hw04

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1 Razavi problem 2.11

There are several "opinions" on the value of n_i at 300K from our textbooks. This is not actually a big deal as long as you say which you are using. When n_i varies by many orders of magnitude with temperature, being off by around a factor of 2 is not significant in context. Calculating the actual n_i involves making some assumptions about the quantum mechanical setup of the calculation, some of which are not entirely accurate.

$$|V_0| = \frac{k_B T}{q} \ln\left(\frac{p_p}{p_n}\right)$$

$p_p = n_i$ $\rightarrow$ *not* zero. The concentration of holes on the "p-side" is, by definition, the intrinsic value because the side is not doped.

$p_n = \frac{n_i^2}{N_D}$. Substituting these yields: $|V_0| = \frac{k_B T}{q} \ln\left(\frac{N_D}{n_i}\right)$

In [2]:
```
k = 1.381e-23  # J/K
q = 1.602e-19  # C
T = 300.0
ND = 3e16
ni_300_options = (1e10,     # Jaeger approximation
                  6.73e9,   # from hw01
                  )

for ni in ni_300_options:
    v0 = (k * T / q) * log(ND / ni)
    print '\nFor ni= %.2e:' % (ni)
    print '  V0 = %.2e V  or %.3f V' % (v0, v0)
```

```
For ni= 1.00e+10:
  V0 = 3.86e-01 V  or 0.386 V

For ni= 6.73e+09:
  V0 = 3.96e-01 V  or 0.396 V
```

2 Razavi problem 2.12

2.1 part (a)

In [5]:
```
ND = 5e17; NA = 4e16

pp = NA; nn = ND
for ni in ni_300_options:
    np = ni**2 / NA
    pn = ni**2 / ND
    print
    print 'For ni = %.2e: (cm^-3)' % ni
    print 'nn = %.2e    pp = %.2e' % (nn, pp)
    print 'pn = %.2e    np = %.2e' % (pn, np)
```

```
For ni = 1.00e+10: (cm^-3)
nn = 5.00e+17    pp = 4.00e+16
pn = 2.00e+02    np = 2.50e+03

For ni = 6.73e+09: (cm^-3)
nn = 5.00e+17    pp = 4.00e+16
pn = 9.06e+01    np = 1.13e+03
```

2.2 part (b)

In [6]:
```
# this time, we need ni as a function of temp,
# use the Jaeger version and assume silicon
def ni(T):
    k = 8.62e-5 # eV/K
    Eg = 1.12   # eV
    B = 1.08e31
    return sqrt(B * T**3 * exp(-Eg / (k * T)))

def v_builtin(T):
    return (k * T / q) * log(NA * ND / ni(T)**2)

for T in (250, 300, 350):
    v0 = v_builtin(T)
    print 'T= %3.f K:  V0= %.3f V' % (T, v0)
```

```
T= 250 K:  V0= 0.925 V
T= 300 K:  V0= 0.872 V
T= 350 K:  V0= 0.817 V
```

The trend: V_0 increases as temperature increases.

3 Consider:

The built-in potential V_0 is found using hole concentrations in equation (2.68). It is also expressed using doping concentrations in equation (2.69). Do the "Exercise" on the middle of Razavi page 40 and also find V_0 using electron concentrations.

End with: $V_0 = (k_B T/q) \ln (n_n/n_p)$. Swapping the ln fraction changes the sign of the answer. Go easy on the sign stuff, we are not interested in the sign of V_0 as it only tells us which order the n and p sides are in our coordinate system.