Examen Halfgeleiderdevices (121706)
Datum: **Woensdag, 31-01-2007**
Tijd: **13.30-17.00 voor volledig tentamen*)**
Plaats: **SP1**

Dit tentamen omvat 4 onderdelen:

Halfgeleider Fysica	Vraagstuk 1
PN-overgang	Vraagstuk 2
Bipolaire Transistor	Vraagstuk 3
MOS Transistor	Vraagstuk 4

Studenten die in het curriculum 2006/07 een voldoende hebben gehaald voor de WASP test mogen vraagstuk 2 overslaan.

U wordt verzocht op uw tentamenformulier en tentamenbriefje aan te geven voor welk vak u tentamen doet.

Beschikbare tijd voor het tentamen:

Indien 3 vraagstukken worden gedaan:	3 uur tot 16.30 uur*)
Indien 4 vraagstukken worden gedaan:	3.5 uur tot 17.00 uur

Bijgeleverd: Formule en constantenblad.

Succes met het tentamen !!!

Constants and equations Semiconductor Device Physics (Sept 2005)

Elementary charge:	$q=1.6\cdot10^{-19}\ C$
Thermal voltage equivalent (@ room temperature):	$u_T=kT/q=0.025\ V$
Dielectric constant (permittivity) Silicon:	$\varepsilon_{Si}=10^{-12}\ F/cm$
Dielectric constant (permittivity) Silicon dioxide:	$\varepsilon_{ox}=3.5\cdot10^{-13}\ F/cm$
Intrinsic carrier concentration (if not given):	$n_i=\sqrt{2}\cdot10^{10}\ cm^{-3}$
Electron diffusion constant (if not given):	$D_n=30\ cm^2/s$
Hole diffusion constant (if not given):	$D_p=10\ cm^2/s$
Electron mobility (if not given):	$\mu_n=1200\ cm^2/Vs$
Hole mobility (if not given):	$\mu_p=350\ cm^2/Vs$

1. **Semiconductor Physics** (spatially in one dimension)

Fermi-Dirac distribution

$$f(E)=\frac{1}{1+\exp\left(\frac{E-E_F}{kT}\right)}$$

Density of states (if not given)

$$g(E)\sim10^{47}\sqrt{E}$$

Carrier concentrations

$$n=N_C\exp\left(\frac{E_F-E_C}{kT}\right)=n_i\exp\left(\frac{E_F-E_{FI}}{kT}\right)$$

$$p=N_V\exp\left(\frac{E_V-E_F}{kT}\right)=n_i\exp\left(\frac{E_{FI}-E_F}{kT}\right)$$

Electrostatic potential

$$\psi=-\frac{E_{FI}}{q}$$

Fermi potential

$$\varphi_F=-\frac{E_F}{q}$$

General formalism

$$n=n_i\exp\left(\frac{\psi-\varphi_F}{u_T}\right)$$

$$p=n_i\exp\left(\frac{\varphi_F-\psi}{u_T}\right)$$

Current equations

$$j_n=qn\mu_n\mathcal{E}+qD_n\frac{dn}{dx}=n\mu_n\frac{dE_{FN}}{dx}$$

$$j_p=qp\mu_p\mathcal{E}-qD_p\frac{dp}{dx}=p\mu_p\frac{dE_{FP}}{dx}$$

Einstein relation

$$D=u_T\cdot\mu=\frac{kT}{q}\cdot\mu$$

Excess recombination rate (electrons)

$$R=\tilde{n}N_tc_n=\tilde{n}N_tv_{th}\sigma_n=\frac{\tilde{n}}{\tau_n}$$

Continuity equation (electrons)

$$\frac{d\tilde{n}}{dt} = \frac{1}{q}\frac{dj_n}{dx} - (R - G) = D_n \frac{d^2\tilde{n}}{dx^2} - \frac{\tilde{n}}{\tau_n}$$

Excess carrier diffusion (electrons)

$$\tilde{n}(x) = \tilde{n}_0 \exp\left(-\frac{x}{L_n}\right)$$

$$L_n = \sqrt{D_n \tau_n}$$

Poisson's equation

$$-\frac{d^2\psi(x)}{dx^2} = \frac{d\mathcal{E}(x)}{dx} = \frac{\rho(x)}{\varepsilon_s}$$

2. pn junction

Built-in potential

$$\phi_{bi} = u_T \ln\left(\frac{N_D N_A}{n_i^2}\right)$$

Depletion layer width

$$W = \sqrt{\left(\frac{2\varepsilon_s (N_A + N_D)}{q N_A N_D}(\phi_{bi} - V_A)\right)}$$

Junction current (Shockley eq.)
long diode

$$I = A(j_n + j_p) = -Aqn_i^2\left(\frac{D_n}{N_A L_n} + \frac{D_p}{N_D L_p}\right)\left(\exp\left(\frac{V_A}{u_T}\right) - 1\right)$$

Gummel number

$$G = \int_0^L \frac{N(x)}{D(x)}dx$$

Diffusion capacitance

$$C_{diff} = \frac{1}{u_T}(\tau_n j_n + \tau_p j_p) \approx \frac{\tau}{u_T} j$$

3. Bipolar transistor

Current density (NPN)

$$j = -\frac{qn_i^2}{G}\left(\exp\left(\frac{V_{BE}}{u_T}\right) - 1\right)$$

Definitions

$$I_E = -(I_B + I_C)$$

$$\beta_F = \frac{I_C}{I_B}$$

Small signal model

$$i_B = g_\pi v_{BE} + g_\mu v_{BC}$$

$$i_C = g_m v_{BE} + g_0 v_{BC}$$