Electrical properties of Indium Phosphide (InP)

**Electrical properties**

**Basic Parameters**

- Breakdown field \(\approx 5 \times 10^5 \text{ V cm}^{-1}\)
- Mobility electrons \(\leq 5400 \text{ cm}^2 \text{V}^{-1} \text{s}^{-1}\)
- Mobility holes \(\leq 200 \text{ cm}^2 \text{V}^{-1} \text{s}^{-1}\)
- Diffusion coefficient electrons \(\leq 130 \text{ cm}^2 \text{s}^{-1}\)
- Diffusion coefficient holes \(\leq 5 \text{ cm}^2 \text{s}^{-1}\)
- Electron thermal velocity \(3.9 \times 10^5 \text{ m s}^{-1}\)
- Hole thermal velocity \(1.7 \times 10^5 \text{ m s}^{-1}\)

**Electron Hall mobility versus temperature for different doping levels.**

- Bottom curve: \(n_o = N_d - N_a = 8 \times 10^{17} \text{ cm}^{-3}\)
- Middle curve: \(n_o = 2 \times 10^{15} \text{ cm}^{-3}\)
- Top curve: \(n_o = 3 \times 10^{13} \text{ cm}^{-3}\)

(Razeghi et al. [1988] and Walukiewicz et al. [1980].)

**Electron Hall mobility versus temperature (high temperatures):**

- Bottom curve: \(n_o = N_d - N_a = 3 \times 10^{17} \text{ cm}^{-3}\)
- Middle curve: \(n_o = 1.5 \times 10^{16} \text{ cm}^{-3}\)
- Top curve: \(n_o = 3 \times 10^{15} \text{ cm}^{-3}\)

(Galavanov and Shtukaev [1970].)

**For weakly doped n-InP at temperatures close to 300 K electron drift mobility:**

\[
\mu_n = (4.2 \pm 5.4) \times 10^3 \cdot (300/T) \quad \text{(cm}^2 \text{V}^{-1} \text{s}^{-1})
\]

**Hall mobility versus electron concentration for different compensation ratios.**

- 0 = \(N_d/N_a\), 77 K.
- Dashed curves are theoretical calculations: 1. \(0 = 0\); 2. \(0 = 0.2\); 3. \(0 = 0.4\); 4. \(0 = 0.6\); 5. \(0 = 0.8\);
- (Walukiewicz et al. [1998]).
- Solid line is mean observed values (Anderson et al. [1985]).

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**Approximate formula for electron Hall mobility**

\[
\mu = \mu_{OH} \left(1 + (N_d/10^7)^{1/2}\right),
\]

where \(\mu_{OH} = 5000 \text{ cm}^2 \text{V}^{-1} \text{s}^{-1}\),
\(N_d\) in \(\text{cm}^{-3}\) (Hilsum [1974]).

At 300 K, the electron Hall factor \(r_m \approx 1\) in n-InP.
for \(N_d > 10^{16} \text{ cm}^{-3}\).
Hole Hall mobility versus temperature for different doping (Zn) levels.

Hole concentration at 300 K: 1. $1.75 \times 10^{18}$ cm$^{-3}$; 2. $3.6 \times 10^{17}$ cm$^{-3}$; 3. $4.4 \times 10^{16}$ cm$^{-3}$.

$\theta = N_d/N_a \approx 0.1$.

(Kohanyuk et al. [1988]).

For weakly doped $p$-InP at temperature close to 300 K the Hall mobility

$\mu_{HP} \approx 150 \cdot (300/T)^{2.2}$ (cm$^2$ V$^{-1}$ s$^{-1}$).

Hole Hall mobility versus hole density, 300 K (Wiley [1975]).

The approximate formula for hole Hall mobility:

$\mu_p = \mu_{po} / \left[ 1 + \left( N_a / 2 \times 10^{17} \right)^{1/2} \right]$, where $\mu_{po} \approx 150$ cm$^2$ V$^{-1}$ s$^{-1}$, $N_a$ in cm$^{-3}$.

At 300 K, the hole factor in pure $p$-InP: $r_p \approx 1$.

**Transport Properties in High Electric Fields**

Field dependences of the electron drift velocity in InP, 300 K.

Solid curve are theoretical calculation. Dashed and dotted curve are measured data.

(Maloney and Frey [1977]) and (Gonzalez Sanchez et al. [1992]).

The field dependences of the electron drift velocity for high electric fields.

T(K): 1. 95; 2. 300; 3. 400.

(Windhorn et al. [1983]).

Field dependences of the electron drift velocity at different temperatures.

Curve 1 - 77 K (Gonzalez Sanchez et al. [1992]).

Curve 2 - 300 K, Curve 3 - 500 K (Fawcett and Hill [1975]).

Electron temperature versus electric field for 77 K and 300 K.

(Maloney and Frey [1977]).

Fraction of electrons in L and X valleys $n_L/n_o$ and $n_X/n_o$ as a function of electric field, 300 K.

(Borodovskii and Osadchii [1987]).
Longitudinal (D || F) and transverse (D ⊥ F) electron diffusion coefficients at 300 K.
Ensemble Monte Carlo simulation.
(Aishima and Fukushima [1983]).

Longitudinal (D || F) and transverse (D ⊥ F) electron diffusion coefficients at 77K.
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Impact Ionization

The dependence of ionization rates for electrons α_i and holes β_i versus 1/F, 300 K.
(Cook et al. [1982]).

Breakdown voltage and breakdown field versus doping density for an abrupt p-n junction, 300 K
(Kvargyn and Yurkov [1989]).

Recombination Parameters

Pure n-type material (n_o ~ 10^{-14} cm^{-3})
The longest lifetime of holes
\[ \tau_p = 3 \times 10^{-6} \text{s} \]
Diffusion length \[ L_p = (D_p \tau_p)^{1/2} \]
\[ L_p \sim 40 \mu\text{m} \]

Pure p-type material (p_o ~ 10^{15} cm^{-3})
(a) Low injection level
The longest lifetime of electrons
\[ \tau_n = 2 \times 10^{-5} \text{s} \]
Diffusion length \[ L_n = (D_n \tau_n)^{1/2} \]
\[ L_n \sim 8 \mu\text{m} \]
(b) High injection level (filled traps)
The longest lifetime of electrons
\[ \tau = 10^{-8} \text{s} \]
Diffusion length \[ L_n \]
\[ L_n \sim 25 \mu\text{m} \]

Surface recombination velocity versus the heat of reaction per atom of each metal phosphide \( \Delta H_R \)
(Rosenwaks et al. [1990]).

If the surface Fermi level \( E_{FS} \) is pinned close to midgap (\( E_{FS} = E_g/2 \)) the surface recombination velocity increases from \( 5 \times 10^3 \text{ cm/s} \) for doping level \( n_o \sim 3 \times 10^{15} \text{ cm}^{-3} \) to \( 10^6 \text{ cm/s} \) for doping level \( n_o \sim 3 \times 10^{18} \text{ cm}^{-3} \) (Bothra et al. [1991]).
Radiative recombination coefficient (300 K) \(1.2 \times 10^{-10} \text{ cm}^3/\text{s}\)
Auger coefficient (300 K) \(-9 \times 10^{-31} \text{ cm}^6/\text{s}\)