Si - Silicon

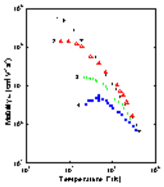
Electrical properties

Basic Properties
Mobility and Hall Effect
Transport Properties in High Electric Field
Impact Ionization
Recombination Parameters
Surface Recombination

Basic Properties

Breakdown field	≈$3\cdot10^5$V/cm
Mobility electrons	≤1400 $cm^2\ V^{-1}s^{-1}$
Mobility holes	≤450 $cm^2\ V^{-1}s^{-1}$
Diffusion coefficient electrons	≤36 cm^2/s
Diffusion coefficient holes	≤12 cm^2/s
Electron thermal velocity	$2.3\cdot10^5$m/s
Hole thermal velocity	$1.65\cdot10^5$m/s

Mobility and Hall Effect



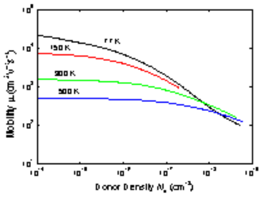
Electron mobility versus temperature for different doping levels.

1. High purity Si ($N_d < 10^{-12}\ cm^{-3}$); time-of-flight technique *(Canali et al. [1973])*

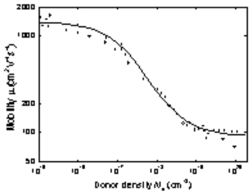
2. High purity Si ($N_d < 4\cdot10^{-13}\ cm^{-3}$): photo-Hall effect *(Norton et al. [1973])*

3. $N_d = 1.75\cdot10^{16}\ cm^{-3}$; $N_a = 1.48\cdot10^{15}\ cm^{-3}$; Hall effect *(Morin and Maita [1954])*.

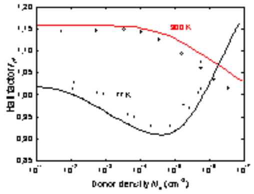
4. $N_d = 1.3\cdot10^{17}\ cm^{-3}$; $N_a = 2.2\cdot10^{15}\ cm^{-3}$; Hall effect *(Morin and Maita [1954])*.



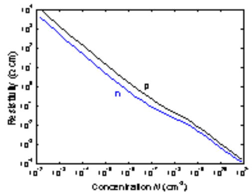
Electron drift mobility versus donor density at different temperatures *(Li and Thumber [1977])*.



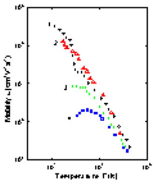
Electron drift mobility versus donor density, T=300 K. *(Jacoboni et al. [1977])*.



The electron Hall factor versus donor density. 77 and 300 K.
Solid lines show the results of calculations.
Symbols represent experimental data
(Kirnas et al. [1974]).



Resistivity versus impurity concentration for Si at 300 K.



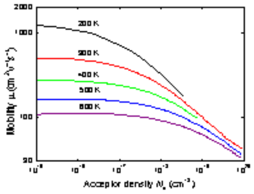
Temperature dependences of hole mobility for different doping levels.

1. High purity Si ($N_a = 10^{12}$ cm^{-3}); time-of-flight technique *(Ottaviany et al. [1975])*;

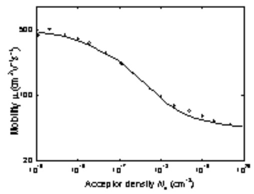
2. High purity Si ($N_a \sim 10^{14}$ cm^{-3}); Hall-effect *(Logan and Peters [1960])*

3. $N_a = 2.4 \cdot 10^{16}$ cm^{-3}; $N_d = 2.3 \cdot 10^{15}$ cm^{-3}; Hall-effect *(Morin and Maita [1954])*

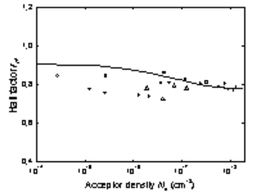
4. $N_a = 2 \cdot 10^{17}$ cm^{-3}; $N_d = 4.9 \cdot 10^{15}$ cm^{-3}; Hall-effect *(Morin and Maita [1954])*



Hole drift mobility versus acceptor density at different temperatures
(Dorkel and Leturcq [1981]).

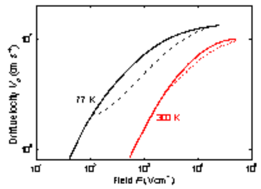


Hole drift mobility versus acceptor density. 300 K.
(Jacoboni et al. [1977]).

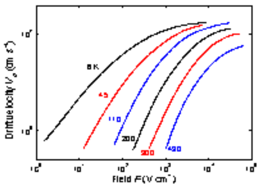


The hole Hall factor versus acceptor density. 300 K.
(Lin et al. [1981]).

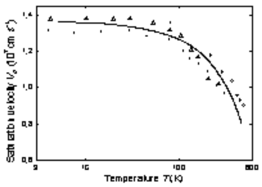
Transport Properties in High Electric Field



Si. Electron drift velocity vs. electric field.
Solid lines: F||(111).
Dashed lines: F||(100).
Jacoboni et al. (1977).



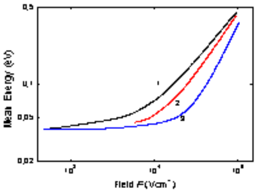
Si. Electron drift velocity vs. electric field at different temperatures.
F||(111).
Jacoboni et al. (1977).



Temperature dependence of the saturation electron drift velocity
(Jacoboni et al. [1977]).
Solid line is calculated according to equation:

$v_s = v_{so} \cdot [1 + C \cdot \exp(T/I)]^{-1}$,

where $v_{so} = 2.4 \cdot 10^7$ cm s^{-1}, C=0.8, I=600K.



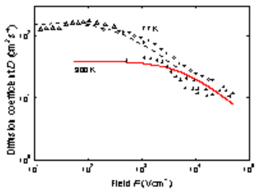
Mean energy of electrons as a function of electronic field F at different donor densities.
F||(111). 300 K.

1. $N_d = 0$;

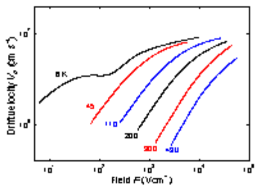
2. $N_d = 4 \cdot 10^{18}$ cm^{-3};

3. $N_d = 4 \cdot 10^{19}$ cm^{-3}.

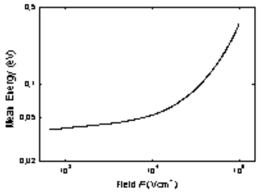
(Jacoboni et al. [1977]).



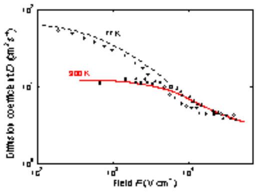
The field dependence of longitudinal electron diffusion coefficient D for 77K and 300 K.
F ∥ (111). Dotted and solid lines show the results of Monte-Carlo simulation.
Symbols represent measured data.
(Canali et al. [1985]).



Field dependences of the hole drift velocity at different temperatures.
F ∥ (100).
(Jacoboni et al. [1977]).

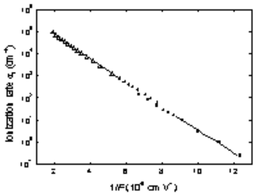


Mean energy of holes as a function of electronic field F.
N_a = 0, T=300 K.
(Jacoboni et al. [1977]).



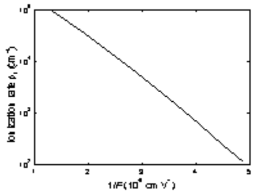
The field dependence of longitudinal hole diffusion coefficient D for 77K and 300 K.
F∥(111). Dotted and solid lines show the results of Monte-Carlo simulation.
Symbols represent measured data.
(Canali et al. [1985]).

Impact Ionization



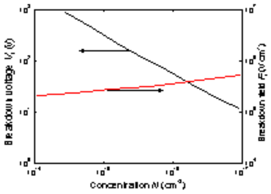
Electron ionization rate α_i vs. 1/F.

T = 300 K. *(Maes et al. [1990])*.

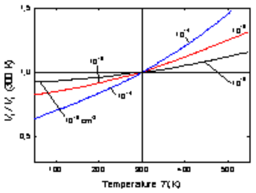


Hole ionization rate β_i vs. 1/F.

T = 300 K. *(Grant [1973])*.

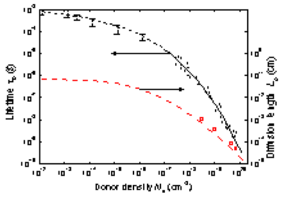


Breakdown voltage and breakdown field vs. doping density for an abrupt *p-n* junction.
T = 300 K. *(Sze [1981])*.



Normalized breakdown voltage vs. temperature for an abrupt *p-n* junction at different doping levels.
(Crowell and Sze [1981]).

Recombination Parameters



Lifetime τ_p and diffusion length L_p of holes in *n*-type Si vs. donor density. T = 300 K.

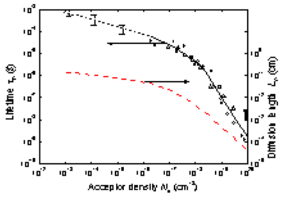
For 10^{12} cm^{-3} < $N_d \le 10^{17}$ cm^{-3}- from numerous experimental data for good quality industrial produced *n*-Si.

For $N_d \ge 10^{17}$ cm^{-3} - (Alamo and Swanson [1987]).

L_p (N_a) dependence (dashed line) is calculated as

$L_p(N_d)=[D_p(N)\cdot\tau_p(N)]^{1/2}$,

where $D_p=(k_B\cdot T/q)\cdot\mu_p$.



Lifetime τ_n and diffusion length L_n of electrons in *p*-type Si vs. acceptor density. T = 300 K.

For 10^{13} cm^{-3} < $N_a \le 10^{16}$ cm^{-3} - from numerous experimental data for good quality industrial produced *p*-Si.

For $N_a \ge 10^{16}$ cm^{-3} - (Tyagi and Van Overstraeten [1983]). $L_n(N_a)$ dependence (dashed line) is calculated as $L_n(N_a)=[D_n(N)\cdot\tau_n(N)]^{1/2}$, where $D_n=(k_b\cdot T/q)\cdot\mu_n$.

Surface recombination

Surface recombination rate depending on treatment of Si surface lies in the range between $10^2 \div (6\text{-}8)\cdot 10^4$cm/s.
Surface recombination rate on the Si-SiO_2 interface can be as small as ≤ 0.5 cm/s.

Si		*Remarks*	*Referens*
The longest lifetime of holes t_p			
Diffusion length $L_p = (D_p \times t_p)^{1/2}$			
Surface Recombinaton Velocity			
Radiative recombination coefficient B	1.1×10^{-14} cm^3/s		Gerlach et al. (1972)
Auger coefficient C_n	1.1×10^{-30} cm^6/s	300 K	
Auger coefficient C_p	0.3×10^{-30} cm^6/s	300 K	
Auger coefficient $C = C_n + C_p$	1.4×10^{-30} cm^6/s	300 K	

For 180 K ≤ T ≤ 400 K - $C \approx 1.4\cdot 10^{-30}\cdot (T/300)^{1/2}$ (cm^6/s).