TCAD Calibration: Challenges and Opportunities

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http:// www.eden.com / ~naomi / tcad

What is TCAD?

T: Tweaking
C: Constants
A: All
D: Day

David Ziskind, 7/24/97

Goals of this Presentation

Reduce allure of “Predictive TCAD”.

Call for common calibration procedures.

Point out some research opportunities.

Outline

How TCAD is used - accuracy requirements.

Why calibration is so difficult.

Is TCAD “predictive” yet?

User needs.

TCAD Accuracy versus Application

Application	Accuracy Required	Comments
Predictive TCAD	Very High	Elusive Goal
Advanced Process Control	High	Provide Macro Models
Process Centering	High	Mature Product
Inverse Modeling	High	Extracting Coefficients
Early Exploration	Medium	Reduce Splits
Failure Analysis	Medium	Test Probable Causes
Learning/Insight	Low	High ROI

Table I: TCAD application, rank-ordered by accuracy required.

Top of the table gets all the attention, bottom of the table does much of the work.

(My favorite TCAD slide)

Time Dependence of Accuracy

Different people do different things with TCAD, and the same person might do different things at different stages in development.

TCAD should be AHEAD of the roadmap.

For each technology node, different levels of accuracy are needed at different points in time.

“The right accuracy at the right time” - Ron Goossens

Calibration in Practice

Tweaking Constants All Day.

Every engineer has his own favorite coefficients.

Calibration is done on a very local scale.

Measurements assumed to be perfect.

Repeat as necessary.

Knowledge Required for Calibration

Specialization	Example Problems
Process/Device	Must know complete flow and process/device physics.
Fab Equipment	Implant temperature affects TED; “local” RTA temperature.
Electrical Test	Electrical versus optical oxide thicknesses (QM effects).
Analytical	SIMS knock-on; SRP probe pressure.
Metrology	Uncertainty in poly length and oxide thickness.
Simulation	Model limitations; grid dependence.

Table II: Knowledge required for TCAD calibration

Difficult to find all this knowledge in one place.

More awareness needed of the various sources of error.

Total Error

Desired *control* on Idsat is less than 10% (3 sigma).

Therefore, *predictive* TCAD needs 2-3% total error.

Assume *only* ten sources of error:

Ten	1%	errors gives	3.2%	total error.
	2%		6.3%	
	3%		9.5%	
	5%		16 %	
	10%		32 %	

A Few Error Examples

Power supply voltage was 0.102 volts, not 0.1 (still within spec) - leads to a 2% error in drain current.

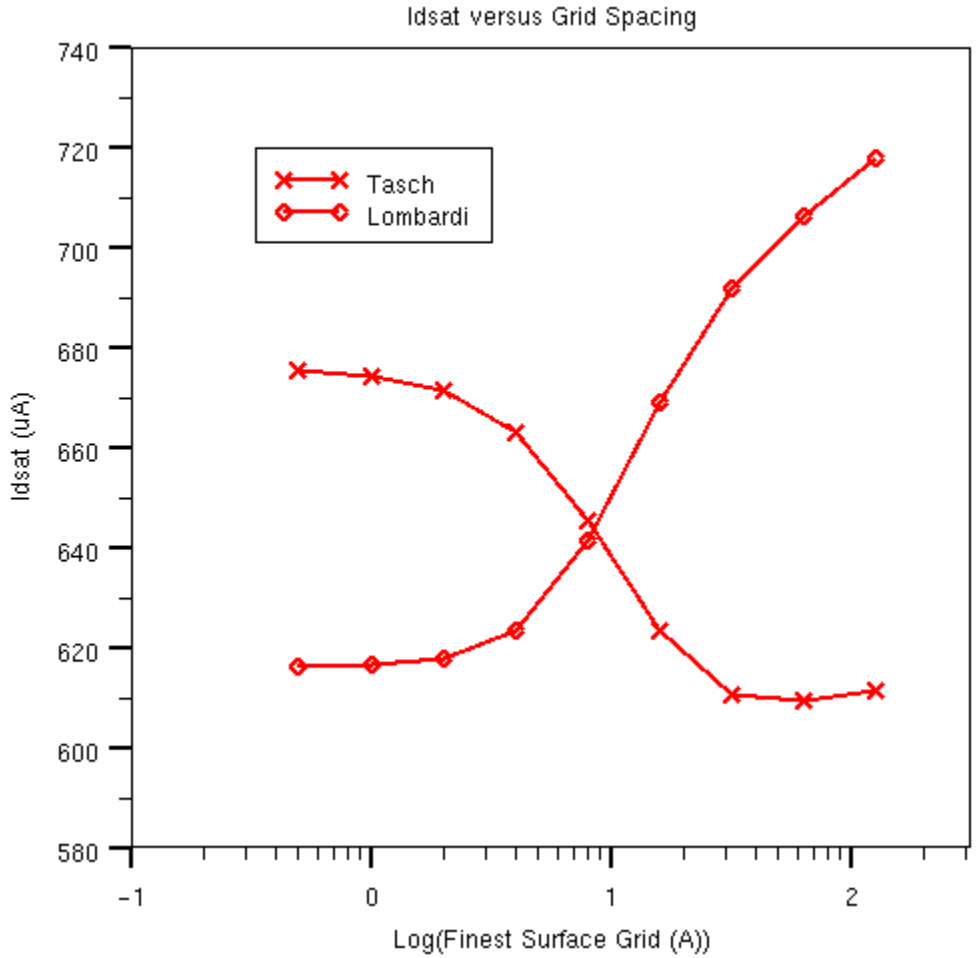
1 volt variation in AC voltage leads to 6 degree change in RTA temperature.

Un-monitored parameters.

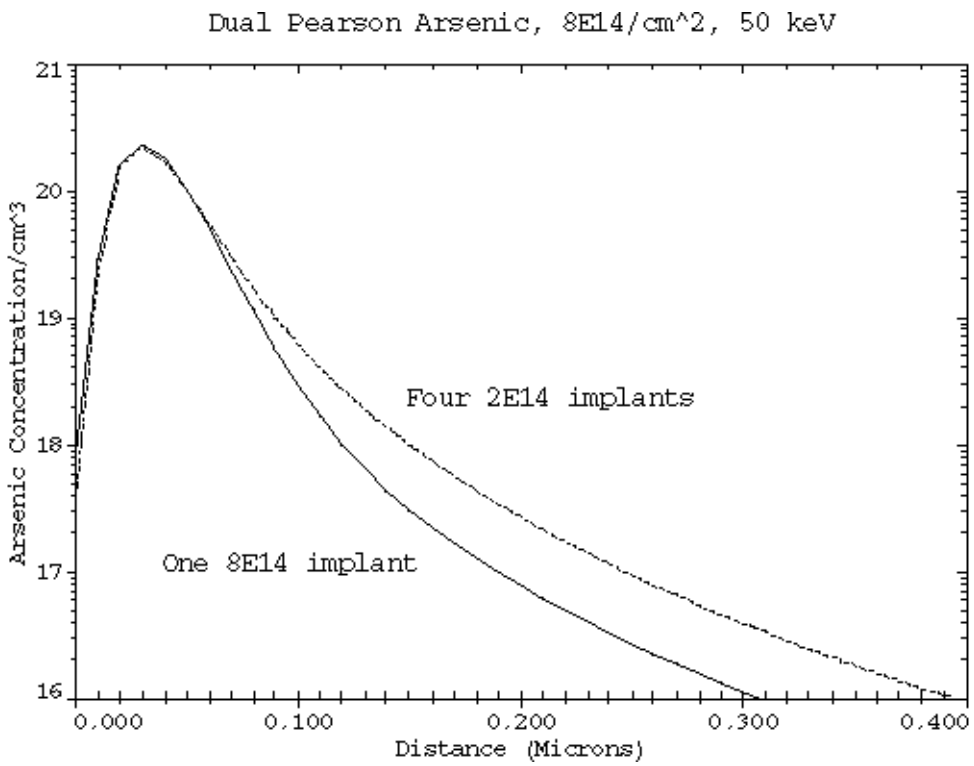
1% accuracy in Lgate or Tox very difficult at 0.25 μm.

One of the largest sources of error is the grid!

Grid Error

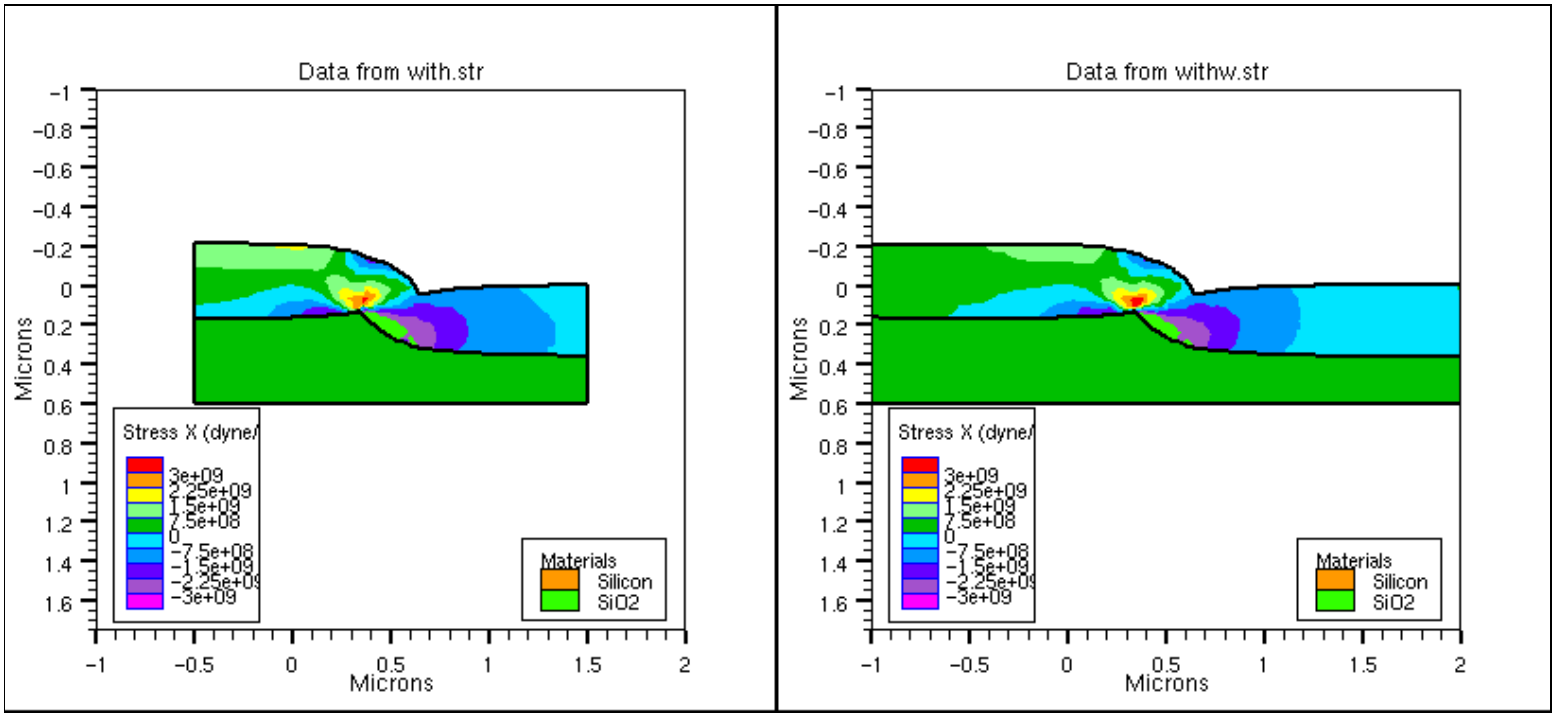

Idsat versus Grid Spacing
740
720
700
680
660
640
620
600
580
Idsat (uA)
Tasch
Lombardi
-1
0
1
2
Log(Finest Surface Grid (A))

Model Error



Channeling tail was not dose dependent in early version of Dual Pearson

Boundary Condition Error



Narrow structure had different oxide thickness on extreme left and right edges. X-component of stress was non-zero.

Is TCAD Predictive Yet?

Above question recently asked by a CEO.

Presumes that predictive TCAD is achievable.

Metrology analogy: can we measure linewidths yet?

1 μm - yes; 0.1 μm - not as well .

“Predictive” is ambiguous.

What do we mean by “predictive”:

> Accurate simulation of current technologies,
> or of future technologies?

The latter definition is often assumed, especially by TCAD *customers*, and may be impossible.

“Prediction is difficult, especially about the future.”
Yogi Berra

Predicting Future Technologies

Technology is always changing, as is the detail of physics required to understand it:

> Law's law: in TCAD, the most complicated explanation is probably the correct one.

Our ability to be "predictive" is limited by our physical understanding, which in turn is limited by our metrology.

TCAD is not predictive

Vt is a basic MOS parameter, yet the following are not modeled very well:

Dopant dependence of poly workfunction.
Dopant diffusion in poly.
Dopant diffusion through gate oxide (BF2).

If Vt can’t be predicted, then TCAD is not predictive.

Some of the basics have been overlooked

N-type segregation coefficient is 30 - *independent of dopant species; substrate orientation; oxidation time, temperature or ambient!*

I'll be more interested in "dynamic transient release of interstitial point defects" and "dislocation loop based interstitial sink models" after the basics (segregation, solid solubility) have been updated.

Top Needs from a User Perspective

Top Needs from a User Perspective
More rapid commercialization of new models (co-development of the models as well as more rapid model transfer).
Generally accepted calibration procedures.
More TCAD *users* and *customers* on TCAD steering committees.
More open software (vendors don't want this, but we know what happens to closed software systems).
Round-robin studies / benchmarking. What are the current error bars?
Better equipment-specific models.
TCAD developers need access to state-of-the-art data.

Table III: TCAD needs from a user perspective.

Currently, the burden of testing falls on each user.

Feedback to TCAD from Process Integration

Need user pull, not developer push.

Need a better telescope, not a better microscope.

Don’t need more coefficients in models.

How can TCAD be used to build better *circuits* ?

Manufacturing control may be larger than TCAD metrics.

(SEMATECH 1994)

TCAD Calibration Needs

TCAD Calibration Needs
Hierarchy of models and calibration (atomistic, continuum, compact ...)
Need calibration method with any new model.
TCAD-specific test structures / metrics / test-suites.
Ab-initio calculations of key coefficients.

Table IV: Calibration Needs

Many of these are pre-competitive.

Hierarchy of Models and Calibration

The goal of ab-initio simulations is to provide better coefficients to continuum models.

Trend is always towards more rigorous models,
but quick response is often important (simpler models).

Need a hierarchy of simulation tools; the trick is knowing when a given model is sufficient for your needs.

"Dial-an-error"

Calibration Methods

New SPICE models also come with a coefficient extraction procedure - good practice to follow.

Are there TCAD-specific test structures? (preferably ones that use the nominal process).

Would like a set of standard examples that we could benchmark against.

2D Dopant Metrology

A complex subject, which deserves it's own talk.

But a couple of quick points:

- Inverse modeling may be our best hope.
- There are not many dopant atoms near the junction (1E18/cm3 --> average dopant spacing of 100 A)
- Dopant statistics will probably hit us sooner than we expect.

TCAD User's Group
(originally presented in conjunction with 1989 IEDM)

Want to form a network of users/developers of TCAD tools to:

prevent re-discovery of bugs.

combine tuning/calibration efforts.

provide direction for code developers.

share evaluations of TCAD software.

share solution methods to common problems.

raise the importance of TCAD.

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Problems with current situation:

Too many programs; not enough manpower to evaluate.

Programs not useable by non-experts (even SUPREM3).

TCAD is mostly a novelty.

Total task time >> CPU time (100x or more).

The only item that has changed is that TCAD is no longer a novelty. However, there still are many skeptics.

Task Time

CPU time is important; the upper limit on allowable time is often “overnight”.

However, for any new problem, there can be many “false starts”.

Therefore, the total task time is usually much longer than the CPU time of the actual “final” simulation.

CPU time isn’t the whole story.

Summary

Need *much* better metrology for predictive TCAD, which could include inverse modeling. However, ...

“The purpose of computation is insight, not numbers”
Richard Hamming.

TCAD is not a show-stopper - issue is how to make it more valuable.

Strong need for cooperation in calibration.