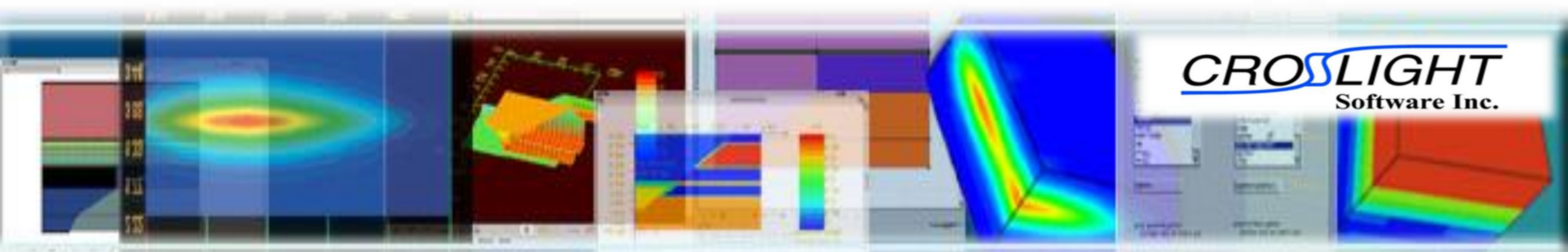


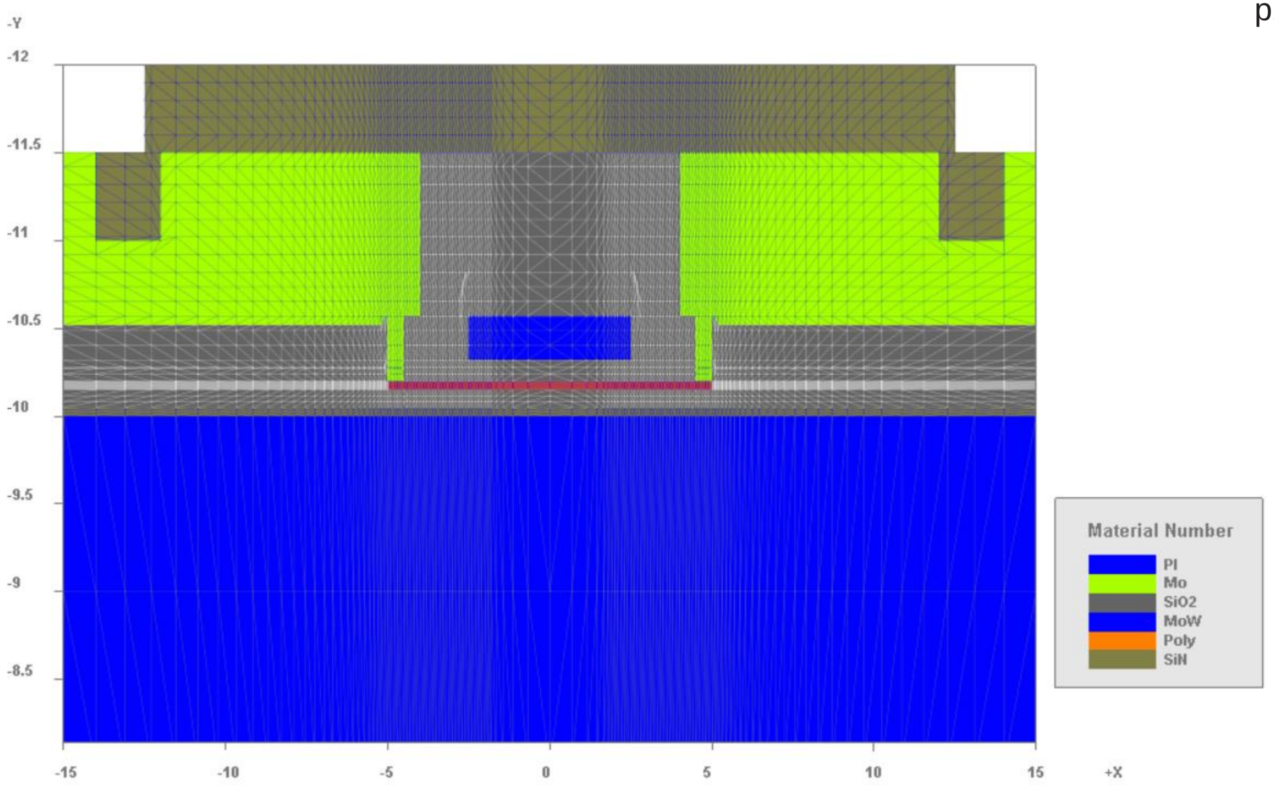
Crosslight Simulation of Effects of Bending in Thinfilm Transistors

CROSSLIGHT
Software Inc.

Contents

- Structure and experiments
- Stress and material models
- Device model: Stressed metal
- Device model: Stressed poly
- Summary

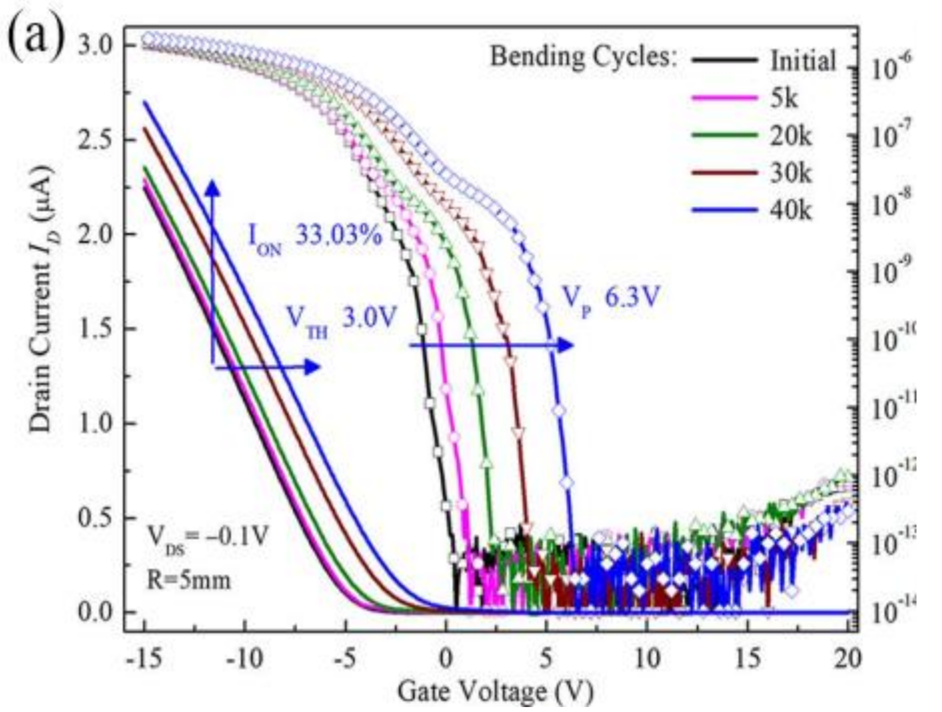
Structure



IEEE TRANSACTIONS ON ELECTRON DEVICES, VOL. 66, NO. 5, MAY 2019
p2214

Spontaneous Degradation of Flexible Poly-Si TFTs Subject to Dynamic Bending Stress

Wei Jiang, Mingxiang Wang, *Senior Member, IEEE*, Huaisheng Wang, and Dongli Zhang



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Model

$$c_{11} * \frac{\partial^2 V_x}{\partial x^2} + c_{44} * \frac{\partial^2 V_x}{\partial y^2} + c_{12} * \frac{\partial^2 V_y}{\partial x \partial y} + c_{44} * \frac{\partial^2 V_y}{\partial y \partial x} = -bx$$

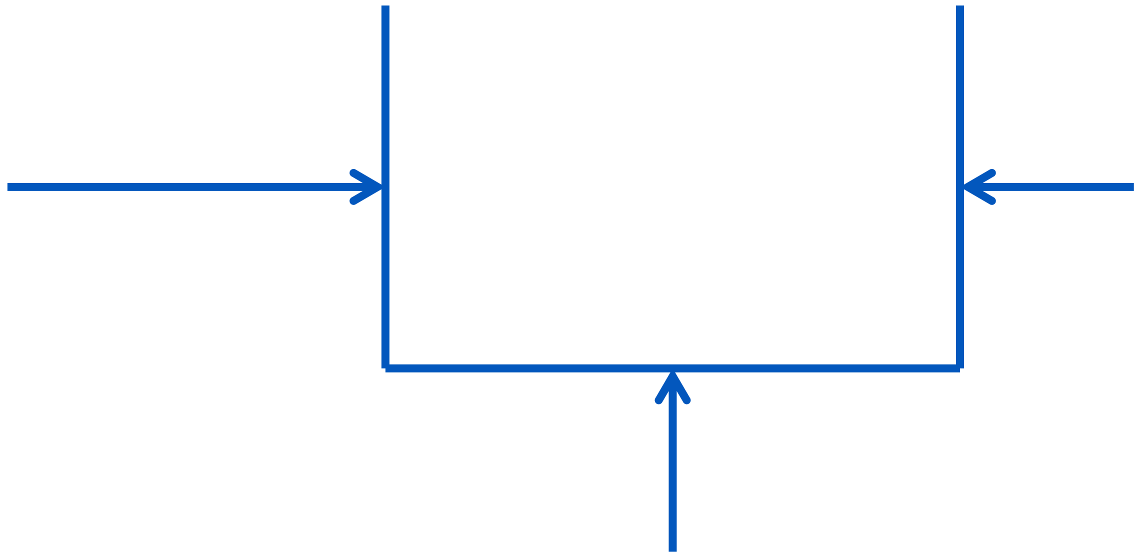
$$c_{12} * \frac{\partial^2 V_x}{\partial y \partial x} + c_{44} * \frac{\partial^2 V_x}{\partial x \partial y} + c_{44} * \frac{\partial^2 V_y}{\partial x^2} + c_{11} * \frac{\partial^2 V_y}{\partial y^2} = -by$$

V=displacement vector
bx/by=initial stress/boundary stress

$$bx = \frac{\partial \sigma_{0,xx}}{\partial x} + \frac{\partial \sigma_{0,xy}}{\partial y}$$

$$by = \frac{\partial \sigma_{0,yy}}{\partial y} + \frac{\partial \sigma_{0,xy}}{\partial x}$$

Strain boundary (default)



By default, boundaries in CSUPREM model are such that all displacement at left/right/bottom are restricted

Not suitable for bending

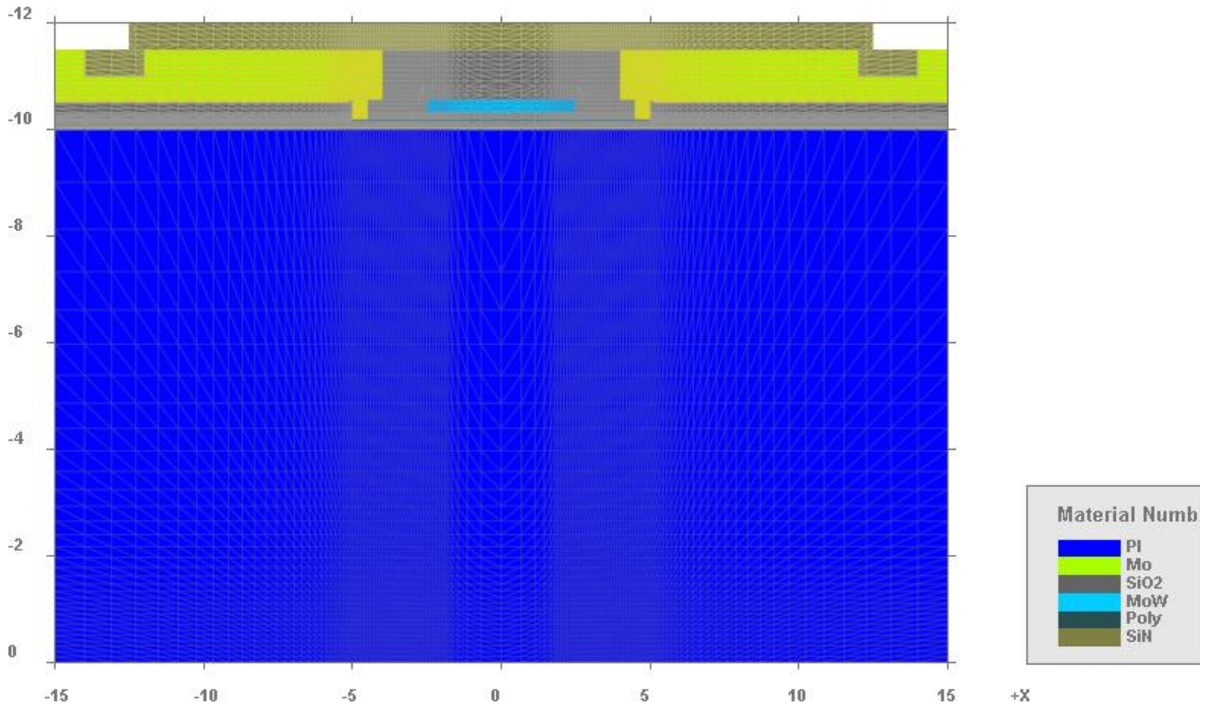
Revised Strain Boundary

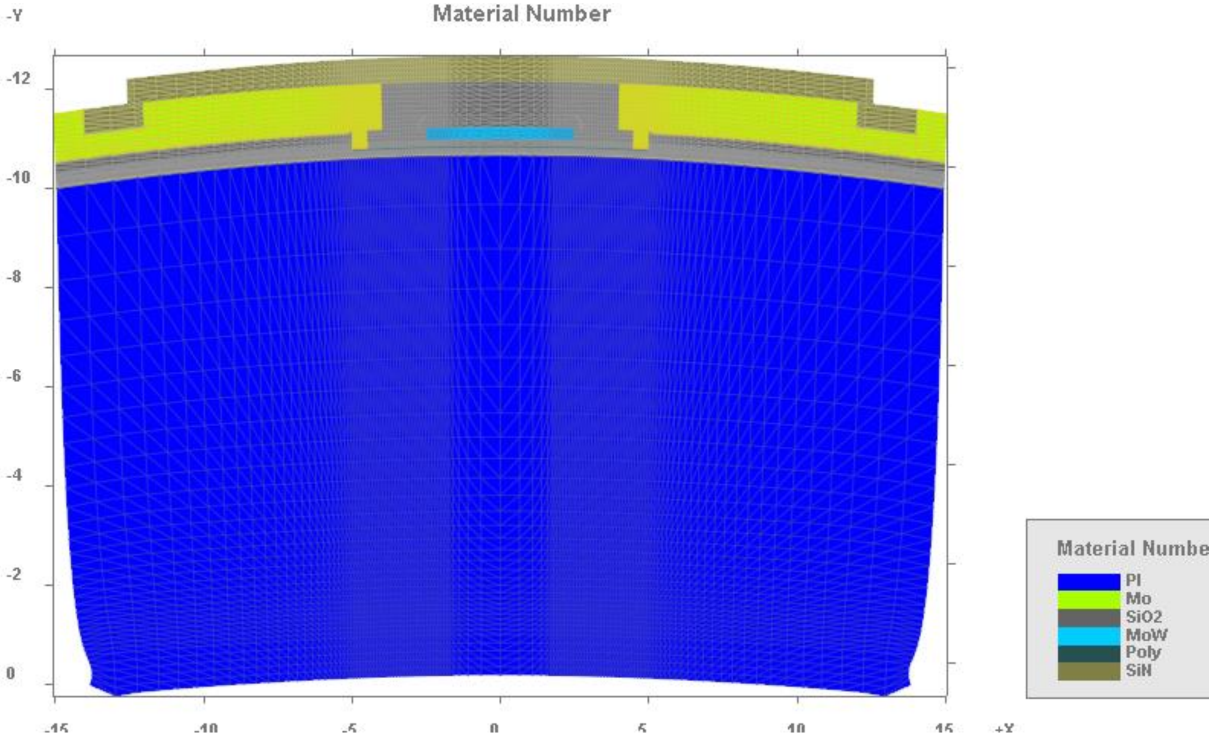
y.free.boundary=bottom
Revised bottom boundary

x.free.boundary=left/right
Revised left/right boundary

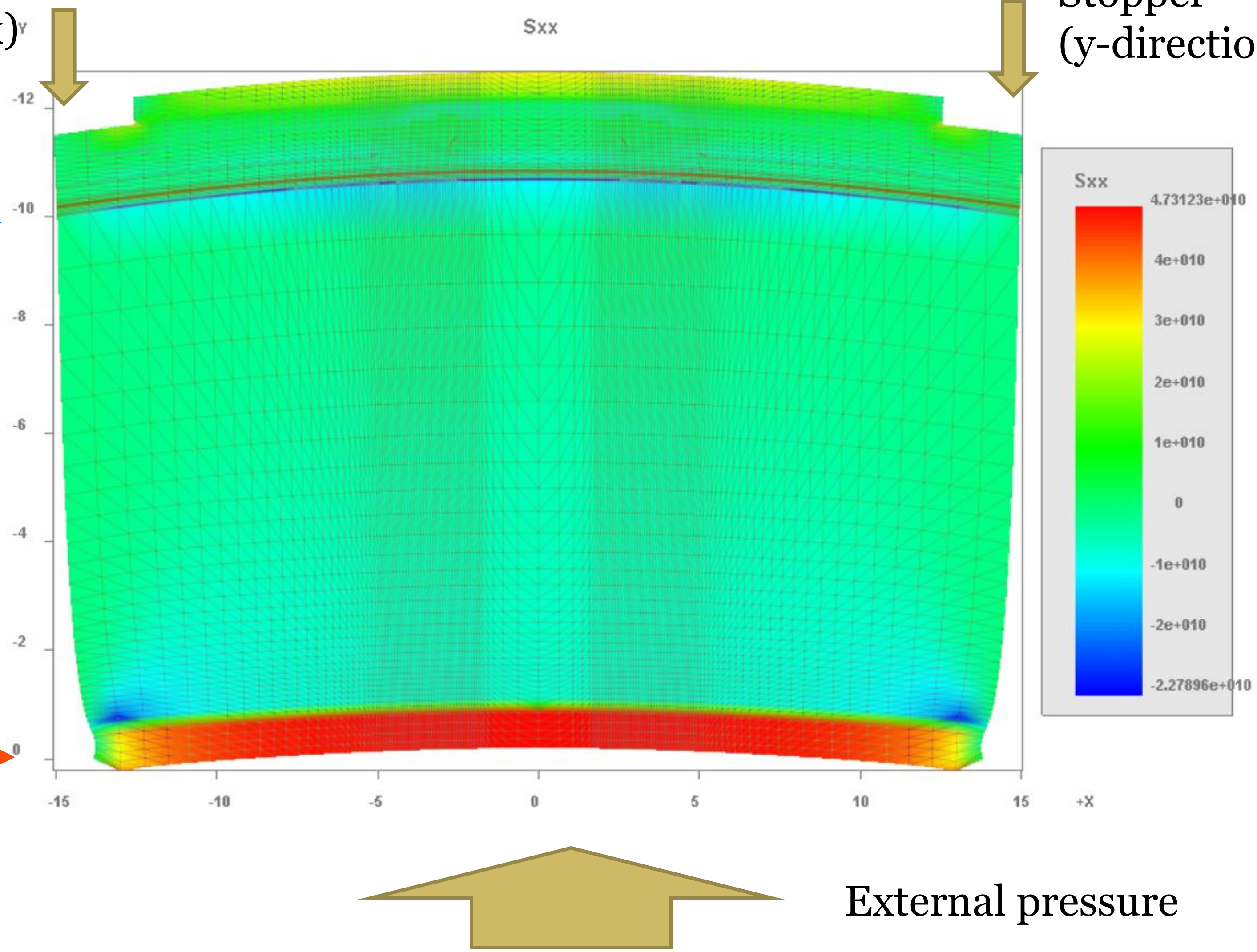
y.fixed.boundary=left/right
Fix the y-direction so that the object would not move in y-direction after bending

With and Without Bending





Stress Distribution



Stopper
(y-direction fix)

Stopper
(y-direction fix)

Tensile
Stress
(negative Sxx)

Compressive
Stress
(positive Sxx)

External pressure

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Files and Commands

Ltps_TFT_30um_nostrain for no-strain

1. Run Csuprem on 2d.in
2. Run APSYS on tft2_vt.sol, tft2_iv.sol
3. Customized MoW, Pi material macro defined as LTPS.mac

Ltps_TFT_30um_strain for with strain

Let work function of MoW be stress dependent:

```
affinity variation=function
function(stress_xx)
4.9+abs(stress_xx)
end_function
```

Files and Commands

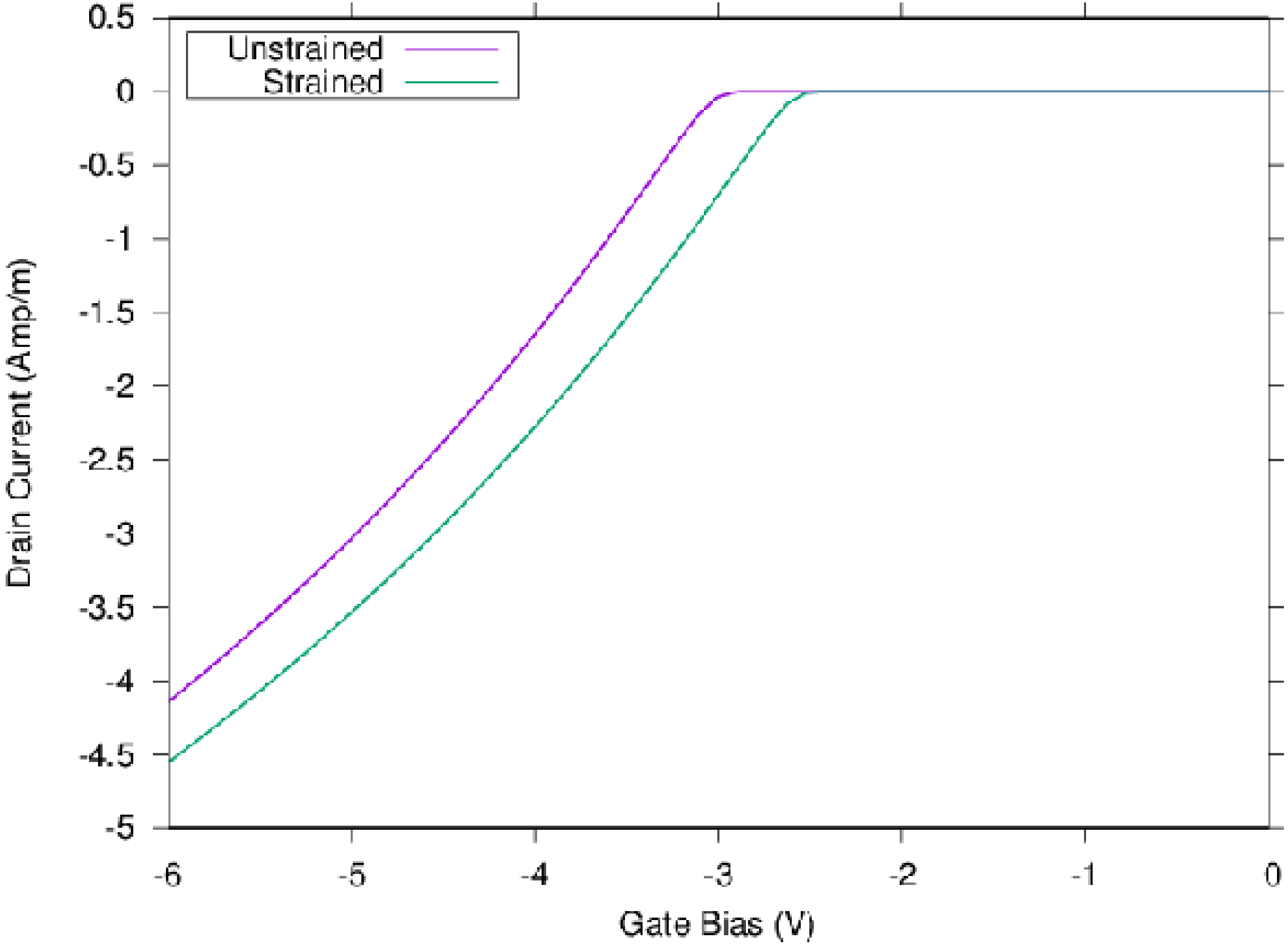
```
#Key commands in    2d.in

external_pressure  xrange_from=-15.0 xrange_to=15.0  depth=0.5 sigma=-1.0e11 bottom
stress temp1=25 temp2=25  y.free.boundary=bottom   x.free.boundary=left/right
y.fixed.boundary=left/right

struct outf=08_final_disp.str add.disp=t
```

External pressure acting from the bottom within a range.
Depth affects mesh region where external pressure acts on.
The results shall not be sensitive to choice of depth of external initial pressure.

Shift of Threshold Voltage



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- Device model: Stressed metal
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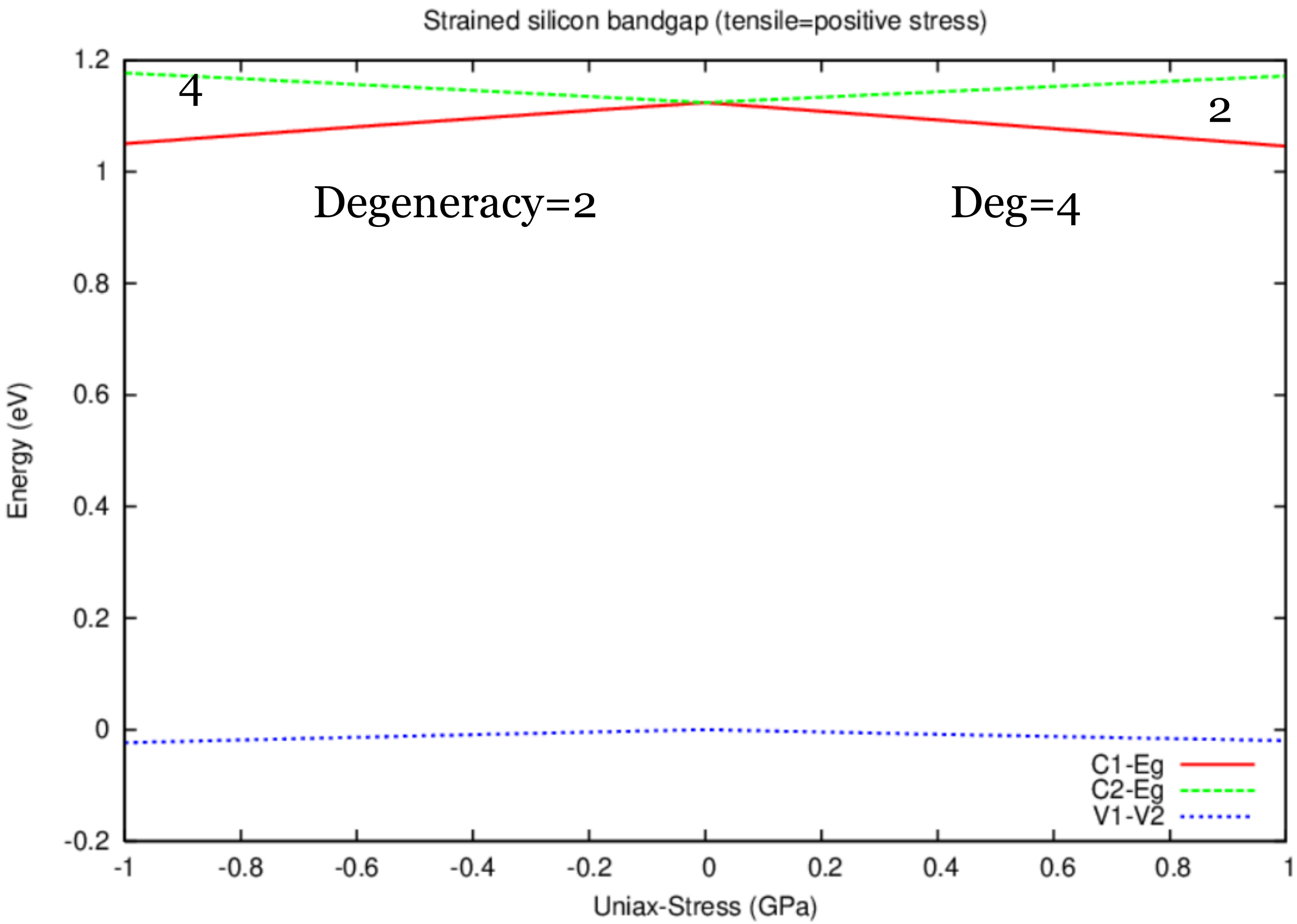
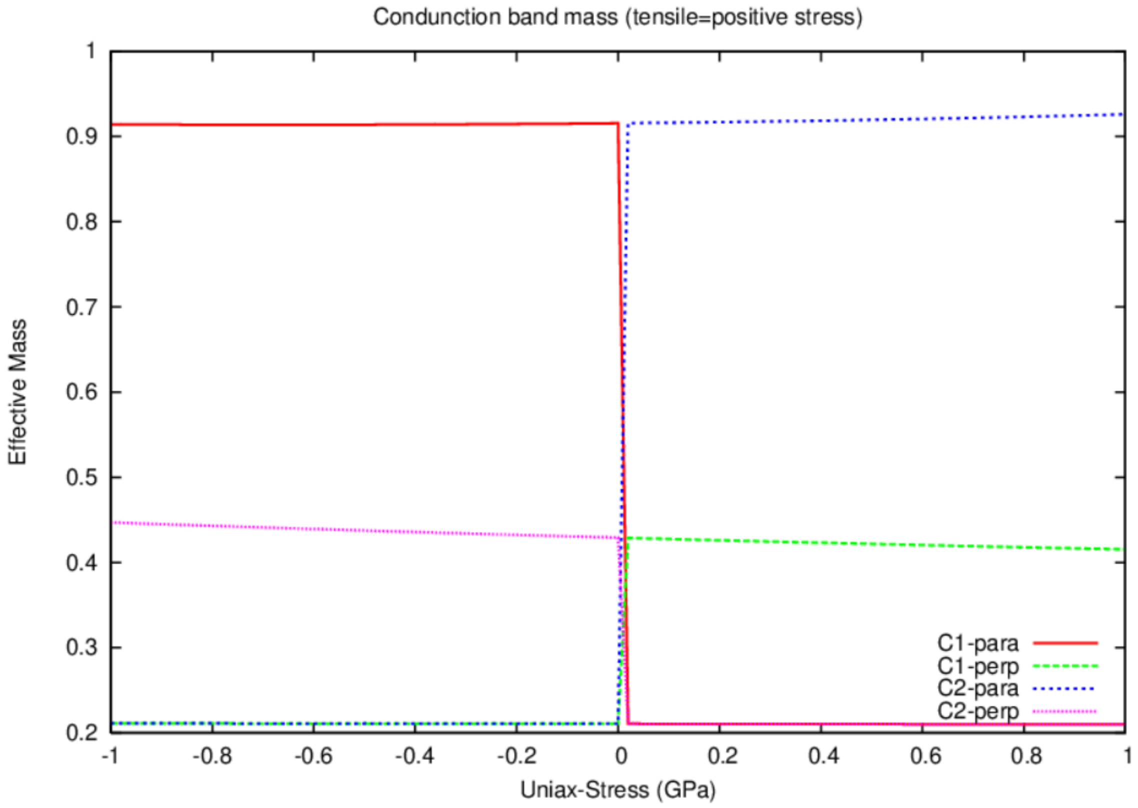
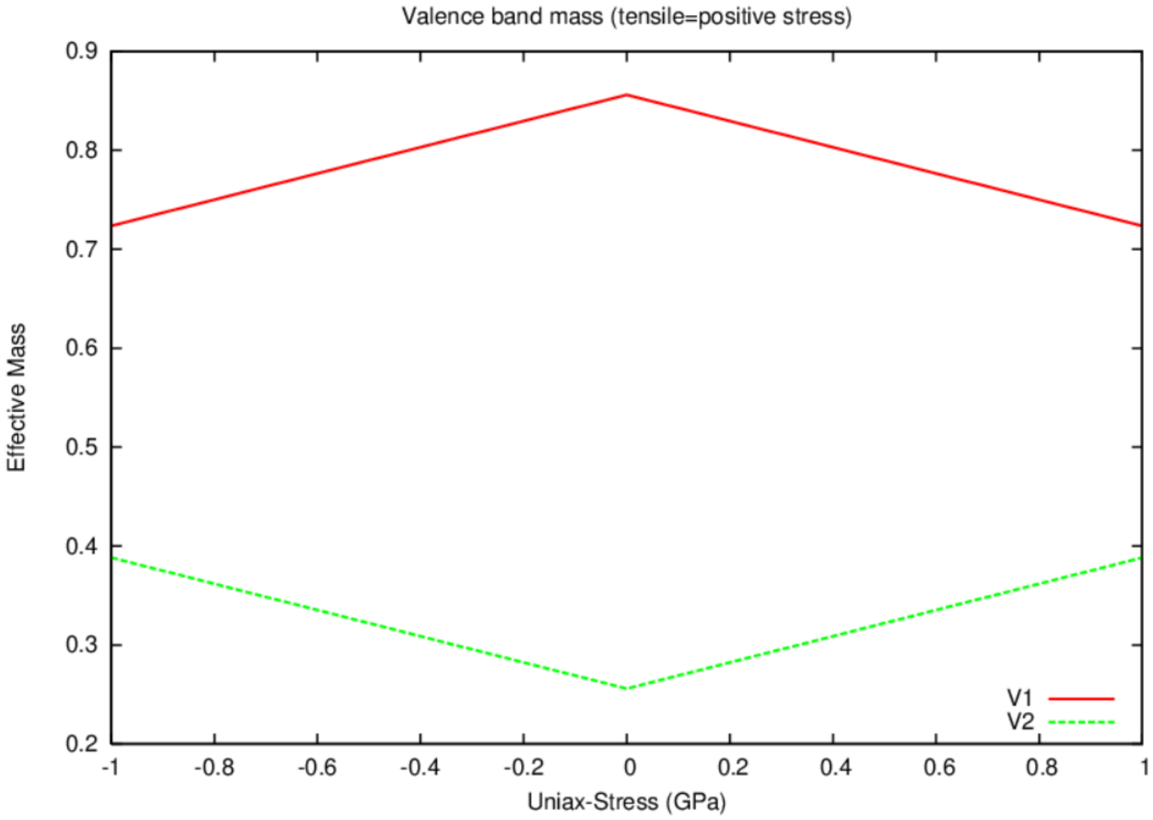
```
$ Main reference:
$ (for basic band structure)
$ [1] M.V. Fischetti and S.E. Laux, "Band structure, deformation
$ potentials, and carrier mobility in strained Si,
$ Ge, and SiGe alloys, J. Appl. Phys., vol. 80, pp. 2234-2252,
1996.
$
$ [2] "Electronic-band parameters in strained Si(1-x)Ge(x)
alloys on
$ Si(1-y)Ge(y) substrates,"  M. M. Rieger and P. Vogl,
$ Phys. Rev. B. Vol. 48, No. 19, 15 Nov. 1993, pp. 14276-287
$ To convert uniaxial strain to biaxial strain in the orthorgonal
$ direction, use eu=-D*eo where eo is the strain in a direction
$ orthorgonal to the uniaxial direction.
$
$ (for shear component of hole mobility enhancement)
$ [3] WANG et al., IEEE TRANSACTIONS ON ELECTRON
DEVICES, VOL. 53, NO. 8,
$ AUGUST 2006, p. 1840
$
$ (for shear component of electron mobility enhancement)
$ [4] CHIDAMBARAM et al.,
$ IEEE TRANSACTIONS ON ELECTRON DEVICES, VOL. 53,
NO. 5, MAY 2006, p. 944
$
```



Stress dependent effective masses



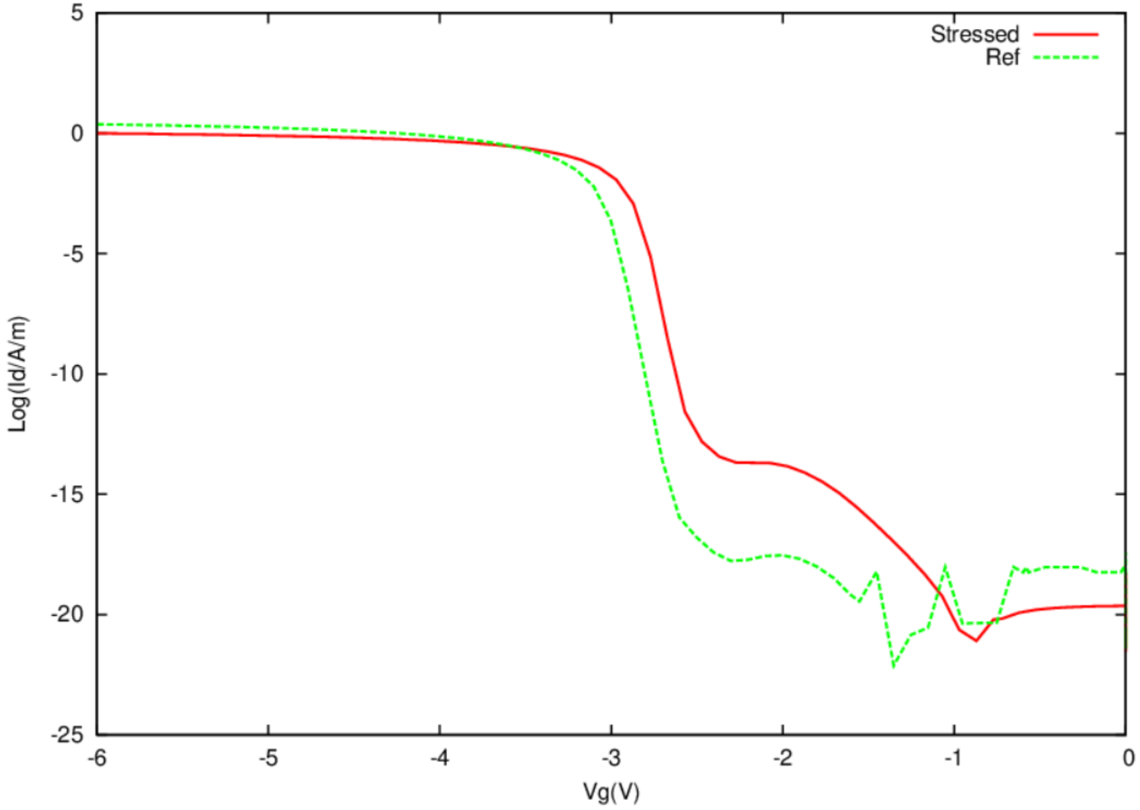


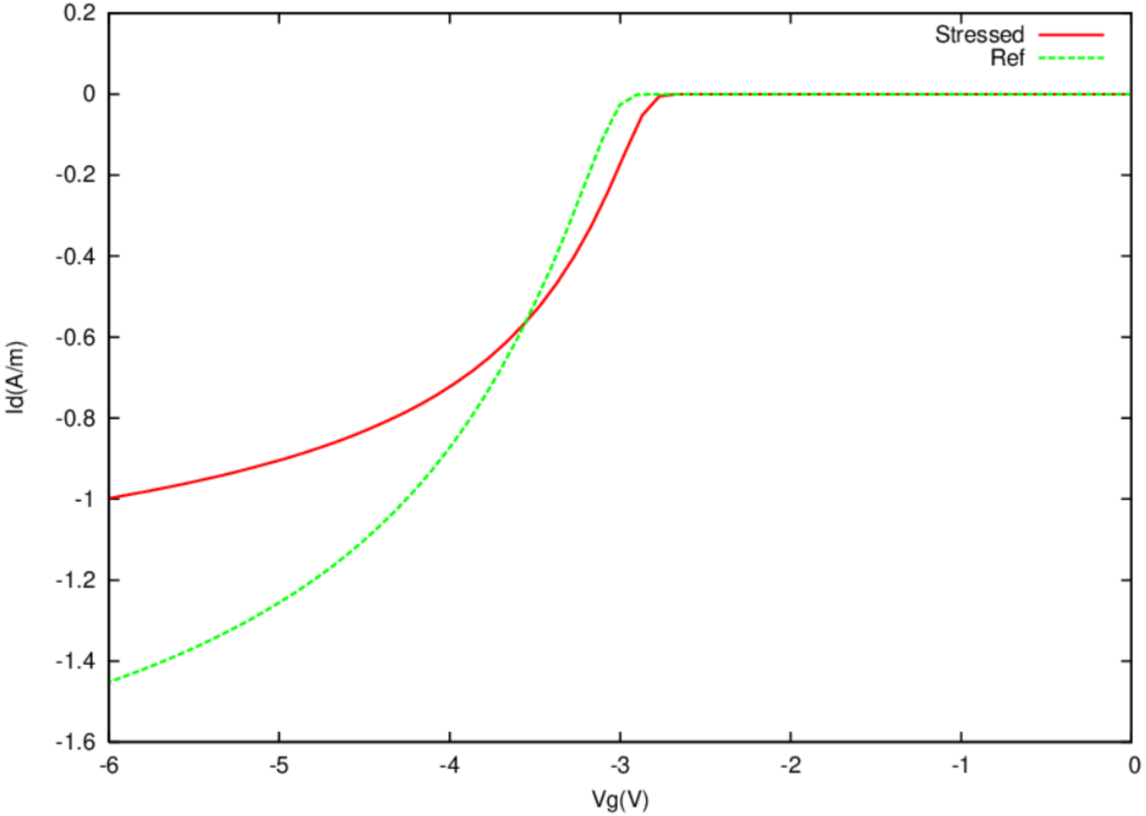
Stress induced mobility change is fitted to theory for single crystal silicon. In material macro presentation, these are stress dependent mobility factors

```
$ this is electron enhancement factor, stress unit = GPa
$ tensile stress enhances electron mobility
intern_func1 variation=table
table(stress_xx)
-1.     1.
0.      1.
0.5     1.4
1.      1.7
end_table

$ this is hole enhancement factor, stress unit = GPa
$ compressive stress enhances electron mobility
intern_func2 variation=table
table(stress_xx)
-1.     2.
-0.5    1.5
0.      1.
1.      1.
end_table
```

Vt shift has the same trend as experiment Using strained silicon theory based on material model fitted to kp theory





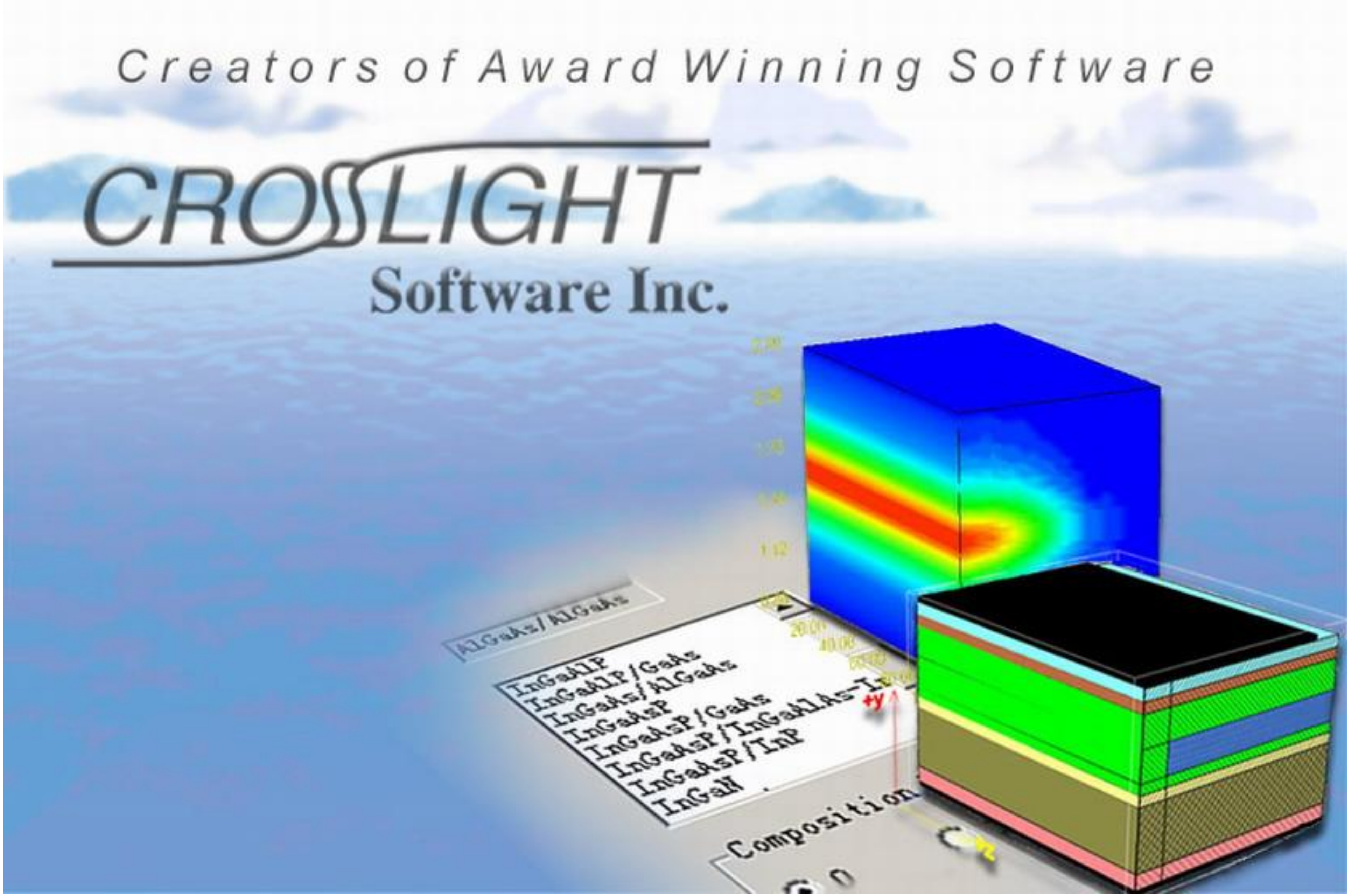
Summary

- ➢Crosslight provides convenient TCAD tools for simulating stress effects in TFT

- ➢While stress computation is relatively straightforward, the exact mechanism for Vt shift may be more complicated

- ➢Stress induced gate work function shift, strained microcrystal-Si, charged traps generation, doping deactivation can all be factor(s) and Crosslight TCAD can be a useful tool for analysis and design

Thanks for your attention!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CROSSLIGHT
Software Inc.
AlGaAs/AlGaAs
InGaAlP
InGaAlP/GaAs
InGaAs/AlGaAs
InGaAsP
InGaAsP/GaAs
InGaAsP/InGaAlAs-In
InGaAsP/InP
InGaN
Composition
+y
z