The General Properties of Si, Ge, SiGe, SiO_2 and Si_3N_4

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A. Introduction

This paper summarizes basic physical properties of Si, Ge, SiGe, SiO_2 and Si_3N_4. It also lists several physical constants and conversion factors. The information is presented in table format with explanations of any approximations or equations used.

B. The Basic Properties of Si, Ge, and SiGe

The following table summarizes many of the basic physical properties of Silicon, Germanium, and Silicon Germanium at different concentrations. The concentrations are given in the form of $Si_{1-x}Ge_x$ where x represents the percent composition of Germanium.

Properties	Ge	$Si_{.25}Ge_{.75}$	$Si_{.5}Ge_{.5}$	$Si_{.75}Ge_{.25}$	Si
Atoms/cm^3	4.42×10^{22} Ge	*4.415×10^{22}	*4.61×10^{22}	*4.805×10^{22}	5.0×10^{22} Si
Atomic weight	72.60 Ge	*61.4725	*50.345	*39.2175	28.09 Si
Breakdown field (V/cm)	~10^5 Ge	*1.5×10^5	*2×10^5	*2.5×10^5	~3×10^5 Si
Crystal Structure	Diamond	Diamond	Diamond	Diamond	Diamond
Density (g/cm^3)	5.3267 Ge	*4.577	*3.827	*3.078	2.328 Si
Dielectric constant	16.0 Ge	*14.975	*13.95	*12.925	11.9 Si
Effective density of States in conduction band, N_c (cm^{-3})	1.04×10^{19} Ge				2.8×10^{19} Si
Effective density of States in valence band, N_v (cm^{-3})	6.0×10^{18} Ge				1.04×10^{19} Si
Effective Mass, m^*/m_0 Electrons Holes	$m^*_l = 1.64$ $m^*_t = 0.082$ $m^*_{l\,h} = 0.044$ $m^*_{h\,h} = 0.28$ Ge				$m^*_l = 0.98$ $m^*_t = 0.19$ $m^*_{l\,h} = 0.16$ $m^*_{h\,h} = 0.49$ Si
Electron affinity	4.0	*4.0125	*4.025	*4.0375	4.05

X(V)	Ge				Si
Minimum Indirect Energy Gap (eV) at 300K	0.66 Ge	***0.804	***0.945	***1.05	1.12 Si
Minimum Direct Energy Gap (eV)	.7 Ge	1.6	2.5	3.1	3.4 Si
Intrinsic carrier concentration (cm^{-3})	2.4×10^{13} Ge	$*1.8 \times 10^{13}$	$*1.2 \times 10^{13}$	$*0.6 \times 10^{13}$	1.45×10^{10} Si
Intrinsic Debye length (μm)	0.68 Ge	*6.51	*12.34	*18.17	24 Si
Intrinsic resistivity (Ω-cm)	47 Ge	$*.575 \times 10^{5}$	$*1.15 \times 10^{5}$	$*1.725 \times 10^{5}$	2.3×10^{5} Si
Lattice Constant (A)	***5.6575 Ge	***5.5960	***5.5373	***5.4825	***5.4310 Si
Linear coefficient of thermal expansion, $\Delta L/L\Delta T$ ($°C^{-1}$)	5.8×10^{-6} Ge	$*5.0 \times 10^{-6}$	$*4.2 \times 10^{-6}$	$*3.4 \times 10^{-6}$	2.6×10^{-6} Si
Melting point (°C)	937 Ge	*1056.5	*1176	*1295.5	1415 Si
Minority carrier lifetime (s)	10^{-3} Ge	$*1.375 \times 10^{-3}$	$*1.75 \times 10^{-3}$	$*2.125 \times 10^{-3}$	2.5×10^{-3} Si
Mobility (drift) (cm^2/V-s)	3900(electron) 1900(hole) Ge	*3300(electron) *1537.5(hole)	*7700(electron) *1175(hole)	*2100(electron) *812.5(hole)	1500(electron) 450(hole) Si
Optical – phonon energy (eV)	0.037 Ge				0.063 Si
Phonon mean free path λ_0(Å)	105 Ge				76 (electron) 55 (hole) Si
Specific heat (J/g-°C)	0.31 Ge	*.4075	*.505	*.6025	0.7 Si
Thermal conductivity at 300 K (W/cm-°C)	0.6 Ge	**.11	**.083	**.085	1.5 Si
Thermal diffusivity (cm^2/s)	0.36 Ge	*0.495	*.63	*.765	0.9 Si
Vapor pressure (Pa)	1 at 1330°C 10^{-6} at 760°C Ge	1 at *1410°C 10^{-6} at *795	1 at *1490°C 10^{-6} at *830°C	1 at *1570°C 10^{-6} at *865°C	1 at 1650°C 10^{-6} at 900°C Si

* value was derived through linear approximation ; ** value was derived through subjective observation of graph/diagram [1]; *** value was derived through quadratic approximation

TABLE 1 lists physical properties of Si, Ge, and SiGe [2][3]

The linear approximations were calculated using the following function where C_{Si} represents the Silicon value, C_{Ge} represents the Germanium value, and x represents the fractional composition of Germanium:

$$a(x)= C_{Si}\,(1-x) + C_{Ge}\,(x).$$

All values in the above table for SiGe are %atm values. The values for the thermal conductivity were taken from a graph[1][7]. The values for the minimum indirect energy gap were determined from both a graph[1][8] and also from the following quadratic expression where x represents the fractional composition of Germanium:

$$E_g(x)= (1.155 - 0.43x + 0.0206x^2)\text{eV} \qquad \text{for} \qquad 0 < x < 0.85 \quad [1][5]$$

and

$$E_g(x)= (2.010 - 1.27x)\text{eV} \qquad \text{for} \qquad 0.85 < x < 1 \quad [1][5]$$

The values for the minimum direct energy gap were determined from references [1],[6].

The lattice constants were determined using the following quadratic expression where x represents the percent of Germanium in the composition:

$$a(x) = 0.002733x^2 + 0.01992x + 0.5431 \text{ (nm)}[9].$$

C. The Basic Properties of SiO_2 and Si_3N_4

Insulator:	**SiO_2**	**Si_3N_4**
Structure	Amorphous	Amorphous
Melting Point (°C)	~1600	-
Density (g/cm^3)	2.2	3.1
Refractive index	1.46	2.05
Dielectric constant	3.9	7.5
Dielectric strength (V/cm)	10^7	10^7
Infrared absorption band (μm)	9.3	11.5 – 12.0
Energy gap	9	~5.0
Thermal Expansion coefficient ($°C^{-1}$)	5 x 10-^{7}	-
Thermal conductivity (W/cm-K)	0.014	-
dc resistivity (Ω-cm) at 25 °C at 500 °C	10^{14} -10^{16} -	 ~10^{14} ~2 x 10^{13}

Etch rate in Buffered HF[a] (Å/min)	1000	5-10

[a] Buffered HF: 34.6% (wt.) NH_4F, 6.8% (wt.) HF, 58.6% H_20

TABLE 2 lists physical properties of SiO_2 and Si_3N_4. [2]

D. Physical Constants

Symbol	Name	Value
q	magnitude of electronic charge	1.602×10^{-19} C
M_0	electron mass in free space	9.109×10^{-31} kg
E_o	permittivity of vacuum	8.854×10^{-14} F/cm
k	Boltzmann's constant	1.381×10^{-23} J/K 8.617×10^{-5} eV/K
h	Planck's constant	6.625×10^{-34} J-s 4.135×10^{-15} eV-s
KT	thermal energy	0.02586 eV (T = 27 °C) 0.02526 eV (T = 20 °C) 0.026 eV (room temperature)

TABLE 3 lists the symbols for several common physical constants and gives their value. [4]

E. Conversion Factors

1 Å $= 10^{-8}$ cm
$= 10^{-10}$ m

$1\ \mu$m $= 10^{-4}$ cm
$= 10^{-6}$ m

1 mil $= 10^{-3}$ in
$= 25.4\ \mu$m

1 mil^2 $= 645.2\ \mu$m^2
$= 6.45 \times 10^{-6}$ cm^2

1 eV $= 1.602 \times 10^{-19}$ J

TABLE 4 list several common conversion factors.[4]

F. Conclusion

In this paper the basic properties of Si, Ge, SiGe, SiO_2 and Si_3N_4 were reviewed along with useful physical constants and conversion factors. Some data was taken directly from reference while other values were derived using linear and quadratic expressions.

G. References

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