# GaAs - Gallium Arsenide

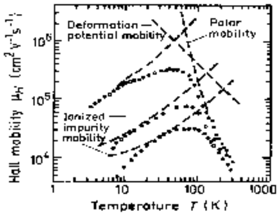
## Electrical properties

*Basic Parameters*
*Mobility and Hall Effect*
*Transport Properties in High Electric Fields*
*Impact Ionization*
*Recombination Parameters*

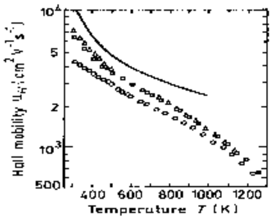
### Basic Parameters

| | |
|---|---|
| Breakdown field | $\approx 4\cdot 10^5$ V/cm |
| Mobility electrons | $\leq 8500$ cm$^2$ V$^{-1}$s$^{-1}$ |
| Mobility holes | $\leq 400$ cm$^2$ V$^{-1}$s$^{-1}$ |
| Diffusion coefficient electrons | $\leq 200$ cm$^2$/s |
| Diffusion coefficient holes | $\leq 10$ cm$^2$/s |
| Electron thermal velocity | $4.4\cdot 10^5$ m/s |
| Hole thermal velocity | $1.8\cdot 10^5$m/s |

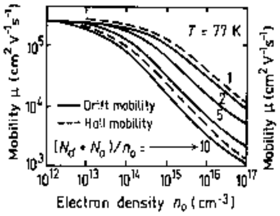
### Mobility and Hall Effect



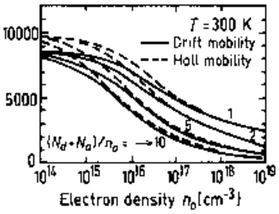
**Electron Hall mobility versus temperature for different doping levels.**
*(Stillman et al. [1970]*
**1**. Bottom curve: $N_d=5\cdot 10^{15}$cm$^{-3}$;
**2**. Middle curve : $N_d=10^{15}$cm$^{-3}$;
**3**. Top curve : $N_d=5\cdot 10^{15}$cm$^{-3}$
For weakly doped GaAs at temperature close to 300 K, electron Hall mobility
$\mu_H=9400(300/T)$ cm$^2$ V$^{-1}$ s$^{-1}$



**Electron Hall mobility versus temperature for different doping levels and degrees of compensation (high temperatures):**
Open circles: $N_d=4N_a=1.2\cdot 10^{17}$ cm$^{-3}$;
Open squares: $N_d=4N_a=10^{16}$ cm$^{-3}$;
Open triangles: $N_d=3N_a=2\cdot 10^{15}$ cm$^{-3}$;
Solid curve represents the calculation for pure GaAs *(Blakemore[1982])*.
For weakly doped GaAs at temperature close to 300 K, electron drift mobility
$\mu_n=8000(300/T)^{2/3}$ cm$^2$ V$^{-1}$ s$^{-1}$



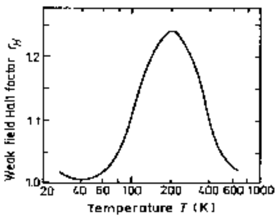
**Drift and Hall mobility versus electron concentration for different degrees of compensation** T= 77 K
*(Rode [1975])*.



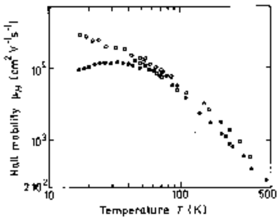
**Drift and Hall mobility versus electron concentration for different degrees of compensation** T= 300 K
*(Rode [1975])*.

**Approximate formula for the Hall mobility**

. $\mu_n=\mu_{OH}/(1+N_d\cdot 10^{-17})^{1/2}$, where $\mu_{OH}\approx 9400$ (cm$^2$ V$^{-1}$ s$^{-1}$), $N_d$- in cm$^{-3}$
*(Hilsum [1974])*.



**Temperature dependence of the Hall factor for pure *n*-type GaAs in a weak magnetic field**
*(Rode [1975])*.

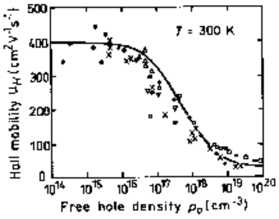


**Temperature dependence of the Hall mobility for three high-purity samples**
*(Wiley [1975])*

**For GaAs at temperatures close to 300 K, hole Hall mobility**

$$\mu_{pH} = \left[0.0025\left(\frac{T}{300}\right)^{2.3} + 4\times10^{21}p\left(\frac{T}{300}\right)^{1.5}\right]^{-1}$$ (cm$^2$V$^{-1}$s$^{-1}$), (p - in cm$^{-3}$)

For weakly doped GaAs at temperature close to 300 K, Hall mobility
$\mu_{pH}=400(300/T)^{2.3}$ (cm$^2$ V$^{-1}$ s$^{-1}$).

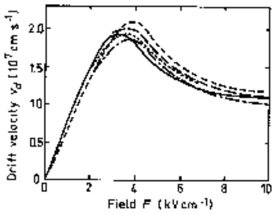


**The hole Hall mobility versus hole density.**
*(Wiley [1975])*

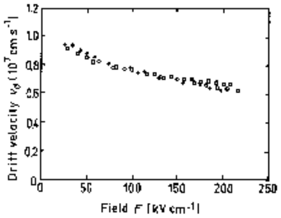
**At *T*= 300 K, the Hall factor in pure GaAs**

$r_H$=1.25.

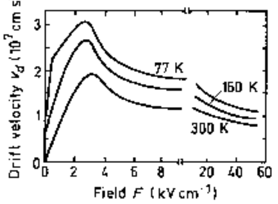
## Transport Properties in High Electric Fields



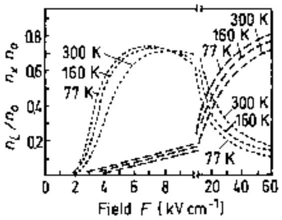
**Field dependences of the electron drift velocity.**
*(Blakemore[1982]).*
Solid curve was calculated by *(Pozhela and Reklaitis[1980])*.
Dashed and dotted curves are measured data, 300 K



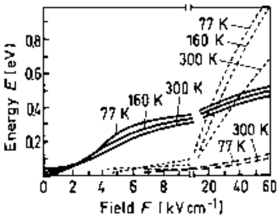
**Field dependences of the electron drift velocity for high electric fields**, 300 K.
*(Blakemore[1982])*.



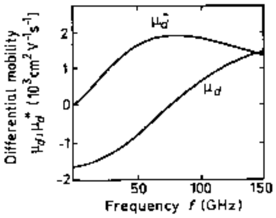
**Field dependences of the electron drift velocity at different temperatures.**
*(Pozhela and Reklaitis[1980])*.



**Fraction of electrons in *L* and *X* valleys. $n_L$ and $n_X$ as a function of electric field *F* at 77, 160, and 300 K,** $N_d$=0
*(Pozhela and Reklaitis[1980])*.
Dotted curve - *L* valleys, dashed curve - *X* valleys.



**Mean energy *E* in *Γ*, *L*, and *X* valleys as a function of electric field *F* at 77, 160, and 300 K,** $N_d$=0
*(Pozhela and Reklaitis[1980])*.
Solid curve - Γ valleys, dotted curve - *L* valleys, dashed curve - *X* valleys.

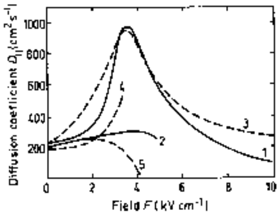


**Frequency dependences of electron differential mobility.**

$\mu_d$ is real part of the differential mobility; $\mu_d^*$ is imaginary part of differential mobility.

$F$= 5.5 kV cm$^{-1}$

*(Rees[1969])*.



**The field dependence of longitudinal electron diffusion coefficient $D \| F$.**

Solid curves 1 and 2 are theoretical calculations. Dashed curves 3, 4, and 5 are experimental data.

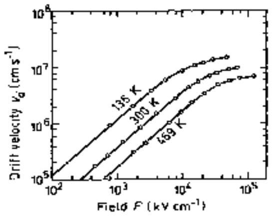
Curve 1 - from *(Pozhela and Reklaitis[1980])*.

Curve 2 - from *(Fauquembergue et al.[1980])*.

Curve 3 - from *(Ruch and Kino[1968])*.

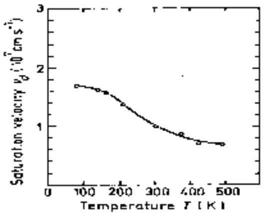
Curve 4 - from *(Bareikis et al.[1978])*.

Curve 5 - *(from de Murcia[1991])*.



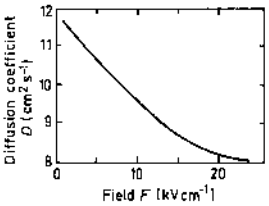
**Field dependences of the hole drift velocity at different temperatures.**

*(Datal et al. [1971]).*



**Temperature dependence of the saturation hole velocity in high electric fields**

*(Datal et al. [1971]).*



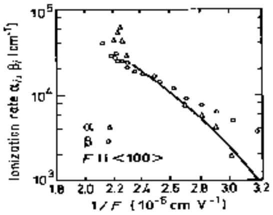
**The field dependence of the hole diffusion coefficient.**

*(Joshi and Crendin [1989])*.

## Impact Ionization

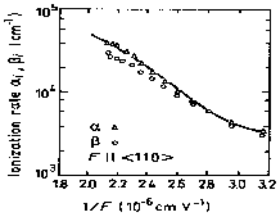
There are two schools of thought regarding the impact ionization in GaAs.

**The first one** states that impact ionization rates $\alpha_i$ and $\beta_i$ for electrons and holes in GaAs are known accurately enough to distinguish such subtle details such as the anisothropy of $\alpha_i$ and $\beta_i$ for different crystallographic directions. This approach is described in detail in the work by Dmitriev et al.[1987].



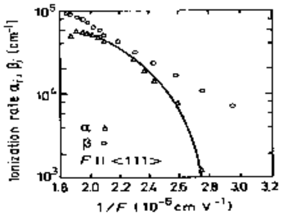
**Experimental curves $\alpha_i$ and $\beta_i$ versus *1/F* for GaAs.**

*(Pearsall et al. [1978]).*



**Experimental curves $\alpha_i$ and $\beta_i$ versus *1/F* for GaAs.**

*(Pearsall et al. [1978]).*

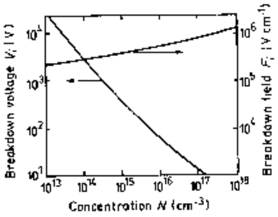


**Experimental curves $\alpha_i$ and $\beta_i$ versus $1/F$ for GaAs.**
(Pearsall et al. [1978]).

**The second school** focuses on the values of $\alpha_i$ and $\beta_i$ for the same electric field reported by different researches differ by an order of magnitude or more. This point of view is explained by Kyuregyan and Yurkov [1989]. According to this approach we can assume that $\alpha_i = \beta_i$. Approximate formula for the field dependence of ionization rates:

$\alpha_i = \beta_i = \alpha_o exp[\delta - (\delta^2 + (F_0 / F)^2)^{1/2}]$

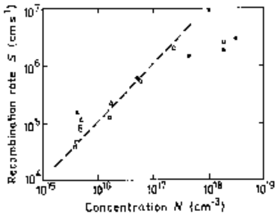
where $\alpha_o = 0.245 \cdot 10^6$ cm$^{-1}$; $\beta = 57.6$ $F_o = 6.65 \cdot 10^6$ V cm$^{-1}$ (Kyuregyan and Yurkov [1989]).



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

## Recombination Parameter

| | |
|---|---|
| **Pure n-type material** ($n_o \sim 10^{14}$cm$^{-3}$) | |
| The longest lifetime of holes | $\tau_p \sim 3 \cdot 10^{-6}$ s |
| Diffusion length $L_p = (D_p \cdot \tau_p)^{1/2}$ | $L_p \sim 30\text{-}50$ µm. |
| **Pure p-type material** | |
| (a)Low injection level | |
| The longest lifetime of electrons | $\tau_n \sim 5 \cdot 10^{-9}$ s |
| Diffusion length $L_n = (D_n \cdot \tau_n)^{1/2}$ | $L_n \sim 10$ µm |
| (b) High injection level (filled traps) | |
| The longest lifetime of electrons | $\tau \sim 2.5 \cdot 10^{-7}$ s |
| Diffusion length $L_n$ | $L_n \sim 70$ µm |



**Surface recombination velocity versus doping density**
(Aspnes [1983]).
Different experimental points correspond to different surface treatment methods.

**Radiative recombination coefficient *(Varshni[1967])***

| | |
|---|---|
| 90 K | $1.8 \cdot 10^{-8}$cm$^3$/s |
| 185 K | $1.9 \cdot 10^{-9}$cm$^3$/s |
| 300 K | $7.2 \cdot 10^{-10}$cm$^3$/s |

**Auger coefficient**

| | |
|---|---|
| 300 K | $\sim 10^{-30}$cm$^6$/s |
| 500 K | $\sim 10^{-29}$cm$^6$/s |