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EKSAMEN I FAG FY3114 Funksjonelle Materialer
Thursday 19 December 2013
Time: 15.00 – 19.00
English text (Norwegian text after English text)

Number of pages: **4** (+ 4 for Bokmål text) Correction deadline: 19.01.2014
Allowed: Hjelpemidler C (simple calculator, English dictionary, Rottmann formulas book).

- There are 5 tasks in total.
- Some questions have sub-questions.
- Attempt to answer all questions, they are independent of each other as far as possible.
- Read the questions carefully and answer completely and legibly!
- Max. score per question is indicated. Total: 100 points = 100%
- This written exam counts 2/3 for final mark in this course
- Answers can be given in English or a Scandinavian language.

TASK 1: Materials for renewable energy solutions - Mini-projects

Multiple-choice. The candidate is supposed to choose one among of the four suggested answers for each of the 10 sub-questions. No motivation is required for a given answer, but in case of a wrong answer, an argumentation could be rewarded with points.

Questions: [Max. score:10 points]

1(a): What is one of the main challenges to realized large scale production of carbon nanotube (CNT) based transistors?
A: To improve purity of CNTs in a batch.
B: Large scale production of long CNTs.
C: To produce semiconductor CNT with a much larger bandgap
D: To produce metallic CNT with a high ON/OFF switch ratio.

1(b): What is a motivation to study graphene as component in transistor?
A: It is easy to make perfect ohmic contacts to graphene sheets.
B: The presence of a tuneable bandgap.
C: The high ON/OFF switching ratio
D: The high carrier mobility.

1(c): The 3D Si-based MOSFET can offer
A: a future solution to fulfill Moore's law if they could be scaled down to the nm-scale.
B: a higher on/off ratio than current MOSFETs.
C: enhanced control of doping levels in the channel.
D: a reduced leakage current as the gate is wrapped around the channel.

1(d): Open – something Moore's law?
A:
B:
C:
D:

1(e): Strain in Si-based MOSFET
A: should be avoided as it reduces the carrier mobility.
B: is of potential interest to reduce leakage current.
C: can enhance carrier mobility and is therefore already used in today's MOSFETS.
D: is advantageous if the strain is biaxial. Uniaxial strain has no effect on device performance.

1(f) Why is there a search for high-k (dielectric constant) materials to replace SiO_2 in MOSFET?
A: To get thinner oxide layers between gate and channel and hence smaller devices
B: To get thicker oxide layers between gate and channel to reduce leakage currents
C: To improve compatibility of the oxide with the other materials of the MOSFET
D: To lower the price of MOSFET component

1(g): The piezoelctric transistors design
A: can integrate sensor and on/off function within one unit.
B: requires in ZnO pn-junctions, but not if GaN is used.
C: has already demonstrated speeds approaching today's MOSFETs.
D: is based on electronstriction

1(h): What will be the main advantage of organic field effect transistors (OFET)?
A: the superior switching speed
B: the long term stability
C: reduction of materials costs
D: none, compared to today's Si-based FETs

1(i): Spintronic transistors are
A: are not yet experimentally proven to work
B: proof-of-principle devices have been realized, the limitations are *technological*
C: have still two states, but are faster than traditional Si based FETs.
D: are only achievable by using exotic materials.

1(j): What is Fe_3O_4 (magnetite) at room temperature?
A: Ferromagnetic
B: Ferrimagnetic
C: Antiferromagnetic
D: None of the above

TASK 2: Solids – Crystallography – symmetry & properties

Question 2(a): [Max. score:10 points]

What is meant with a "crystallographic system"? Give two examples of such systems and two different functional properties that depend on the crystallographic system.

Question 2(b): [Max. score:10 points]

What is meant with "$\frac{4}{m}\bar{3}\frac{2}{m}$" (short notation: "$m\bar{3}m$")? Explain the symmetry elements present in the given notation. To what crystal system does this example belong?

Question 2(c): [Max. score:5 points]

What is meant with a "non-centrosymmetric point group"? Give an example of a functional property that is only found in such a group.

TASK 3: Tensor description materials properties

Question 3(a): [Max. score:10 points]

For a crystal the electrical conductivity (in $10^8\ \Omega^{-1}m^{-1}$) is given by

$$\sigma_{ij} = \begin{bmatrix} 18.25 & -\sqrt{3}\times 2.25 & 0 \\ -\sqrt{3}\times 2.25 & 22.75 & 0 \\ 0 & 0 & 9 \end{bmatrix} \quad (1)$$

Find the electrical conductivity σ'_{ij} expressed in its principle components, by applying a clockwise rotation of θ=60° around the x_3-axis. Call the new axis x'_1, x'_2 and x'_3. In your answer include the deduction and an expression for the directional cosines (rotation operation) a_{ij} (R_{ij}). The transformation rule for 2nd rank tensor is $T'_{ij} = a_{ik}a_{jl}T_{kl}$.

Question 3(b): [Max. score:7.5 points]

Using the answer from question 3(a), **deduce** the principal components of the electrical resistivity tensor $\boldsymbol{\rho_{ij}}$ (in Ωm). In case of no answer to question 3(a) use for questions 3(b,c) the following fictitious principle components: σ_{11} = 9, σ_{22} = 36 and σ_{33} = 9 (in $10^8\ \Omega^{-1}m^{-1}$). These are not the correct answers for question 3(a).
Sketch the representative quadric for the electric resistivity tensor ρ_{ij}.

Question 3(c): [Max. score:7.5 points]

An electrical field **E** of 100 Vm^{-1} is applied over the crystal. **E** make an angle of 60 degrees with the x'_1-axis in the plane $x'_3 = 0$. What is the resulting angle between the total current density **J** and the applied field **E** in this plane? Given is that $J_i = \sigma_{ij} E_j$. In your answer include the components of **E** and **J** in the x'_1 and x'_2 directions.

TASK 4: Energy bands – semiconductor devices

Question 4(a): [Max. score:10 points]

A metal is deposited on a p-doped semiconductor. The work function ϕ of the metal is lower than the electron affinity χ of the semiconductor.
Sketch the band picture of this configuration. In your sketch include if band bending (if applicable) for both valence and conduction band, the Fermi level and the acceptor level in the semiconductor. Explain the choices made in the drawing.
What is such metal-semiconductor contact called? Draw the schematic I-V diagram of such a contact.

Question 4(b): [Max. score:10 points]

How does the carrier concentration of a doped semiconductor depend on the temperature? Include a schematic diagram of this temperature behaviour in your answer.
Explain how this temperature behaviour depends on the characteristics of the semiconductor as the bandgap E_g and the type of band alignment (e.g. direct/indirect).

TASK 5:

Question 5(a): [Max. score:10 points]

Describe the principle and configuration of a pn-junction used as light detector (also called photodetector). What currents contribute to the total photo current and how can the fast prompt current ("the fast response") be increased? Limit your answer to max 15 lines and include a drawing to demonstrate the working principle.

Question 5(b): [Max. score:10 points]

For infrared or heat detectors, pyroelectrics devices are commonly used.
Explain what pyroelectricity is and how this phenomenon is related to piezo- and ferroelectricity.
Explain how a pyroelectric heat detector works and give one example advantage of such pyroelectric based photodetectors compared to semiconductor photodetectors for this relatively long wavelength.

End of exam, question 5(b) is the last question