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MICRO-435 HW6

Qualitative Questions

Question 1 Which are the 3 most important characteristics that a nanogap for Molecular Transistors should have?

1- They can be arranged small enough to place the molecule.

2- They should not lead a thermal runaway suh as bowtie type.

Question 2 Identify 3 fundamental conditions that must be verified in order to generate nanogap based on electromigration without thermal runaway

1- Many electrons are present

2- High current density

3- Atoms are free to move

Question 3 Identify 3 critical points when using F.I.B. for nanogap creation

1- Energy of the coming ions should be sufficient to overcome the binding energy of the substrate's atom.

2- Requires a precise tuning of beam parameters.

3-Due to atom bounce backs, effective gap is exploited

Question 4 Identify 3 advantages in the case of CDBJ technology for the generation of nanogaps

1- CDBJs avoid the need for anexternal equipment to drive the breaking process; EBJs and MCBJs rely on sophisticated external apparatuses to achieve sufficient process control to obtain sub-5 nm gaps (feedbackcontrolled current source and motorized bending stage, respectively). In place of this, crackdefined break junctions rely on internal stress created in the brittle layer, which, without using any electronic devices, is a completely integrated method to cause the breaking of metal constrictions instantly and in a highly parallel manner [1]

2- Due to the self-generated nature of the cracking-pulling-breaking processes, CDBJs may be mass produced and integrated; all that is required are the hanging and notched bridge structures. Consequently, the lithography criteria are substantially eased. [1]

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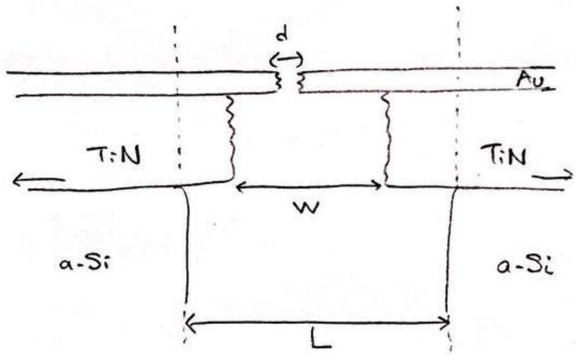
[1] Valentin Dubois Doctoral Thesis, KTH,2018 Bridging the gap between nano electronics and giga manifacturing https://www.diva-portal.org/smash/get/diva2:1209050/FULLTEXT01.pdf

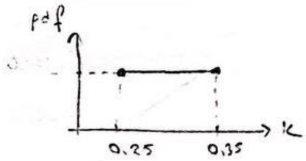
Quantitative Questions

Question 5



d: 0.8nm

$\boxed{d = kw}$



Mean k = 0.3 ←

$d = kw = k\underbrace{L\varepsilon}_{w}$ elastic strain of TiN , $0.25 \leq k \leq 0.35$

$0.8 = 0.25 \times L_{max} \times (2.7)\,\frac{nm}{\mu m}$

$$L_{max}\,(\mu m) = \frac{0.8\,nm}{0.25 \times 2.7\,\frac{nm}{\mu m}} \simeq 1.185\ \mu m$$

$$L_{min} = \frac{0.8\,nm}{0.35 \times 2.7\,\frac{nm}{\mu m}} \simeq 0.85\ \mu m$$

$0.85\,\mu m \leq L \leq 1.185\,\mu m$

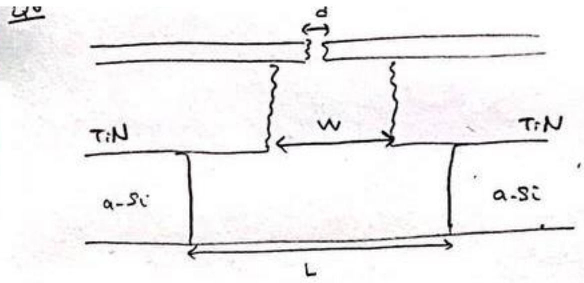
for $L < 1\mu m$, no gaps can be created.

Thus. let choose $k = 0.25$ (min) , $L = 1.185\ \mu m$, $\varepsilon = 2.7\ nm/\mu m$

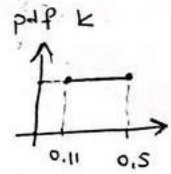
$\Downarrow$

$w = 3.2nm$

4.



$d = 1.8\,nm$



$d = k\sqrt{W}$

ϵ can change around 15% wrt avg. value $2.7\,nm\,\mu m^{-1}$

Bridge width is around 60nm. (?)

$2.7 \times \frac{85}{100} \leq \epsilon \leq (2.7) \times \frac{115}{100}$

$2.295 \leq \epsilon \leq 3.105$

$1.8\,nm = (0.11)_{k_{min}} \sqrt{L \cdot \epsilon_{min}}$

$L\epsilon_{min} = \left(\frac{1.8\,nm}{(0.11)}\right)^2$

$L_{max} = \left(\frac{1.8}{0.11}\right)^2 \cdot \frac{1}{2.295} = 116\,\mu m \rightarrow$ too big!

$L_{min} = \left(\frac{1.8\,nm}{0.5}\right)^2 \cdot \frac{1}{3.105} = 4.173\,\mu m \rightarrow$ It is a very good approximation, since $1 < L < 6\,\mu m$

Thus choose $k = 0.5$, $\epsilon = 3.105$; which yields $L_{min} = 4.173 \rightarrow W = 12.96\,nm$

? In that case, I ignored that W is around 60nm

$W \sim 60\,nm$

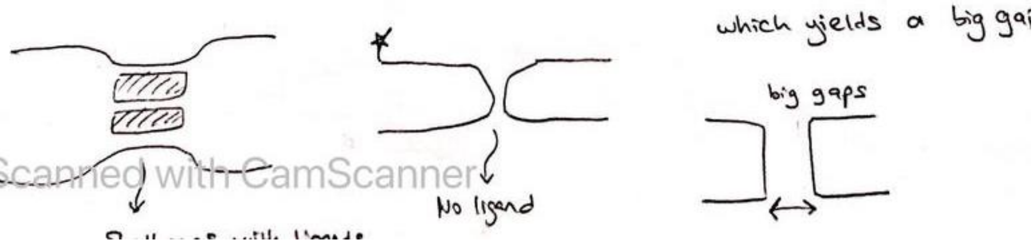
$d = k\sqrt{w} = k\sqrt{L\epsilon}$

$k \simeq \frac{1.8}{\sqrt{60}} \simeq 0.232$

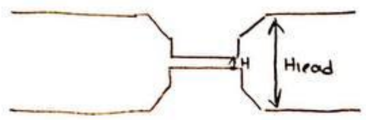
$L\epsilon \simeq 60$

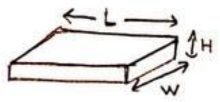
$\epsilon_{max} = 3.105$

$L_{min} = 19.32\,\mu m \rightarrow$ which is not good since $L > 6\,\mu m$ which yields a big gap



Question 7





$H = 15nm$

$L = 250\,nm$

$W = 100\,nm$

$H_{lead} = 150nm$

$R_{TOT} = 36\Omega$ @ $T = 77K$ just before E.M starts.

$T_{crit} = 345K$

Acc to Joule Heating $\rightarrow T = T_0 + \beta j^2$

$j_{crit} = 4\times10^8\ A/cm$

a) Find P_{crit} and V_{crit}

$$P_{crit} = \rho \cdot j_{crit}^2 = 36\Omega \times (4\times10^8 A/cm)^2$$

- $P_{crit} = 576 \times 10^{16}\ \frac{A^2\Omega}{cm^2}$

- $V_{crit} = \rho \cdot j_{crit} = 36 \times 4\times10^8\ A/cm$
$= 144 \times 10^8\ \frac{A\,\Omega}{cm}$

b) Constraints for the terrace size in order to avoid thermal runaway.

As migration happens the wire gets narrower, which leads $\underset{\sim}{R}\uparrow \rightarrow P\uparrow \rightarrow T\uparrow$

$R_u \leftarrow T_u \leftarrow P_m \leftarrow R_M$

Themal Runaway?

$$\rho(t) = \rho_{critic}\left(\frac{1 + \frac{R_S}{R_C(0)}}{1 + \frac{R_S}{R_C(t)}}\right)^2$$

$$\rho_{critic} = \frac{V_{CRIT}^2}{\rho\, \ell^2} \Big/ \left(1 + \frac{R_S}{R_C(0)}\right)^2$$

If $\boxed{\frac{R_S}{R_C(0)} \ll 1}$ $\rightarrow \rho(t) \approx \rho_{critic}$

If $\frac{R_S}{R_C(0)} \gg 1$ $\rightarrow \rho(t)$ increases rapidly. which yields ion accumulation and thermal runaway later on.

c) $$J_m = \frac{\alpha}{T}(j - j_{min})\, e^{-\frac{E_0}{kT}} \quad \text{where} \quad \alpha = \frac{c D_0 Z^* e \rho}{K}, \quad j_{min} = \frac{\Omega \Delta \sigma_{max}}{Z^* e \rho L}$$

$$J_{M\,crit} = \frac{\alpha}{T}(j_{crit} - j_{min})\, e^{-\frac{E_0}{kT}}$$

$J_{M\,crit} \rightarrow 1$, $j_{crit} \rightarrow 4\times10^8$

$$\boxed{-\frac{T}{\alpha} e^{E_0/kT} + 4\times10^8 = j_{min}}$$

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