Space-charge-limited conduction mechanism I

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D. R. Lamb, Electric Conduction Mechanisms in Thin Insulating Films (Methuen, London, 1967)

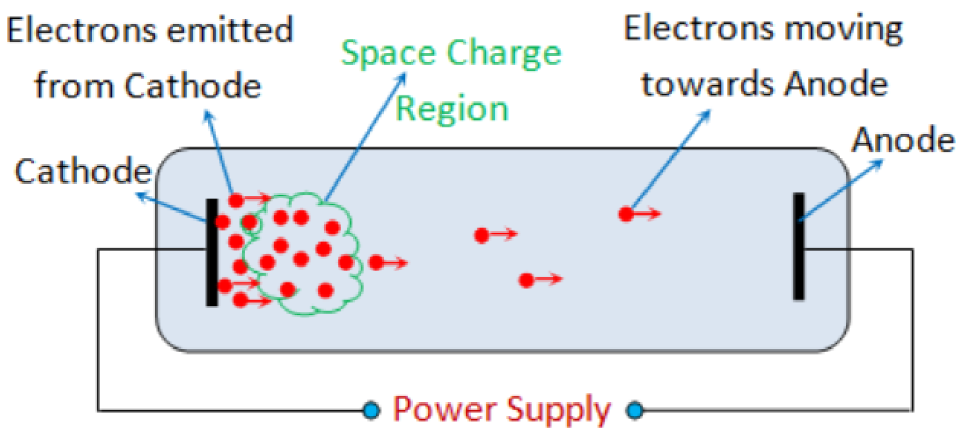
1. Space-charge-limited flow

- One-carrier space-charge-limited flow without traps. (electrons)
- One-carrier space-charge-limited flow with traps.
- Two-carrier space-charge-limited flow without traps or recombination centers. (cathode electrons, anode holes)
- Two-carrier space-charge-limited flow with recombination centers

2. One-carrier space-charge-limited

Definition: if an electron injecting contact is applied to an insulator, electrons will travel from the metal into the conduction band of the insulator and form a space-charge similar to that of a vacuum diode.

Accumulation of charges in a particular region is referred to as **space charge**.



3. Theory

- At low voltages where the injected carrier density is less than n_0, which is the thermally generated free carrier density, Ohm's law will be obeyed:

$$J = en_0\mu\frac{V}{s} \quad (1)$$

- At transition voltage, V_{tr}, the transition from Ohm's law to Mott and Gurney law takes place:

$$J = \frac{9}{8}k\mu\frac{V^2}{s^3} \quad (2)$$

The theory is based on purely field driven currents and diffusion current:

$$J = ne\mu E - De(\frac{dn}{dx}) \quad (3)$$

- The presence of traps will reduce the space-charge-limited current since any empty traps will remove most of the injected carriers. The occupancy of a trap level at ϵ_t in thermal equilibrium is given by

$$n_t(x) = \frac{N_t}{1+\frac{N}{gn(x)}} \quad (4)$$

where $N = N_c\exp[\frac{(\epsilon_t-\epsilon_c)}{KT}]$

s: film thickness
μ: mobility
V: voltage
k: dielectric constant
n: free electron density
D: diffusion coefficient
N_t: trap density
g: degeneracy factor for traps
N_c: effective density of states in the conduction band
ϵ_t: trap level
ϵ_c: bottom of conduction band

Situation 1: shallow trapping

- 'shallow' traps are defined as being at least KT above the electron-steady-state Fermi level (ESSFL). Only shallow traps can be effective in capturing injected electrons.

$$n(x) = N_c \exp[\frac{(\epsilon_{Fn(x)} - \epsilon_c)}{KT}]$$

$$1 + \frac{N}{gn(x)} = 1 + \frac{N_c}{\mathrm{g}} \exp\left[\frac{(\epsilon_t - \epsilon_c)}{KT}\right] / \exp[\frac{(\epsilon_{Fn(x)} - \epsilon_c)}{KT}] = 1 + \frac{N_c}{\mathrm{g}} \exp\left[\frac{(\epsilon_t - \epsilon_{Fn(x)})}{KT}\right] \approx \frac{N}{gn(x)}$$

Thus from Eqn. (4), the ratio of free to trapped charge is

$$\frac{n(x)}{n_t(x)} = \frac{N}{gN_t} = \theta$$

$$J = \frac{9}{8} \theta k \mu \frac{V^2}{s^3}$$

Assuming all trapped charges in the states between initial Fermi level and the final Fermi level, so the shift in the Fermi level will be proportional to the space charge,

$$\Delta\epsilon = Q/(eN_t s) \approx VC/(eN_t s)$$

$$n(x) = N_c \exp[\frac{(\epsilon_F - \epsilon_c)}{KT}] \exp[\frac{\Delta\epsilon}{KT}] = n_0 e^{tV}$$

$$n_t = \frac{Q}{es} = \frac{VC}{es}$$

$$\theta = \frac{n(x)}{n_t(x)} = \frac{n_0 e^{tV}}{VC/es} = \left(\frac{n_0 es}{VC}\right) e^{tV}$$

$$J = \frac{9}{8} \theta k \mu \frac{V}{s^2} \left(\frac{n_0 e}{C}\right) e^{tV}$$

Situation 2: deep trapping

- ‘deep’ traps are defined as being at least KT below the ESSFL

The traps are full and have little influence on the free carrier density.

In this case, $1 + \frac{N}{gn(x)} \approx 1$,

$$n_t(x) \approx N_t$$

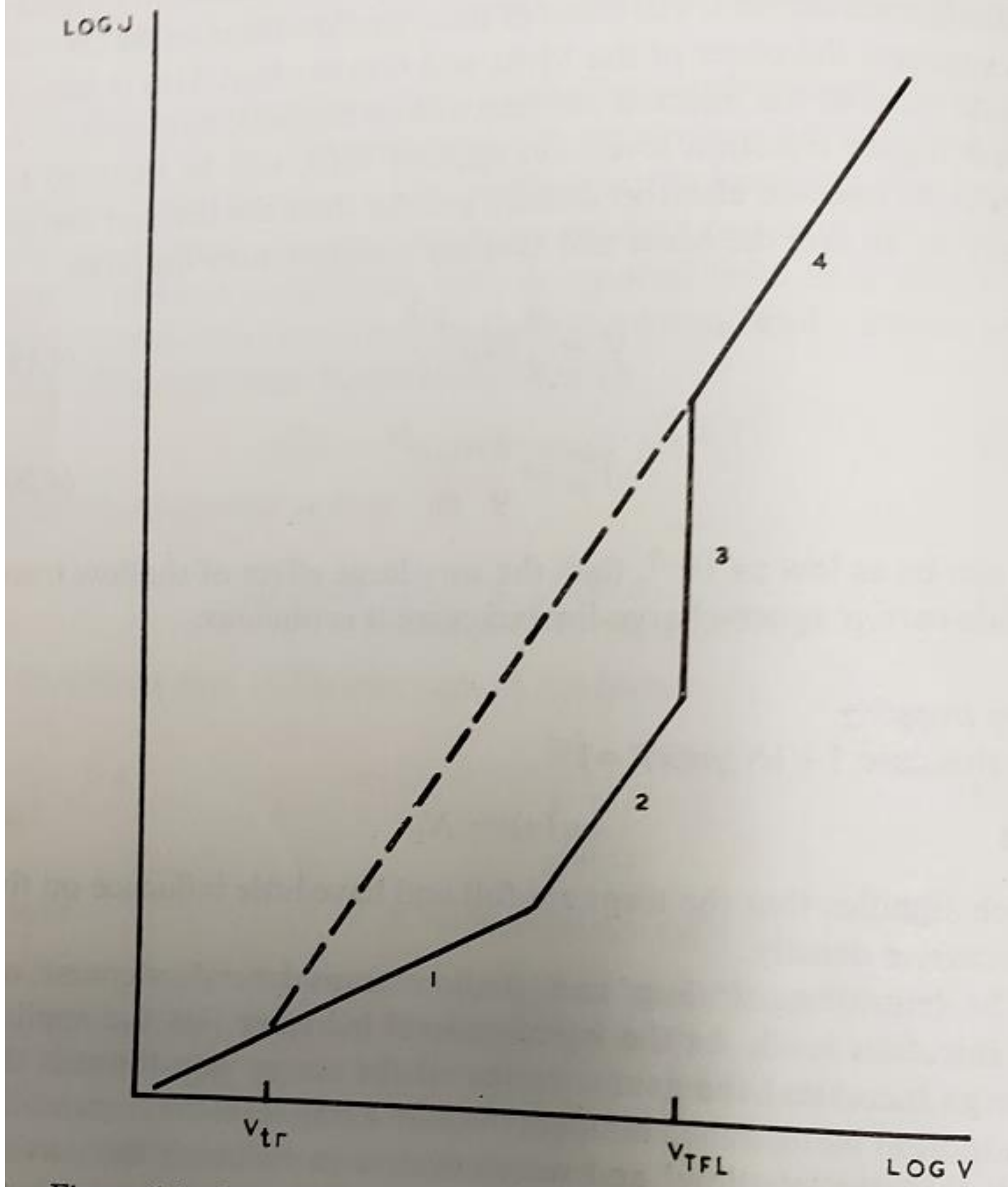


Figure 4.1. One-carrier space-charge-limited current-voltage characteristic for an insulator with a single trap level. (1) Ohm's law. (2) Modified Mott and Gurney law due to the traps. (3) Trap-filled-limit region. (4) Trap free Mott and Gurney law.

3. Comparison of experiment and theory

Amorphous selenium (20 u)/ tin oxide / glass substrate

For film 2, the dependence of current on voltage was between V and V^2 at lower voltages.

$$I = 2.2 \times 10^{-11} V e^{V/31.1}$$

$$I = 1.3 \times 10^{-11} V e^{V/57.0}$$

For voltages less than 10 v the current was probably a mixture of ohmic and SCLC. This suggests that the thermal equilibrium Fermi level was less than kT above a uniform distribution of hole capture levels

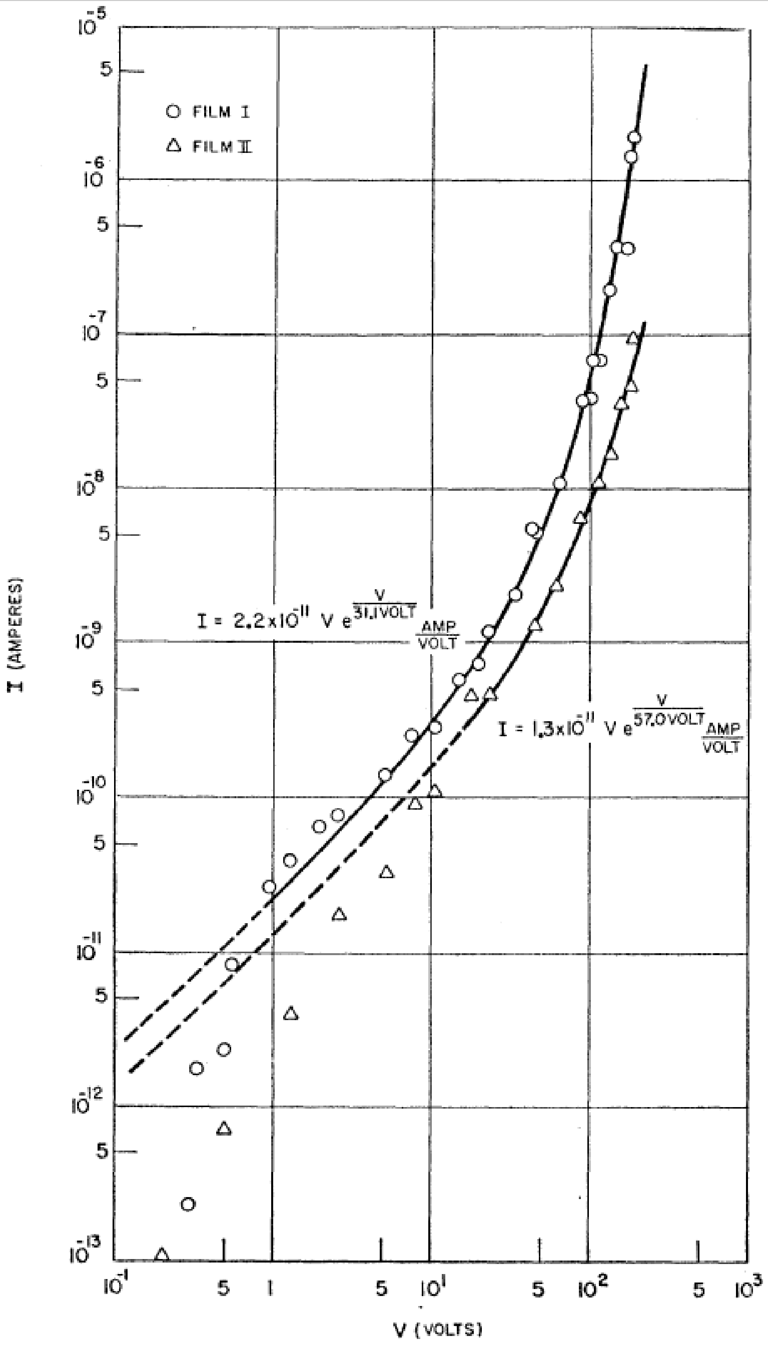


FIG. 11. Space-charge-limited currents in amorphous selenium films having gold hole-injecting contacts.

Thanks and questions?