NAMIBIA UNIVERSITY
OF SCIENCE AND TECHNOLOGY

FACULTY OF HEALTH AND APPLIED SCIENCES

DEPARTMENT OF NATURAL AND APPLIED SCIENCES

QUALIFICATION: BACHELOR OF SCIENCE HONOURS	
QUALIFICATION CODE: 08BOSH	**LEVEL:** 8
COURSE CODE: MAP 821 S	**COURSE NAME:** MATERIALS PHYSICS
SESSION: JANUARY 2019	**PAPER:** THEORY
DURATION: 3 HOURS	**MARKS:** 100

SUPPLEMENTARY/SECOND OPPORTUNITY EXAMINATION QUESTION PAPER	
EXAMINER(S)	**Prof. Dr. Hans-Dieter Bauer**
MODERATOR:	**Dr. Zivayi Chiguvare**

INSTRUCTIONS
1. Answer any 5 of the 6 questions given. 2. Write clearly and neatly. 3. Number the answers clearly.

PERMISSIBLE MATERIALS

Non-programmable calculator

THIS QUESTION PAPER CONSISTS OF 5 PAGES (Incl. front page) **+ 1 PAGE OF ATTACHMENTS**

Question 1: Thermal properties of materials **[20]**

A cuboid room is perfectly isolated on all sides, except one. This side, 6m long and 2m high, is 25cm thick and shows a heat conductivity of 0.8W/(Km). The wall has no windows.

a) The temperature of the inner wall surface is 10°C, the temperature of the outer wall surface is -10°C. Calculate the heat flow through the wall? (4)

b) Given that the heat transfer coefficient of the inside wall is $7W/(Km^2)$, and that of the outside wall is $20W/(Km^2)$,

(i) Calculate the heat flow through the wall if the air inside the room has a temperature of 20°C, and the air outside has a temperature of -20°C,

(ii) What temperatures do the inside and outside wall surfaces have, respectively? (8)

c) It is desired to keep the temperature inside the room at a constant value of 20°C, and a simple heating device is to be installed to compensate for the heat loss. The heating element is a simple electric resistor, the emissive area of which is spherical. The surface of the sphere, an ideal black-body radiator, is heated up to 350°C. What radius should the sphere have? (4)

d) Consider that the heating exactly compensates the energy lost from the room through the uninsulated wall. If the heating works with an efficiency of 80%, what amount of electrical energy does it consume during a day (24 hours), measured in kWh? (4)

$$\sigma = 5.67 * 10^{-8}\ W/(m^2K^4)$$

Question 2: Optical properties of materials **[20]**

A ray of blue light, randomly polarized, travelling in air (n=1.0) is incident on the surface of a transparent material ($n_b = 1.6$) at an angle of 45°.

a) Calculate the ratio of intensities for reflected s- and p-polarized light, I_s/I_p. (8)

b) Which angle of incidence would you chose to use the surface as a polarizer? (4)

c) For normal dispersion, would the angle calculated in b) be higher or lower for red light? Justify your answer in words. No calculation necessary. (4)

d) If it would be necessary to find a glass material where the difference between the angles discussed in b) and c) (above) had to be remarkably less, would you choose a material with a higher or a lower Abbe number? Justify your answer in words and with the help of a formula, if necessary. (4)

Question 3: (Di)electrical properties of materials **[20]**

A static voltage of 10kV is applied to two identical capacitors arranged in parallel. Each of the two capacitors, consists of two parallel metal plates each of area of $20cm^2$, separated by air, a distance of 2cm.

a) Calculate (i) the capacitance of each of these capacitors, in pF, and
(ii) The amount of charge stored in each of the capacitors, in nC. (4)

b) (i) Explain what happens, at microscopic scale, to the capacitance, and to the charge stored, if water (non-conducting) is brought between the plates of one of the capacitors, so that it completely fills the gap between the plates?
(ii) Calculate the change with respect to (a). (4)

c) Calculate flux density and polarization inside the water-filled capacitor. (4)

d) Calculate the capacitance of the whole arrangement (filled plus unfilled capacitor). (4)

e) How will the water-filled capacitor behave, if not a static, but a high-frequency voltage is applied, e.g. 300GHz. Explain in words and with the help of a sketch. No calculations. (4)

$$\varepsilon_0 = 8.854 \cdot 10^{-12} C^2 J^{-1} m^{-1} \qquad \varepsilon_r (H_2O) = 88$$

Question 4 Pulsed lasers for material patterning **[20]**

A Nd:YAG laser system emits light pulses of wavelength 1064 nm, energy 5 mJ, and a duration of 50 ps with a pulse rate of 2 kHz.

a) Calculate the number of photons "contained" in one of these pulses. (4)

b) Calculate the pulse power and the average beam output power of this system. (3)

c) The beam's cross section has a diameter of 2mm. What is the average intensity of the laser beam, hitting a workpiece perpendicularly, in W/cm^2? (3)

d) What is meant by the expression "cold ablation"? What is the energy of one of the laser's photons, expressed in eV? Would it be useful for this process? Why (not)? (4)

e) When investigating the ablation behavior of this laser, you may observe, that the ablation rate is not increasing with increasing fluence but keeps constant. In words: What is the most probable reason for that? And how can this problem be overcome by modern laser technology? (6)

$$h = 6.626 \cdot 10^{-34} Js. \quad e = 1.19 \cdot 10^{-19} As. \quad c_0 = 3 \cdot 10^8 m/s.$$

Question 5: Etching of materials **[20]**

An etchant, *A*, shows an etch rate of 4 µm/min with respect to the wafer material *M*, independent of direction. As an etch mask, resist can be used.

a) (i) What is the anisotropy of this process?
(ii) Is such kind of process more likely a wet or a dry etching process? (2)

b) Using this etching process, you want to generate two circular "pots" in a silicon wafer's surface which are separated 80µm (rim-to-rim). The depth of the pots shall be 30µm. The full diameter shall be 100µm. Design the mask under the prerequisite that you have to use a negative photoresist. (8)

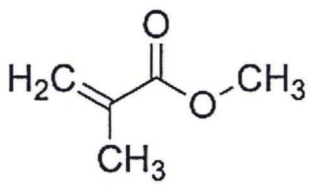
c) How long do you need to etch to achieve the pots' dimensions given in a) with the mask you have designed? (2)

d) Assuming the pots are allowed to become bigger: How long are you allowed to over-etch, if the pots shall be still separated from each other? Still use the mask from a). (4)

e) Provided, the selectivity of your etch process with respect to wafer material and resist is 20: Which minimum resist thickness you have to choose for c) and d)? (4)

Question 6: Polymer materials **[20]**

The formula below is the reduced structure formula of methylmethacrylate (MMA):



a) Draw the complete structure of the molecule (with all atoms, all bonds; use the paper space!). Number all C-atoms from left to right. Number also all bonds. (5)

b) What kind of hybridization do the different C-atoms show? (2)

c) Which orbitals are involved in the formation of the double bonds? (4)

d) Which area of the molecule is arranged as a "stiff" plane and which parts may rotate, around which axes? (3)

e) MMA may be polymerized radically to form PMMA (poly-MMA). Describe, in words and formulae, how this reaction looks like and give the structure formula of the polymer. (4)

f) What is the molecular weight of a PMMA molecule with 10^6 repeat units? (2)

Atomic masses for C: 12; H: 1; O: 16

END

ANNEX 1 - Formula Sheet: Materials Physics

Mechanical properties: stress σ=F/A, strain $\varepsilon=(l-l_0)/l_0=\Delta l/l_0$, stress-strain curve $\sigma = f(\varepsilon) = E\varepsilon$

shear stress τ=F/A, shear strain $\Delta b/h=\tan\gamma$, $\tau = G \tan\gamma$, compressibility $\Delta V/V_0 = -\kappa p = -p/K$

$K = E/(3(1-2\nu))$ $G = E/(2(1+\nu))$ $E/G = 9/(3+(G/K))$

Elastic energy W_{def} = E = $\int_0^S F(s)ds = \int_0^S Dsds = \frac{1}{2}DS^2$ or $E = \frac{1}{2}\frac{\sigma 2}{E} = \frac{1}{2}E\varepsilon^2$

Thermal properties: Heat capacity $C = \Delta Q/\Delta T$, specific heat capacity $c = \Delta Q/(m\Delta T)$

Thermal expansion $l_1 - l_0 = \alpha(T_1 - T_0)$, $\Delta V = \gamma\Delta T$

Heat conductivity and heat transition: $\frac{\Delta Q}{\Delta t} = \dot{Q} = -\lambda\frac{A}{d}|grad(T)| = \lambda\frac{A}{d}\Delta T = \lambda\frac{A}{d}(T1 - T2)$

H. transfer: $\frac{\Delta Q}{\Delta t} = \dot{Q} = \alpha A\Delta T = \alpha A(T1 - T2)$, h. transition: $\frac{\Delta Q}{\Delta t} = \dot{Q} = kA\Delta T = kA(T1 - T2)$

Stefan-Boltzmann law: $= \sigma A T^4$, Wien's displacement law: $\lambda_{max} = \frac{2897{,}8\ \mu\text{m K}}{T}$

Optical properties: Snell's law: $n_1\sin(\alpha) = n_2\sin(\beta)$,

Some of Fresnel's laws: reflection coeff. $r_p = \frac{\tan(\alpha-\beta)}{\tan(\alpha+\beta)}$ $r_s = \frac{\sin(\alpha-\beta)}{\sin(\alpha+\beta)}$,

transmission coeff. $t_s=r_s+1$, $n_2t_p=n_1(r_p+1)$, reflectivity $\rho=r^2$, transmissivity $\tau=(n_2\cos\beta)/(n_1\cos\alpha)t^2$,

Brewster angle: $\tan\alpha_B = n_2/n_1$. critical angle: $\sin\alpha_G = n_2/n_1$, spectr. reflectivity $R(\lambda) = \frac{I_{ref}(\lambda)}{I_0(\lambda)}$

Lambert-Beer law: $I_t(x,\lambda) = I_0(\lambda)\exp[-\alpha(\lambda)x]$ $I_t(x,\lambda) = I_0(\lambda)10^{-OD}$ $-\lg(I/I_0) = ODBel$

Abbe number: ν=(n(green)-1)/(n(blue)-n(red))

Electrical properties: resistance $R = \rho L/A$, electr. conductivity $\sigma = 1/\rho$, $\rho(T) = \rho(T_0)[1 + \beta(T - T_0)]$

Current density $j = I/A = Q/\tau A = neAL/A\tau = nev$, electron mobility $v = \mu_e E$,

Lorentz force: $\vec{F} = q(\vec{v} \times \vec{B})$, capacity of a parallel plate capacitor $C_0 = \varepsilon_0\frac{A}{d}$,

$C = \varepsilon_r\varepsilon_0\frac{A}{d}$ flux density $D=\varepsilon_r\varepsilon_0 E$ Susceptibility $\chi_e = \varepsilon_r-1$, $P=\varepsilon_0 c_e E$,

Magnetic properties: MF of a straight wire: $\vec{H}(r) = \mu_0\frac{I}{r}\vec{e_\varphi}$, coil: $H = \frac{NI}{L}$

magnetic flux density: $\vec{B_0} = \mu_0\vec{H}$, $\vec{B} = \mu_0\mu_r\vec{H}$, $\vec{B} = \mu_0\vec{H} + \mu_0\vec{M} = \mu_0(\vec{H} + \vec{M}) = \mu_0(\vec{H} + \chi_m\vec{H}) = \mu_0\vec{H}(1 + \chi_m)$ Faraday effect: $\beta = VdB$

Metallic materials: Force on charged particle in field E: $\vec{F}_{el} = q\vec{E} = m\dot{\vec{v}}$ drift velocity: $v_D = \frac{e\tau}{m}E$

Conductivity $\sigma = \frac{j}{E} = \frac{ne^2\tau}{m}$ thermo voltage $U_{th} = (S_B - S_A)\,DT$

Magnetic materials: magnetic moment: $\vec{m} = I\vec{A}$, $\vec{m} = m_l\mu_B$, $\vec{\mu} = g_e\mu_B\frac{\vec{s}}{\hbar}$

Etching: Anisotropy: $A = 1 - \frac{v_{lateral}}{v_{vertical}}$ $A = 1 - \frac{v_{111}}{v_{100}}$ Selectivity: $S = \frac{v_{A-Material}}{v_{A-Mask}}$ $S = \frac{v_{111}}{v_{100}}$