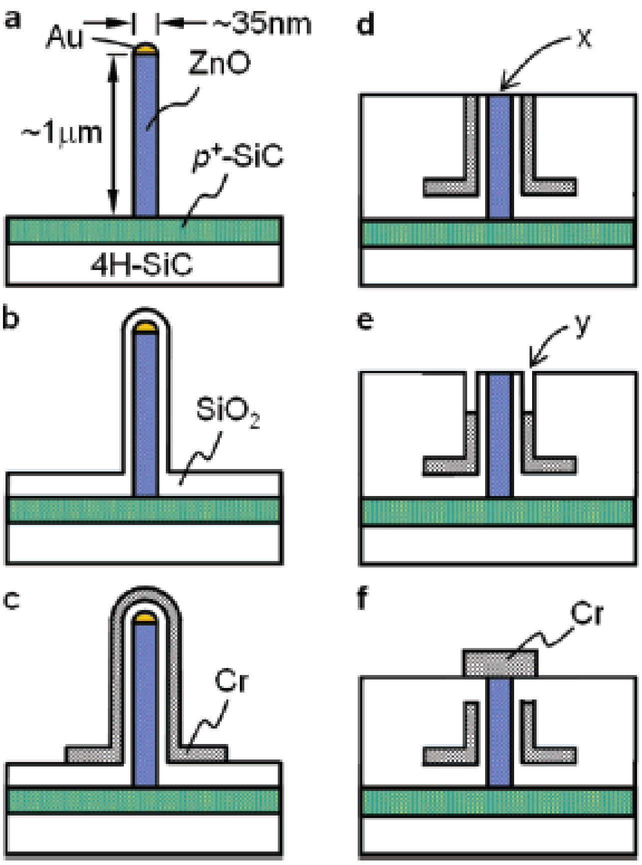
Department of Materials Science and Engineering
Norwegian University of Science and Technology

TMT4320 Nanomaterials, fall 2015

EXERCISE 12 - SOLUTION

PROBLEM 1

The successive processing is shown in the figure below:



1. Deposit a gold nanoparticle on the p^+-SiC layer by electron beam lithography, gold deposition and resist lift-off. Can also deposit a gold layer by sputter coating. The gold coated sample can then be heated up to induce de-wetting and formation of nanoparticles on the surface.
2. Grow a ZnO nanowire by the vapor-liquid-solid (VLS) method using pulsed laser deposition (PLD). The minimum lattice mismatch (~5.5%) between ZnO (0001) and hexagonal SiC (0001) is predicted to promote vertically aligned growth of ZnO nanowires and enables good electrical contact.
3. Surround-gate oxide formation. Chemical vapor deposition (CVD) of thin film (~20 nm) of SiO_2 using tetraethylorthosilicate as the precursor at an elevated temperature of 700 °C.

4. Surround-gate electrode formation. Ion-beam deposition of ~40 nm chromium metal surrounding the gate oxide.
5. A second SiO_2-deposition by CVD to encapsulate the nanowire.
6. Chemical mechanical polishing to planarize and fully expose the top of the nanowire (denoted x in the figure) and the Cr surround-gate electrode. This planarization step served both to remove the Au-alloyed head and define the vertical channel length of the *p*-VSG-FET.
7. A recess (denoted y in the figure) ~30 nm was introduced in the Cr surround-gate by selective wet chemical etching of Cr.
8. This is followed by a third SiO_2 CVD deposition to fill in the recess.
9. A second chemical mechanical polishing step to expose only the tip of ZnO nanowire.
10. The top Cr electrode (100 nm thickness) is deposited by ion-beam deposition. The deposit area can be masked by lithography. The top Cr electrode constitutes the drain electrode of the *p*-VSG-FET.

These particular steps avoid direct electrical contact between the Cr gate and top drain electrodes. Sufficient recess was performed to minimize large overlap capacitance between the gate and the drain electrodes, which can be crucial in high-frequency applications and fill voids with SiO_2.

[The figures and the processing route were adapted from Ng *et al.*, "Single Crystal Nanowire Vertical Surround-Gate Field-Effect Transistor", *Nano Lett.*, 2004, 4 (7), 1247-1252.]

PROBLEM 2

a) $$f = \frac{A_{\text{etched}}}{A_{\text{total}}} = \frac{5 \cdot 0.1\ \mu\text{m} \cdot 1\ \mu\text{m}}{1\ \mu\text{m} \cdot 1\ \mu\text{m}} = 0.5$$

$h_i = h_c + f \cdot h_m$ = 40 nm + 0.5·150 nm = <u>115 nm</u>

b) $$f = \frac{A_{\text{etched}}}{A_{\text{total}}} = \frac{1\mu m \cdot 1\mu m - 16 \cdot \pi \cdot \left(\frac{0.100\ \mu\text{m}}{2}\right)^2}{1\ \mu\text{m} \cdot 1\ \mu\text{m}} = 0.8743$$

$h_i = h_c + f \cdot h_m$ = 40 nm + 0.8743·150 nm = <u>171 nm</u>

PROBLEM 3

Below there are listed a number of abbreviations which are relevant to nanomaterials and nanotechnology and which we have used in this course. For each abbreviation, write out the full name.

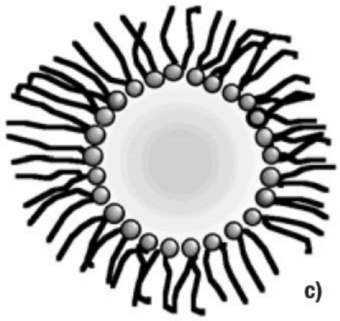
CVD Chemical vapor deposition
RIE Reactive ion etching
FIB Focused ion beam
VLS Vapor-liquid-solid
AFM Atomic force microscopy

EBL Electron beam lithography
SEM Scanning electron microscopy
fcc face-centered cubic
SAM Self-assembled monolayer
PLD Pulsed laser deposition
MBE Molecular beam epitaxy
TEM Transmission electron microscopy
hcp hexagonal close-packed
CTAB Cetyltrimethylammonium bromide
STM Scanning tunneling microscopy

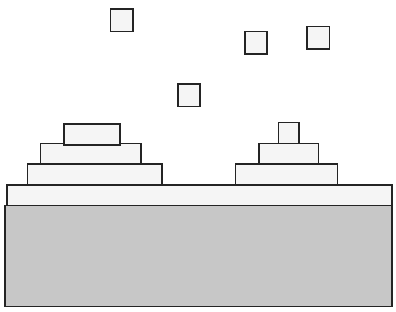
PROBLEM 4

Explain briefly the following concepts which we have covered in this course:

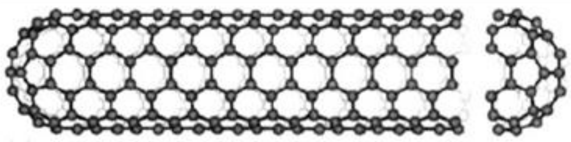
a) *Reverse micelle*: A nanoscale structure formed by surfactants (long-chain organic molecules with a polar end and a non-polar end). The surfactants have their polar ends oriented towards each other with the polar solvent phase (water) inside the reverse micelle and the non-polar solvent outside the reverse micelle.



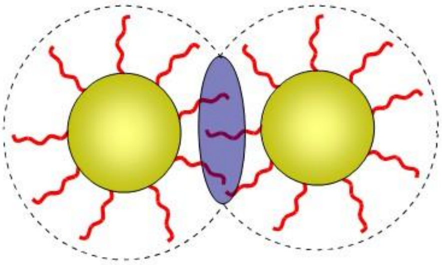
b) *Stranski-Krastanov growth mode*: Intermediate growth mode between pure layer-by-layer growth (Frank-van der Merwe) and pure island growth (Volmer-Weber). Initially, the growth is layer-by-layer on the substrate, but because of change in the overall interaction energy or lattice mismatch, further layers grow by island growth.



c) *Armchair carbon nanotube*: Carbon nanotube with a (n,n) chiral vector. The carbon atoms form an "armchair" configuration when the nanotube is cut in the radial direction.



d) *Steric repulsion*: Repulsion between nanoparticles covered with adsorbed surfactants because of entanglement of carbon chains in the region between the nanoparticles.



e) *Hydrothermal synthesis*: Synthesis in water at a temperature above room temperature and at a pressure above atmospheric pressure. In a typical hydrothermal synthesis the precursor(s) and possibly surfactant(s) are dissolved/dispersed in water, and the solution/dispersion is poured into a Teflon cup which is inserted into a steel container autoclave and sealed carefully. The autoclave is inserted into a furnace and the influence of temperature on the water raises the pressure autogeneously (self-generated pressure).

f) *Coordination number*: The number of nearest neighbors for an atom arranged in a crystal structure. The coordination number, with value 12 for an atom in the bulk of a single-element close-packed structure, can take a range of values at the surface: 9 for close-packed (111) faces, 8 for (100) faces, 7 for atoms on edges and 6 for atoms at corners in fcc metals.