Implementation of Optical Response of Thin Film Transistor with Verilog-A for Mobile LCD Applications

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Outline

- Background
- Model
- Model Evaluation
- Application
- Conclusion
Background
Liquid Crystal Displays (LCDs) have become widely used in our daily life.
Expectations for LCDs

- **High Image Quality**
  - High contrast
  - Fast response
  - Low power consumption
  - Image uniformity, etc...

- **Compact in Design**
  - Narrow Frame
  - Thinner profile, etc...

- **Inexpensive in Price**

More accurate and fast simulation is in demand
Background

- Operation of general LCDs

Block diagram of typical LCD

Cross sectional view of LC cell

Equivalent circuit of a pixel
Background

- **Operation of general LCDs**

Block diagram of typical LCD

Cross sectional view of LC cell

**VERY IMPORTANT!!**
Issues for the display quality in LCDs (1)

Possible defects of display quality

Flicker
Vertical Cross-talk
Un-uniformity

Cause of the malfunctions

“Photo-Leakage Current”
Issues for the display quality in LCDs (2)

- TFTs are constantly under the influence of the light.
- They are required to maintain voltage for a long time.
- The effect of photo-leakage is significant.

Circuit analysis considering the effect of the light is strongly in demand.
Background

Device model for TFT

Rensselaer Polytechnic Institute (RPI) model

- Popular TFT device model
- Accurately expresses TFT device characteristics

Ways to include an optical response

- Modify a proven device model
  - models provided by EDA vendors are not opened for modification
- Develop an original device model
  - takes too much time!!

Use Verilog-A to model ONLY an optical response of TFT

Model
Proposed method

Connect photo-current module as an **EXTERNAL** instance of the RPI model

Transistor model and Photo-Current Module are connected in parallel.

Condition to be met

Photo-leakage current needs to be modeled as independent of characteristics calculated by the RPI model.
**Model**

- Two generation paths of photo-carriers
  1. Inside the depletion region.
     - Carriers separated by the field.
     - Drift component.
     - Not in the RPI model.
     - Empirically known to be dominant.
  2. Outside edge of the depletion region.
     - Originated from the diffusion.
     - Diffusion component.
     - Empirically known to be less dominant.
Two generation paths of photo-carriers

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Photo-leakage current is assumed as an independent current of the RPI
Generation inside the depletion region

- Photo-generation rate \( G \) (s\(^{-1}\)cm\(^{-3}\))

\[
G(x) = \int_{\lambda_{\text{min}}}^{\lambda_{\text{max}}} \alpha(\lambda, x)\Phi(\lambda, x)e^{-\int_{0}^{x} \alpha(\lambda, x) d\lambda} d\lambda
\]

\[
G = \frac{P_{\text{in}} \alpha}{h \nu}
\]

- Photo-leakage current in the depletion region \( I_{\text{photo}} \) (A)

\[
I_{\text{photo}} = q t_{\text{Si}} w l_{\text{dep}} G
\]

\[
l_{\text{dep}} = \sqrt{\frac{2 \varepsilon_{\text{Si}} (N_a + N_d) (\phi_{\text{bi}} + V_{\text{ds}})}{q N_a N_d}}
\]

Convergence issues

SPICE is based on Ohm’s Law

When \( V_{ds} \) is 0 V, \( I_{ds} \) should be 0 A.

\[
I_{\text{photo}_{\text{mod}}} = I_{\text{photo}} \tanh^2(\alpha_{\text{mod}} V_{ds})
\]

Convergence is greatly improved by introducing tanh
// Verilog-A for Photo-leakage current module

module iphoto(d, s);
    inout d, s;
    electrical d, s;
    ...
    analog begin
        begin
            if (V(d, s) >= 0.0) begin
                mode = 1;
                vds = V(d, s);
            end
            else begin
                mode = -1;
                vds = -V(d, s);
            end
            if (acm == 0)
                weff = w * scale;
            else if (acm == 1)
                weff = (w * scale * wmlt + xw - 2 * wd * scale);
        ...
        ...V(d,s)

        ldep = sqrt(2.0 * EPSILON_SI * (eb + vds)
                / (Q_E * na * nd) * (na + nd));
        ...
        iphoto = Q_E * tsi * weff * ldep *
                (brightness * alpha) / (H * C / lambda);
        iphoto = iphoto * pow(tanh(alphamod
                * vds), 2);
        if (mode > 0)
            I(d, s) <+ iphoto;
        else
            I(d, s) <+ -iphoto;
        end
    endmodule
Model Evaluation
Good agreement with the experiment data
Simulation runtime

- 1001 pixels in series.
- Tran. analysis of 40 msec.

Built-in Model

Built-in Model w/ photo-current module

Simulation runtime comparison

Only 1.06 times more simulation runtime is consumed
Application
Application to the LCD design

Schematic diagram of LCD panel
A typical pixel circuit of LCD

Photo-leakage current model and liquid crystal model described in Verilog-A are used

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Following optimizations should be applied during LCD design processes

1. \( V_{\text{com}} \) optimization
2. \( C_{\text{sc}} \) optimization
Optimization 1: $V_{\text{com}}$

- Flicker level increases with light exposure.
- Optimal $V_{\text{com}}$ shifts with light intensities.
- Failure to optimize $V_{\text{com}}$ may lead to flicker image.

$V_{\text{com}}$ should be $\sim -0.35$ V

Designers can estimate the optimal $V_{\text{com}}$ for supposed light intensities.
Optimization 2: $C_{sc}$

- As $C_{sc}$ is increased:
  - Flicker level is decreased
- BUT...
  - Less aperture ratio
  - Hard to accumulate the charge during switch-on time

Choose max $C_{sc}$ that fulfills customer’s specification

Designers can estimate the optimal $C_{sc}$ for supposed light intensities with given specification
Realized **accurate** and **fast** simulation considering optical illumination.

Enabled **detection of possible malfunctioning** in the LCD property during designing process.

**Verilog-A** is suitable for this **plug-in approach** modeling.
Thank you for your attention