varepsilon(t_1) = 0{,}9331\%}$$

$$\varepsilon(t_{\searrow p}) = \frac{\Delta t}{t_{\searrow p}} = \frac{0{,}3266}{0{,}0031^{-1} - 273{,}15} \approx 0,6607\%$$

$$\boxed{t_{\searrow p} = (49{,}4306 \pm 0{,}3266)\ {}^\circ\text{C pie } \beta = 0{,}95 \text{ un } \varepsilon(t_{\searrow p}) = 0{,}6607\%}$$

$$\varepsilon(t_{\nearrow p}) = \frac{\Delta t}{t_{\nearrow p}} = \frac{0{,}3266}{0{,}003^{-1} - 273{,}15} \approx 0,5427\%$$

$$\boxed{t_{\nearrow p} = (60{,}1833 \pm 0{,}3266)\ {}^\circ\text{C pie } \beta = 0{,}95 \text{ un } \varepsilon(t_{\nearrow p}) = 0{,}5427\%}$$

$$\varepsilon(t_7) = \frac{\Delta t}{t_7} = \frac{0{,}3266}{71} \approx 0{,}4628\%$$

$$\boxed{t_7 = (71 \pm 0{,}3266)\ {}^\circ\text{C pie } \beta = 0{,}95 \text{ un } \varepsilon(t_7) = 0{,}4628\%}$$

$$\Delta R_{\searrow 1} = \Delta R_{\searrow p} = \Delta R_{\searrow 7} =$$
$$= \Delta R_{\nearrow 1} = \Delta R_{\nearrow p} = \Delta R_{\nearrow 7} = \Delta R = \sqrt{\Delta R_s^2} = \frac{\delta_R}{3} \cdot t_{0{,}95}(\infty) = \frac{1}{3} \cdot 1{,}96 \approx 0{,}6533$$

$$\varepsilon(R_{\searrow 1}) = \frac{\Delta R}{R_{\searrow 1}} = \frac{0{,}6533}{342} \approx 0{,}191\%$$

$$\boxed{R_{\searrow 1} = (342 \pm 0{,}6533)\ \Omega \text{ pie } \beta = 0{,}95 \text{ un } \varepsilon(R_{\searrow 1}) = 0{,}191\%}$$

$$\varepsilon(R_{\searrow p}) = \frac{\Delta R}{R_{\searrow p}} = \frac{0{,}6533}{1 : e^{-5{,}7138}} \approx 0{,}2156\%$$

$$\boxed{R_{\searrow p} = (303{,}0204 \pm 0{,}6533)\ \Omega \text{ pie } \beta = 0{,}95 \text{ un } \varepsilon(R_{\searrow p}) = 0{,}2156\%}$$

$$\varepsilon(R_{\searrow 7}) = \frac{\Delta R}{R_{\searrow 7}} = \frac{0{,}6533}{270} \approx 0{,}242\%$$

$$\boxed{R_{\searrow 7} = (270 \pm 0{,}6533)\ \Omega \text{ pie } \beta = 0{,}95 \text{ un } \varepsilon(R_{\searrow 7}) = 0{,}242\%}$$

$$\varepsilon(R_{\nearrow 1}) = \frac{\Delta R}{R_{\nearrow 1}} = \frac{0{,}6533}{339} \approx 0{,}1927\%$$

$$\boxed{R_{\nearrow 1} = (339 \pm 0{,}6533)\ \Omega \text{ pie } \beta = 0{,}95 \text{ un } \varepsilon(R_{\nearrow 1}) = 0{,}1927\%}$$

$$\varepsilon(R_{\nearrow p}) = \frac{\Delta R}{R_{\nearrow p}} = \frac{0{,}6533}{1 : e^{-5{,}7311}} \approx 0{,}2119\%$$

$$\boxed{R_{\nearrow p} = (308{,}3082 \pm 0{,}6533)\ \Omega \text{ pie } \beta = 0{,}95 \text{ un } \varepsilon(R_{\nearrow p}) = 0{,}2119\%}$$

$$\varepsilon(R_{\nearrow 7}) = \frac{\Delta R}{R_{\nearrow 7}} = \frac{0{,}6533}{262} \approx 0{,}2494\%$$

$$\boxed{R_{\nearrow 7} = (262 \pm 0{,}6533)\ \Omega \text{ pie } \beta = 0{,}95 \text{ un } \varepsilon(R_{\nearrow 7}) = 0{,}2494\%}$$

$$\Delta E_1 = \Delta E_{\searrow \text{sāk.}} = 1{,}3633 \cdot 10^{-20}\ \text{J}$$

$$\Delta(\Delta E_1) =$$

$$= \sqrt{\left(\frac{\partial \Delta E_1}{\partial R_{\searrow p}} \cdot \Delta R\right)^2 + \left(\frac{\partial \Delta E_1}{\partial R_{\searrow 1}} \cdot \Delta R\right)^2 + \left(\frac{\partial \Delta E_1}{\partial t_1} \cdot \Delta t\right)^2 + \left(\frac{\partial \Delta E_1}{\partial t_p} \cdot \Delta t\right)^2} =$$

$$= \sqrt{\left(\frac{-2k \cdot \Delta R}{(T_1^{-1} - T_p^{-1}) \cdot R_{\searrow p}}\right)^2 + \left(\frac{2k \cdot \Delta R}{(T_1^{-1} - T_p^{-1}) \cdot R_{\searrow 1}}\right)^2 + \left(\frac{-2k(\ln\left(R_{\searrow 1}^{-1}\right) - \ln\left(R_{\searrow p}^{-1}\right))T_p^2 \cdot \Delta t}{(T_1 - T_p)^2}\right)^2 + \left(\frac{2k(\ln\left(R_{\searrow 1}^{-1}\right) - \ln\left(R_{\searrow p}^{-1}\right))T_1^2 \cdot \Delta t}{(T_p - T_1)^2}\right)^2} =$$

$$= \sqrt{\left(\frac{-2 \cdot 1{,}381 \cdot 10^{-23} \cdot 0{,}6533}{((35 + 273{,}15)^{-1} - 0{,}0031) : e^{-5{,}7138}}\right)^2 + \left(\frac{2 \cdot 1{,}381 \cdot 10^{-23} \cdot 0{,}6533 : 342}{(35 + 273{,}15)^{-1} - 0{,}0031}\right)^2 + \left(\frac{-2 \cdot 1{,}381 \cdot 10^{-23} \cdot (\ln(342^{-1}) + 5{,}7138) \cdot 0{,}3266}{((35 + 273{,}15) - 0{,}0031^{-1})^2 : (0{,}0031^{-1})^2}\right)^2 + \left(\frac{2 \cdot 1{,}381 \cdot 10^{-23} \cdot (\ln(342^{-1}) + 5{,}7138)}{(0{,}0031^{-1} - (35 + 273{,}15))^2 : (35 + 273{,}15)^2 : 0{,}3266}\right)^2} =$$

$$= \sqrt{(-4{,}1018 \cdot 10^{-22})^2 + (3{,}6343 \cdot 10^{-22})^2 + (-5{,}4547 \cdot 10^{-22})^2 + (-4{,}9776 \cdot 10^{-22})^2} =$$

$$= 9{,}1958 \cdot 10^{-22}\ \mathrm{J}$$

$$\varepsilon(\Delta E_1) = \frac{\Delta(\Delta E_1)}{\Delta E_1} = \frac{9{,}1958 \cdot 10^{-22}}{1{,}3633 \cdot 10^{-20}} = 6{,}7543\%$$

$$\boxed{\Delta E_1 = (1{,}3633 \cdot 10^{-20} \pm 9{,}1958 \cdot 10^{-22})\ \mathrm{J\ pie}\ \beta = 0{,}95,\ \varepsilon(\Delta E_1) = 6{,}7543\%}$$

$$\Delta E_2 = \Delta E_{\searrow\,\mathrm{beig.}} = 3{,}3797 \cdot 10^{-20}$$

$$\Delta(\Delta E_2) =$$

$$= \sqrt{\left(\frac{-2 \cdot 1{,}381 \cdot 10^{-23} \cdot 0{,}6533 : 270}{0{,}0031 - (71 + 273{,}15)^{-1}}\right)^2 + \left(\frac{2 \cdot 1{,}381 \cdot 10^{-23} \cdot 0{,}6533 \cdot e^{-5{,}7138}}{0{,}0031 - (71 + 273{,}15)^{-1}}\right)^2 +} \\ \overline{+\left(\frac{-2 \cdot 1{,}381 \cdot 10^{-23} \cdot (-5{,}7138 - \ln(270^{-1})) \cdot 0{,}3266}{(0{,}0031^{-1} - (71 + 273{,}15))^2 : (71 + 273{,}15)^2}\right)^2 +} \\ \overline{+\left(\frac{2 \cdot 1{,}381 \cdot 10^{-23} \cdot (-5{,}7138 - \ln(270^{-1})) \cdot 0{,}3266}{((71 + 273{,}15) - 0{,}0031^{-1})^2 : (0{,}0031^{-1})^2}\right)^2} =$$

$$= \sqrt{(-3{,}4397 \cdot 10^{-22})^2 + (3{,}0649 \cdot 10^{-22})^2 + (2{,}6496 \cdot 10^{-22})^2 + (2{,}3279 \cdot 10^{-22})^2} =$$

$$= 5{,}8021 \cdot 10^{-22}\ \mathrm{J}$$

$$\varepsilon(\Delta E_2) = \frac{\Delta(\Delta E_2)}{\Delta E_2} = \frac{5{,}8021 \cdot 10^{-22}}{3{,}3797 \cdot 10^{-20}} = 1{,}7168\%$$

$$\boxed{\Delta E_2 = (3{,}3797 \cdot 10^{-20} \pm 5{,}8021 \cdot 10^{-22})\ \mathrm{J\ pie}\ \beta = 0{,}95,\ \varepsilon(\Delta E_2) = 1{,}7168\%}$$

$$\Delta E_3 = \Delta E_{\nearrow\,\mathrm{s\bar{a}k.}} = 2k\frac{\ln(R_p^{-1}) - \ln(R_1^{-1})}{T_1^{-1} - T_p^{-1}} = 2 \cdot 1{,}381 \cdot 10^{-23} \cdot \frac{-5{,}7311 - \ln(\frac{1}{339})}{\frac{1}{35+273{,}15} - 0{,}003} \approx$$

$$\approx 1{,}8055 \cdot 10^{-20}\ \mathrm{J} \approx 0{,}1127\ \mathrm{eV}$$

$$\Delta(\Delta E_3) =$$

$$= \sqrt{\left(\frac{-2 \cdot 1{,}381 \cdot 10^{-23} \cdot 0{,}6533}{((35 + 273{,}15)^{-1} - 0{,}003) : e^{-5{,}7311}}\right)^2 + \left(\frac{2 \cdot 1{,}381 \cdot 10^{-23} \cdot 0{,}6533 : 339}{(35 + 273{,}15)^{-1} - 0{,}003}\right)^2 +} \\ \overline{+\left(\frac{-2 \cdot 1{,}381 \cdot 10^{-23} \cdot (\ln(339^{-1}) + 5{,}7311) \cdot 0{,}3266}{((35 + 273{,}15) - 0{,}003^{-1})^2 : (0{,}003^{-1})^2}\right)^2 +} \\ \overline{+\left(\frac{2 \cdot 1{,}381 \cdot 10^{-23} \cdot (\ln(339^{-1}) + 5{,}7311)}{(0{,}003^{-1} - (35 + 273{,}15))^2 : (35 + 273{,}15)^2 : 0{,}3266}\right)^2} =$$

$$= \sqrt{(-2{,}3872 \cdot 10^{-22})^2 + (2{,}171 \cdot 10^{-22})^2 + (1{,}4998 \cdot 10^{-22})^2 + (-1{,}2831 \cdot 10^{-22})^2} =$$

$$= 3{,}7826 \cdot 10^{-22}\ \mathrm{J}$$

$$\varepsilon(\Delta E_3) = \frac{\Delta(\Delta E_3)}{\Delta E_3} = \frac{3{,}7826 \cdot 10^{-22}}{1{,}8055 \cdot 10^{-20}} = 2{,}095\%$$

$$\boxed{\Delta E_3 = (1{,}8055 \cdot 10^{-20} \pm 3{,}7826 \cdot 10^{-22})\ \text{J pie}\ \beta = 0{,}95,\ \varepsilon(\Delta E_3) = 2{,}095\%}$$

$$\Delta E_4 = \Delta E_{\nearrow\,\text{beig.}} = 2 \cdot 1{,}381 \cdot 10^{-23} \cdot \frac{\ln(\frac{1}{262}) + 5{,}7311}{0{,}0031 - \frac{1}{71+273{,}15}} \approx 2{,}3137 \cdot 10^{-20}\ \text{J} = 0{,}1444\ \text{eV}$$

$$\Delta(\Delta E_4) =$$

$$= \sqrt{\left(\frac{-2 \cdot 1{,}381 \cdot 10^{-23} \cdot 0{,}6533 : 262}{0{,}003 - (71 + 273{,}15)^{-1}}\right)^2 + \left(\frac{2 \cdot 1{,}381 \cdot 10^{-23} \cdot 0{,}6533 \cdot e^{-5{,}7311}}{0{,}003 - (71 + 273{,}15)^{-1}}\right)^2 + \overline{+\left(\frac{-2 \cdot 1{,}381 \cdot 10^{-23} \cdot (-5{,}7311 - \ln(262^{-1})) \cdot 0{,}3266}{(0{,}003^{-1} - (71 + 273{,}15))^2 : (71 + 273{,}15)^2}\right)^2 +} \overline{+\left(\frac{2 \cdot 1{,}381 \cdot 10^{-23} \cdot (-5{,}7311 - \ln(262^{-1})) \cdot 0{,}3266}{((71 + 273{,}15) - 0{,}003^{-1})^2 : (0{,}003^{-1})^2}\right)^2}} =$$

$$= \sqrt{(-7{,}3041 \cdot 10^{-22})^2 + (6{,}207 \cdot 10^{-22})^2 + (-1{,}2862 \cdot 10^{-21})^2 + (-1{,}2943 \cdot 10^{-21})^2} =$$

$$= 2{,}0611 \cdot 10^{-21}\ \text{J}$$

$$\varepsilon(\Delta E_4) = \frac{\Delta(\Delta E_4)}{\Delta E_4} = \frac{2{,}0611 \cdot 10^{-21}}{2{,}3137 \cdot 10^{-20}} = 8{,}9082\%$$

$$\boxed{\Delta E_4 = (2{,}3137 \cdot 10^{-20} \pm 2{,}0611 \cdot 10^{-21})\ \text{J pie}\ \beta = 0{,}95,\ \varepsilon(\Delta E_4) = 8{,}9082\%}$$

5. Secinājumi

Pētamā viela visticamāk ir germānijs – tā $\Delta E_{T=300^\circ\text{K}}$ ir mazāka par 1 eV (apmēram 0,62 eV), atšķirībā no citiem iespējamiem pusvadītājiem. Eksperimentāli iegūtās vērtības ir vistuvāk šai atzīmei.

Grafiks nav taisne, jo viela nav ideāli viendabīga – tā sastāv no piejaukumiem, kam no temperatūras mainījās pretestība savā veidā atkarībā no pamata materiāla.

Neskatoties uz to, ka $\varepsilon(\Delta E) < 10\%$, darbu ir iespējams vēl vairāk pilnveidot. Eksperimentāli iegūtās vērtības tomēr nav tuvu germānijam, bet ir tam vistuvāk. Labākus rezultātus būtu iespējams iegūt, ja tiktu ievērots pirmais uzdevuma punkts: būtu veikti mērījumi no 26, nevis 35 $^\circ$C – lielāks datu apjoms varētu koreģēt gala ΔE vērtības, kas labāk atbilstu kādam materiālam (iespējams pat citam).