Charge relaxation times

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AZO(AI2O3+ZnO) relaxation times

\[ \rho = R \frac{S}{l} = (90 - 500) \times 10^{12} \Omega \frac{1.29 \times 10^{-9} m^2}{1.6 \times 10^{-3} m}, \]
\[ \rho = (0.725 - 4.03) \times 10^{10} (\Omega \cdot cm). \]
\[ \sigma = (1.38 - 0.25) \times 10^{-10} (\Omega \cdot cm)^{-1} \]
\[ \varepsilon = 6.9 \]

<table>
<thead>
<tr>
<th>Channel Resistive Layer Material</th>
<th>60% Zn/(Zn+Al)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maxwell relaxation time</td>
<td>6.1×10^{-3} sec</td>
</tr>
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</table>

\[ \rho = (0.725 - 4.03) \times 10^{7} (\Omega \cdot cm). \]
\[ R_i = (90 - 500) \times 10^9 \Omega, \]
\[ R = R_i / N = (20 - 100) \times 10^3 \Omega. \]

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<th>Channel Resistive Layer Material</th>
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<td>Maxwell relaxation time</td>
<td>6.1×10^{-6} sec</td>
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Figure 7. Resistivity of ZnO/Al2O3 alloy films measured using the four-point probe and the mercury probe.
Microscopic Drift-Diffusion Model of charge relaxation

\[ \vec{J}_e = eD_e \nabla n_e + e \mu_e n_e \vec{E}, \]
\[ \vec{J}_h = -eD_h \nabla n_h + e \mu_h n_h \vec{E}, \]
\[ \text{div } \vec{E} = \rho / \varepsilon \varepsilon_0, \rho = n_h - n_e, \]
\[ \frac{\partial n_e}{\partial t} = -\frac{1}{q} \nabla J_e = D_e \Delta n_e + e n_e \mu_e / \varepsilon \varepsilon_0 (n_h - n_e), \]
\[ \frac{\partial n_h}{\partial t} = -\frac{1}{q} \nabla J_h = D_h \Delta n_h - e n_h \mu_h / \varepsilon \varepsilon_0 (n_h - n_e) + \left( \frac{\partial n_h}{\partial t} \right)_{\text{Auger}}, \]
\[ n_i^2 = N_c N_v \exp(-E_g / k_B T), E_g = 3.2 - 4.3 \text{ eV} \]
\[ N_c N_v = 2(2\pi kT / h^2)^{3/2} (m_e m_h)^{3/4}, \] - density of states
\[ \nabla^2 \phi = \frac{e}{\varepsilon \varepsilon_0} (n_e - n_h), \]
\[ \mu_{e,h} = \sigma_{e,h} / e n_{e,h}, \]
\[ D_{e,h} = \mu_{e,h} k_B T / e. \]

\( D_\alpha \) – diffusion coefficient, \( \mu_\alpha \) - mobility, \( n_\alpha \) - density of carriers 
\((\alpha = e, h)\)

A. Spherical symmetry

B. Cylindrical symmetry

Primary electron

Primary electron $r = 10$ nm
Al$_2$O$_3$+ZnO

$\Delta r = 10$ nm
Aspect ratio 40

$\Delta r = 20$ $\mu$m

**Relaxation times via Drift-Diffusion Model**

- Diffusion coefficients of amorphous alumina are unknown
- Carrier mobilities for alumina are known for limited mixture content

- Exp. ZnO with 1% of Al\textsubscript{2}O\textsubscript{3}: $\mu=40$ cm$^2$/Vs, $\rho = 1.4 \times 10^{-4}$ (Ωcm) [1]

- Resistivity of AZO with 20% Al: $\rho = 10^7$ (Ω cm), mobility unknown.

- Using linearity of conductivity vs mobility ($\sigma = en\mu$), the mobility of mixture AZO was extrapolated from low Al-content to high.

- Diffusion coefficients were found via Einstein relation: $D = \mu k_B T/e$.

Proposed material constants

- Mobility and diffusion constants of carriers were extrapolated from low Al-content to high [1]
Set of equations for the drift-diffusion model were numerically solved for several values of material constants and the relaxation times were obtained.
Hole densities vs time, AL2O3+ZnO

- Variable – diffusion coefficients, $D_h$

$$D_h = 1.2 \times 10^{-11} \text{ cm}^2/\text{s}$$

$$D_h = 1.2 \times 10^{-10} \text{ cm}^2/\text{s}$$

$$D_h = 1.2 \times 10^{-9} \text{ cm}^2/\text{s}$$

$$D_h = 1.2 \times 10^{-8} \text{ cm}^2/\text{s}$$
Relaxation times calculated via DDM

- Relaxation time vs diffusion coefficients

![Graphs showing relaxation times for different diffusion coefficients](image-url)
Temperature effects

- Conductivity of glass drastically depends on the T
- We need similar dependence for Al2O3+ZnO
- For higher T, the mobility will be difficult to obtain

Conductivity of Borosilicate Glass

![Graph showing the conductivity of borosilicate glass as a function of temperature.](image)