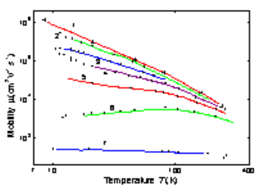
Ge - Germanium

Electrical properties

Basic Parameters

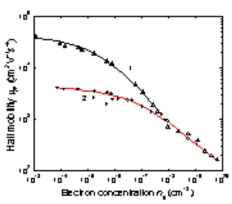
Breakdown field	$\approx 10^5$ V cm^{-1}
Mobility electrons	≤ 3900 cm^2 V^{-1}s^{-1}
Mobility holes	≤ 1900 cm^2 V^{-1}s^{-1}
Diffusion coefficient electrons	≤ 100 cm^2 s^{-1}
Diffusion coefficient holes	≤ 50 cm^2 s^{-1}
Electron thermal velocity	$3.1\cdot 10^5$ m s^{-1}
Hole thermal velocity	$1.9\cdot 10^5$ m s^{-1}

Mobility and Hall Effect



Electron mobility versus temperature for different doping levels.
1. High purity Ge; time-of-flight technique *(Jacoboni et al. [1981])*;
2-6. Hall effect $N_d - N_a$(cm^{-3}):
2. $1\cdot 10^{13}$; **3**. $1.4\cdot 10^{14}$; **4**. $1.7\cdot 10^{15}$; **5**. $7.5\cdot 10^{15}$; **6**. $5.5\cdot 10^{16}$ *(Debye and Conwell [1954])*;
7. Hall effect $N_d - N_a = 1.2\cdot 10^{19}$(cm^{-3}) *(Fistul et al. [1962])*.

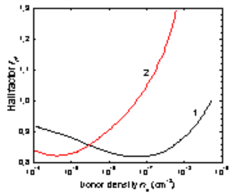
For weakly doped Ge in the range 77-300 K electron mobility
$\mu_n \approx 4.9\cdot 10^7\cdot T^{-1.66}$ (cm^2 V^{-1} s^{-1}).



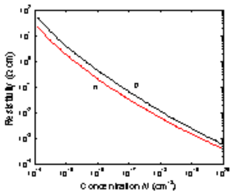
Electron Hall mobility versus electron concentration
1. T = 77 K;
2. T = 300 K.
(Fistul et al. [1962]).

Approximate formula for the Hall mobility. 300 K.

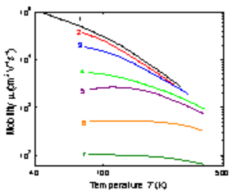
$\mu_n = \mu_{OH}/(1+N_d\cdot 10^{-17})^{1/2}$,
where $\mu_{OH} \approx 3900$ (cm^2 V^{-1} s^{-1}),
N_d- in cm^{-3}
(Hilsum [1974]).



The electron Hall factor versus donor density.
1. T = 300 K;
2. T = 77 K. *(Babich et al. [1969])*.

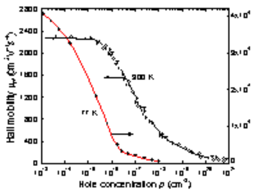


Resistivity versus impurity concentration., T = 300 K.
(Cuttris [1981]).

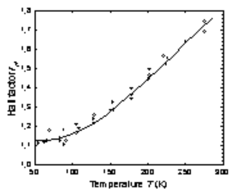


Temperature dependences of hole mobility for different doping levels.
1. High purity Ge; time-of-flight technique *(Ottaviany et al. [1973])*.
2-**7**. Hall-effect *(Golikova et al. [1961])*.
N_a- N_d (cm^{-3}): **2**. = $4.9\cdot10^{13}$; **3**. $3.2\cdot10^{15}$; **4**. $2.7\cdot10^{16}$; **5**. $1.2\cdot10^{17}$; **6**. $4.9\cdot10^{18}$; **7**. $2.0\cdot10^{20}$.

For weakly doped Ge in the range 100-300 K hole mobility
$\mu_p \approx 1.05\cdot10^9\cdot T^{-2.33}$ (cm^2 V^{-1} s^{-1})

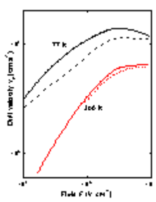


The hole Hall mobility versus hole concentration.
Experimental points: data from three References (*Golikova et al. [1961]*).

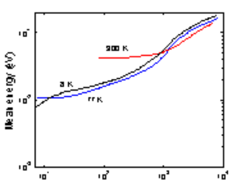


The hole Hall factor versus temperature for high purity *p*-Ge
(Morin [1954]).

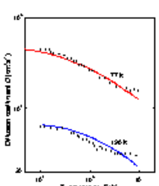
Transport Properties in High Electric Fields



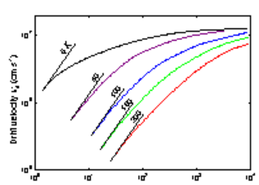
Field dependences of the electron drift velocity.
Solid lines: F||(100)
Solid lines: F||(111).
(Jacoboni et al. [1981]).



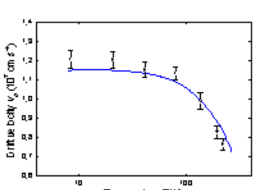
Mean energy of electrons in lower valleys as a function of electronic field for three lattice temperatures.
(Jacoboni et al. [1981]).
(Jacoboni et al. [1981]).



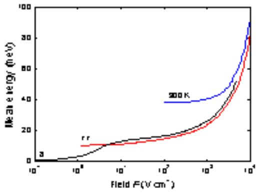
The field dependence of longitudinal electron diffusion coefficient D for 77 K and 190 K. F||(100).
Solid lines show the results calculation.
Symbols represent measured data.
(Jacoboni et al. [1981]).



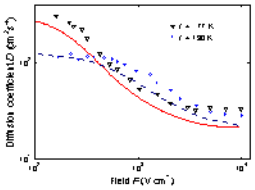
Field dependences of the electron drift velocity at different temperatures.
F||(100).
(Ottaviani et al. [1973]).



Drift velocity v_d as a function of temperature
for electric field F=10^4(V cm^{-1}). F||(100).
Solid line show the results of calculation in the case where non-parabolic effect are taken into account *(Reggiani et al. [1977])*.



Mean energy of hole as a function of electronic field F at different lattice temperatures.
Solid line are Monte-Carlo calculations for F‖(111) *(Reggiani et al. [1977])*.
Points show experimental results for 82 K. *(Vorob'ev et al. [1978])*.

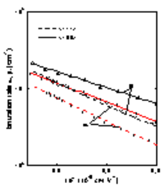


The field dependence of longitudinal hole diffusion coefficient D
for 77 K and 190 K. F‖(111).
Dashed and solid lines show the results of the calculations.
Symbols represent measured data.
(Reggiani et al. [1978]).

Impact Ionization

There are two schools of thought regarding the impact ionization in Ge.

The first one states that impact ionization rates α_i and β_i for electrons and holes in Ge are known accurately enough to distinguish such subtle details as the anisothropy of α_i and β_i for different crystallographic directions.



Ionization rates in (111) and (100) directions versus 1/F. T = 300 K.
(Mikava et al. [1977]).

From *(Mikava et al. [1980])*

For electrons: $\alpha_i = \alpha_o \exp(-F_{no}/F)$

(111) direction $\alpha_o = 2.72 \cdot 10^6$ cm^{-1} $F_{no} = 1.1 \cdot 10^6$ V cm^{-1}

(100) direction $\alpha_o = 8.04 \cdot 10^6$ cm^{-1} $F_{no} = 1.4 \cdot 10^6$ V cm^{-1}

For holes: $\beta_i = \beta_o \exp(-F_{po}/F)$

(111) direction $\beta_o = 1.72 \cdot 10^6$ cm^{-1} $F_{po} = 9.37 \cdot 10^5$ V cm^{-1}

(100) direction $\beta_o = 6.39 \cdot 10^6$ cm^{-1} $F_{po} = 1.27 \cdot 10^6$ V cm^{-1}

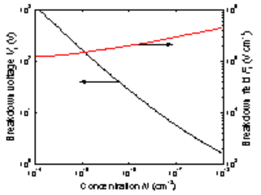
The second school contends that the values of α_i and β_i for the same electric field reported by different researches differ by an order of magnitude. This point of view is explained by *Kyuregyan and Yurkov [1989]*. In accordance with this approach we can assume for all crystallographic directions that

For electrons: $\alpha_i = \alpha_o \exp(-F_{no}/ F)$

where $\alpha_o = 2.84 \cdot 10^6$ cm^{-1} $F_{no} = 1.14 \cdot 10^6$ V cm^{-1}

For holes: $\beta_i = \beta_o \exp(-F_{po}/ F)$

where $\beta_o = 4.21 \cdot 10^6$ cm^{-1} $F_{po} = 1.11 \cdot 10^6$ V cm^{-1}



Breakdown voltage and breakdown field versus doping density for an abrupt *p-n* junction.
(Kyuregyan and Yurkov [1989]).

Recombination Parameters

Pure *n*-type material

300 K

The longest lifetime of holes	$\tau_p \geq 10^{-3}$ s
Diffusion length	$L_p \geq 0.2$ cm

77 K

The longest lifetime of holes	$\tau_p \geq 10^{-4}$ s
Diffusion length	$L_p \geq 0.15$ cm
Pure p-type material	
300 K	
The longest lifetime of electrons	$\tau_n \geq 10^{-3}$ s
Diffusion length	$L_n \geq 0.3$ cm
77 K	
The longest lifetime of electrons	$\tau_n \geq 10^{-4}$ s
Diffusion length	$L_n \geq 0.15$ cm
Surface recombination	$10 \div 10^{6}$ cm/s.
Radiative recombination coefficient at 300 K	$6.41 \cdot 10^{-14}$ cm^3 s^{-1}
Auger coefficient at 300 K	$\sim 10^{-30}$ cm^6 s^{-1}