PS-10-15

Extended Abstracts of the 2018 International Conference on Solid State Devices and Materials, Tokyo, 2018, pp1265-1266

# Mechanical Bending Stress Simulation of Thin Film Transistor On Flexible Substrate

Debin Li[1], Sungwon Kong[2], Heetaek Lim[2], Andreas Hoessinger[3], Eric Guichard[2]

[1] Silvaco Japan.
Yokohama, Japan
Phone:+81-45-640-6188 E-mail:debin.li@silvaco.com
[2] Silvaco, Inc.
2811 Mission College Blvd
Santa Clara, USA

[3] Silvaco Austria
Rennweg 79-81, 1030 Wien
Vienna, Austria

**Abstract**

**The mechanical stress in a thin-film transistor on flexible substrate is an important problem for display device. The electrical performance is affected by the deformation stress when various deformation modes including bending and stretching are applied to film stack, or when those deformations are repeated on thin film device. There are few literatures to describe the mechanical stress calculation based on analytic calculations when bending moment is quite small and substrate is very larger than film thickness. These approaches are limited to small deformation and uniform bending, and therefore cannot be applied to devices on flexible substrates with large deformations under general bending conditions, which is the motivation behind the development of a comprehensive numerical stress model. We extend this simulation method to evaluate the impacts of the deformation induced stress on device performance.**

## 1. Introduction

During the past decade, numerical device simulation has successfully demonstrated various thin-film transistor devices such as a-Si:H, polysilicon, and IGZO (InGaZnO). A recent study shows that when the thin-film transistor device is fabricated on a flexible substrate or brittle layers for display application, it has stress-induced device degradation which changes the performance of device such as mobility, sub-threshold slope, and threshold voltage. The most common method to measure the stress is to bend the device on a flexible substrate by attaching it to circular shaped carrier [1] [2].

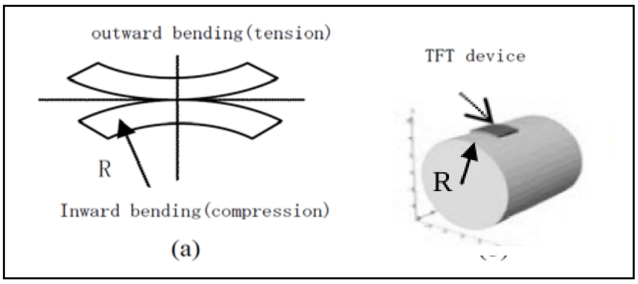


Fig. 1 (a) Tensile and compressive strain of film. (b) Bending test condition (actual TFT device is very small)

The inward bending causes tensile strain at the top and compressive strain at the bottom of the film. In the following, we define inward bending as a compressive strain and outward bending as a tensile strain. In uniform bending case, the strain in the device can be approximated by the following analytic equation.

$$\sigma = d/R \qquad (1)$$

Here, d is film thickness and R is bending radius.
This is only available when the structure is simple so that we can easily locate the neutral axis where stress is zero.

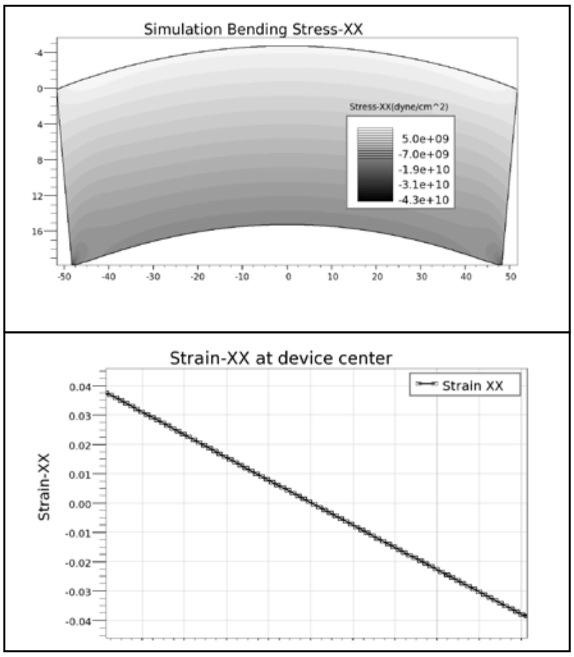


Fig. 2 Numerical simulation result(strain=3.76%) versus analytical calculation(strain =3.51%) at bending radius of 0.573 mm. Substrate is 20um thick polyimide(PI). Top is simulated two dimensional stress-x distribution and bottom plot is strain-x at device center ( x=0 ).

We obtained the two dimensional stress-xx distribution and one dimensional strain-xx value from numerical simulation at device in Fig. 2. We also compared the bending radius versus strain-x value in Fig. 3 which shows that simulation result is very close to analytic calculation given by equation (1) in this simple case. In this simulation, polyimide substrate thickness of 20 um is bended by applying moment at the both end of film with fixed angle. The bending radius is given by the arc length of angle with the assumption of fixed device length. The material is isotropic and each material has equal Poisson ratio. Details of numerical approach will be discussed in the upcoming article. Here, we demonstrate the real-world application using the newly developed numerical model for thin film transistor on flexible substrate and validated the result through published data.

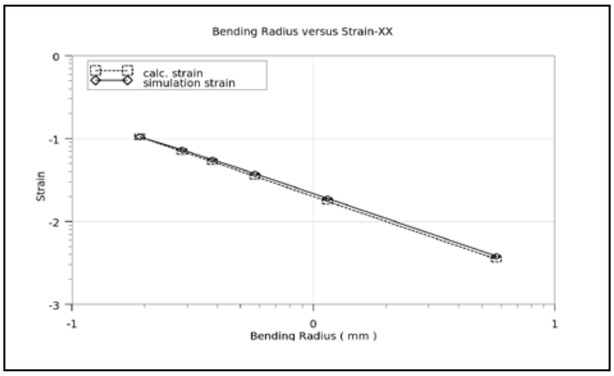


Fig. 3 Comparison of analytic strain versus numerical strain calculation.

## 2. Bending stress simulation

Figure 4 show that polymer dielectric IGZO TFT has smaller stress than SiNx dielectric IGZO TFT case. The polymer dielectric reduce the stress

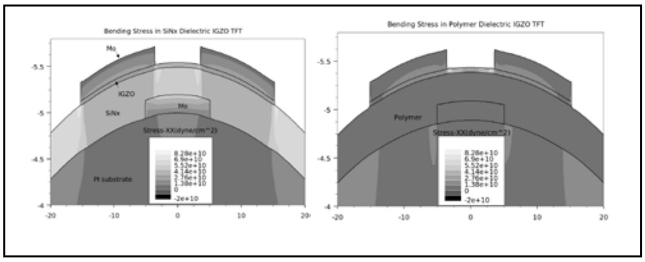


Fig. 4 Simulation result of SiNx dielectric IGZO TFT versus polymer dielectric IGZO TFT. Left is SiNx dielectric TFT and right is polymer dielectric TFT.

We simulated transfer curve of IGZO thin film transistor of compressive stress and tensile stress in Figure 5. Without additional details of physical explanation of microscopic change of material with stress, we believe that the reason why tensile stress show larger current than compressive case is related to reduced effective channel length shown by majority carrier. The inset plot shows the electron carrier distribution in tensile stress at the front channel ( IGZO/gate insulator interface) shorten the channel length and the drain current is increased in tensile stress case because of reduced channel length. In this simulation, the bending radius or angle of moment is exaggerated and in moderate condition the degree of drain current change would be very small without change of material parameters such as band gap or mobility.

We listed the simulation input parameters in Table I.

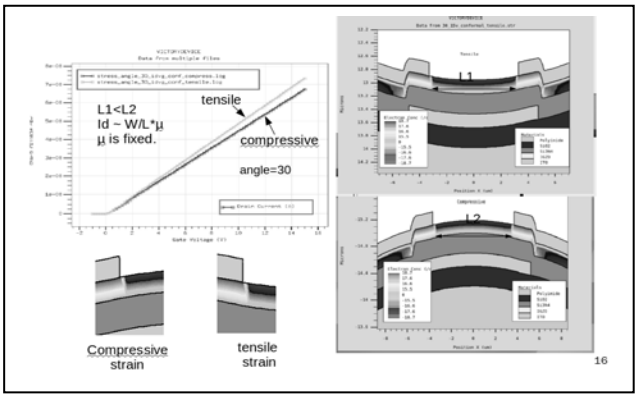


Fig. 5 Simulation result of transfer curve in compressive and tensile strain. Top right bended TFT is tensile strain and bottom right bended TFT is compressive strain. The electron concentration is plotted in IGZO channel region at Vg=15V and Vds=0.1. The constant mobility is used in this simulation.

TABLE 1. SIMULATION INPUT

| | Young's Modulus(dyne/cm2) | Poisson Ratio | Thickness(um) |
|---|---|---|---|
| IGZO | 1.37e12 | 0.36 | 0.05 |
| $SI_3N_4$ | 2.5e12 | 0.23 | 0.3 |
| Mo | 3.3e12 | 0.38 | 0.2 |
| Cr | 2.79e12 | 0.21 | 0.2 |
| SiO2 | 0.7e12 | 0.17 | 0.2 |
| PI | 0.29e12 | 0.34 | 10 |
| Polymer | 2e10 | 0.34 | 0.3 |

## 3. Conclusions

We have applied a new simulation method for bending induced stress to the analysis of thin film transistor on a flexible substrate. The numerical simulation results show good agreements with the linear deformation approximation in case of very large bending radius and uniform bending conditions. Since the analytic solutions cannot be used in the most application areas with general bending conditions, it is inevitable to use numerical approaches. We demonstrated that we can evaluate the impact of the bending stresses obtained from different dielectric materials on polyimide substrate. Given the mechanical properties, we can predict the optimum material stack, thickness, and size to relieve the film stress through comprehensive numerical simulations. We will extend this general numerical model to include other deformation modes such as torsion that must be considered to fabricate a device on flexible substrate.

## References


[1] Zhang Yong-Hui et al,. "Review of flexible and transparent thin-film transistors based on zincoxide and related materials", Chinese Physics B.

[2] Mohammad Masum Bilah, Md Mehedi Hasan, Jin Jang, "Effect of Tensile and Compressive Bending Stress on Electrical Performance of Flexible a-IGZO TFTs, IEEE Electron Device Letters, Vol. 38, No. 7, July 2017.

[3] Kinkeldei et al., IEEE Electron Device Lett. 32, 1743 (2011)