Detailed Comparison of the SP2001, EKV, and BSIM3 Models

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ABSTRACT

Practical comparisons are made of three available or soon to be available compact MOS models----SP2001 (surface potential 2001), EKV, and BSIM3. They are compared both in their DC and AC quality of fits to measured data, including Id-Vg, Id-Vd, Gm-Vg, Gds-Vd, and C-V curves. Also included are curves of Gms/Is versus log Is. The comparisons are meant to show weaknesses and strengths of each particular model so the user community can decide which model is appropriate for their use.

Readers should note that the quality of fit is not the only criterion for choosing a compact model. Ease of parameter extraction, correlation of parameters, number of parameters, redundancy of parameters, and wild model behavior should also be considered. We touch on these features as well.

Keywords: surface potential, EKV, BSIM3, compact model

1 INTRODUCTION

We extracted nominal DC sets of parameters for three models, SP2001, EKV, and BSIM3 on our standard 0.13U technology. The parameter extraction program ICCAP from Agilent was used to do the extractions for SP2001 and EKV. These two models were implemented in Mentor Graphic's Eldo circuit simulator, which is called by ICCAP during the parameter extraction process. Utmost was used to extract the BSIM3 model parameters.

The EKV model is the quickest to extract, not surprising since it has the fewest number of parameters. The SP2001 model is the next easiest, with BSIM3 being the most difficult. In all cases, we obtained a single global model covering the entire geometry space (no binning). The EKV model took a few hours, SP2001 took two days, and BSIM3 took 5 days to extract. We followed our own extraction strategies, not using any canned routines in ICCAP or Utmost.

SP2001 is the most physically based model since it solves the Poisson equation directly through quite accurate and fast numerical approximation methods. The model has a total of 65 DC parameters, of which we used only 33.

The EKV model has 22 DC parameters and we used all of them. The EKV model is less physical than SP2001, but much more so than BSIM3. The model is relatively easy to extract because there are few parameters and the correlation between them is quite low.

The BSIM3 model has been available for a long time and needs little introduction. Suffice to say that for BSIM3 we used about 95 DC parameters out of a total of over 400 (if binning is used). Many of these parameters are highly correlated, making the extraction process quite tedious.

2 DC FITTING RESULTS

We now examine various quality of fits for all three models. Although the quality of fit depends on who does the fitting, we tried to avoid any prejudice in the extraction of all three models. The comments below can be considered to be quite general and not dependent on our particular skills in curve fitting. Note that due to page limits on this publication, only a very few of the hundreds of plots that will be shown during the conference presentation can be included here.

2.1 Id vs. Vg, Id vs. Vd, etc.

In all cases, Id vs. Vg, Id vs. Vd, Gm vs.Vg, and Gds vs. Vd the SP2001 model fits better than the other two. BSIM3 fits better than EKV, but this is to be expected since EKV has far fewer parameters than BSIM3. However, in most cases the EKV model fits reasonably well and in many cases quite well.

The BSIM3 model is notorious for not fitting wide-long Id vs. Vd curves very well at high Vg. This is due to the peculiar use of the Abulk term. Both SP2001 and EKV fit the Id vs. Vd curves for wide-long devices better than BSIM3.

The EKV model, version 2.63, has a problem fitting Id vs. Vg at both low and high Vd. If you fit at high Vd, you can't fit well at low Vd, and vice versa. This is a problem in the DIBL formulation of EKV2.63. The newer EKV3.0, which will be released sometime in 2002, fixes this problem.

The BSIM3 model is also well known for producing completely wrong characteristic curves if model parameters are not chosen carefully. Much of this problem has been overcome through the years by restricting the range of parameter values, but it is still possible to get wild results out of BSIM3. Both the SP and EKV models are extremely well behaved with no such problems. All curves are smooth and without glitches.

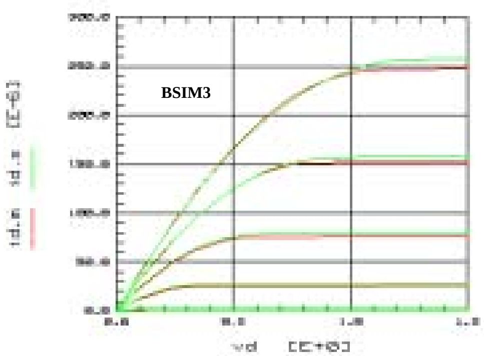

Figure 1: Id vs. Vd, BSIM3, N-ch, W/L=10/10, Vbs=0V, Vgs=0.3V to 1.5V.

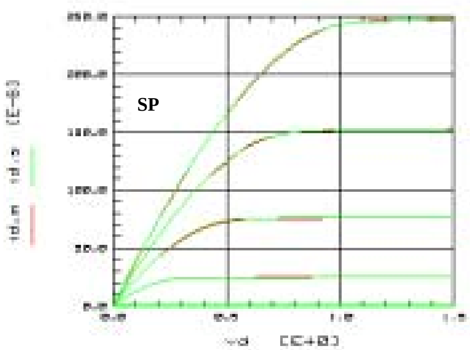

Figure 2: Id vs. Vd, SP2001, N-ch, W/L=10/10, Vbs=0V, Vgs=0.3V to 1.5V.

2.2 Gms/Is vs. Log Is

We now consider Gms/Is vs. log(normalized Is). Gms is defined as the derivative of Is with respect to Vsb (Is being the source current). The curves were obtained by tying Vgb=Vdb=0.5v, Vb=0v, sweeping Vsb from -0.2 to 0.5v, measuring Is. The reason for this peculiar way of doing the sweep is to go through all regions of operation, from weak, through moderate, and into strong inversion.

The x axis is plotted as a log, and we normalize the current Is as follows [3]:

Is(norm.) = Is / (n0 * k0 * vt * vt)

,where
n0 = subthreshold slope factor (close to 1.0)
k0 = u0 * Cox
u0 = mobility
Cox = oxide capacitance/unit area
vt = kT/q

WARNING: Because we plot Gms/Is vs. log Is, the x axis values are measured or simulated values, and thus will be different for measurement and simulation. Be sure you plot Gms(meas.)/Is(meas.) vs. log Is(meas.) and Gms(sim.)/Is(sim.) vs. log Is(sim.).

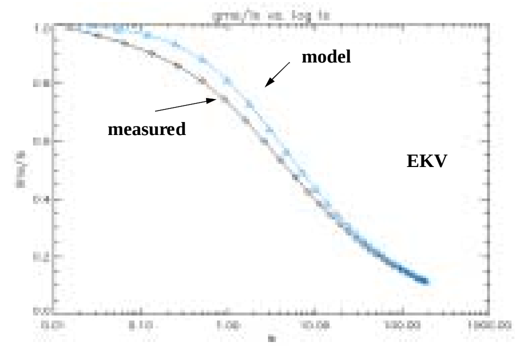

Figure 3: Gms/Is vs. log Is, EKV, N-ch, W/L=10/10, Vsb=-0.2v to 0.5v, Vgb = Vdb = 0.5v.

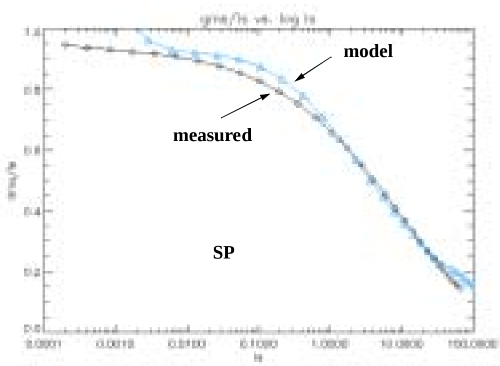

Figure 4: Gms/Is vs. log Is, SP2001, N-ch, W/L=10/10, Vsb=-0.2v to 0.5v, Vgb = Vdb = 0.5v.

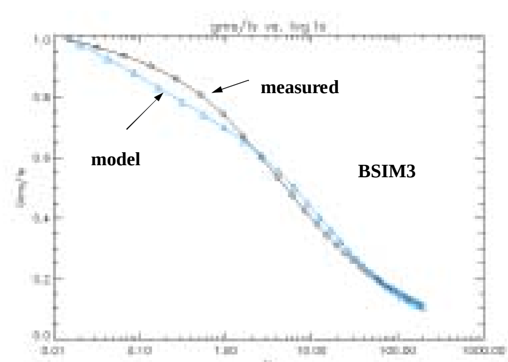

Figure 5: Gms/Is, BSIM3 vs. log Is, N-ch, W/L=10/10, Vsb=-0.2v to 0.5v, Vgb = Vdb = 0.5v

The Gm/Is vs. log Is curve for EKV has the proper shape and asymptotic behavior (this is no accident; EKV was designed to have this behavior). The SP2001 curve is not quite as good as EKV, but is still correct. The BSIM3 curve is misbehaved, crossing the measured data curve.

3 AC FITTING RESULTS

The BSIM3 model is well known for having very bad intrinsic mosfet capacitance behavior. Both EKV and SP2001 have very similar correct behavior. Therefore, we show only a few results here comparing BSIM3 with EKV (the SP2001 curves look just like the EKV curves). Note that all capacitances plotted are normalized (divided by Cox) [6].

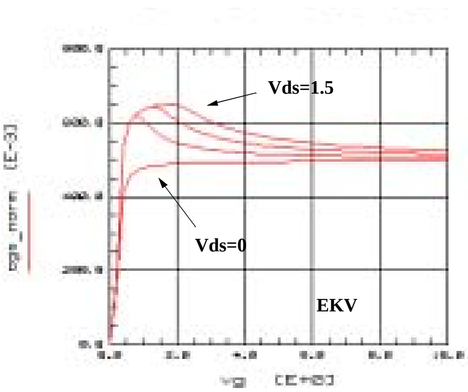

Figure 6: Cgs vs. Vg, EKV,N-ch,W/L=10000/10,Vbs=0,Vds=0 to 1.5v.

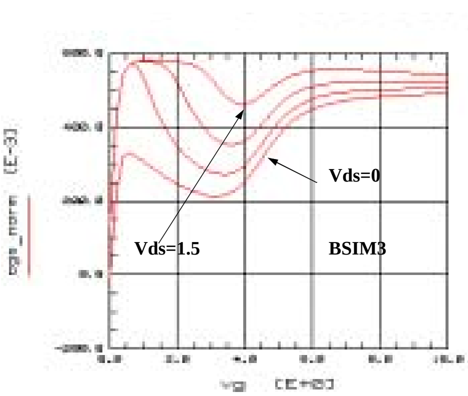

Figure 7: Cgs vs. Vg, BSIM3,N-ch,W/L=10000/10,Vbs=0,Vds=0 to 1.5v.

The completely wrong behavior of the Cgs vs. Vg curves for BSIM3 is due to the Ngate parameter. It is possible to get BSIM3 curves to behave better, but this is an example of how things can go wrong in BSIM3. No such behavior is seen in EKV or SP2001.

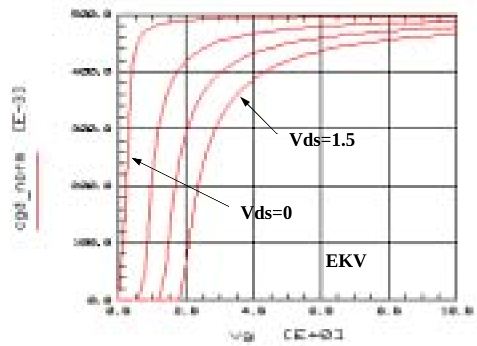

Figure 8: Cgd vs. Vg, EKV,N-ch,W/L=10000/10,Vbs=0,Vds=0 to 1.5v.

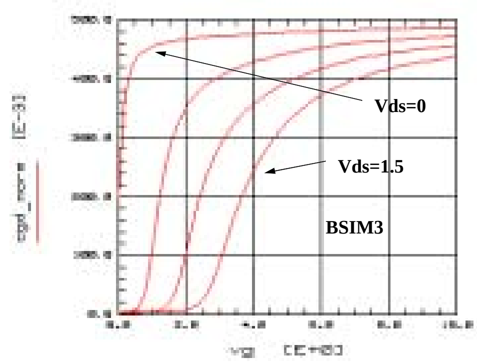

Figure 9: Cgd vs. Vg, BSIM3,N-ch,W/L=10000/10,Vbs=0,Vds=0 to 1.5v.

The EKV (and SP2001) Cgd vs. Vg curves have the correct shape and go to zero where they should. The BSIM3 curves have the correct shape, but the Vds=0 curve is non-zero at Vg=0, which is incorrect.

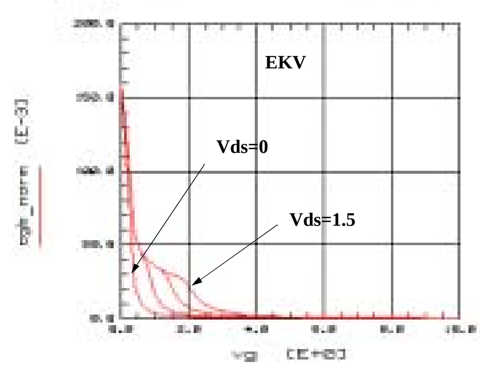

Figure 10: Cgb vs. Vg, EKV,N-ch,W/L=10000/10,Vbs=0,Vds=0 to 1.5v.

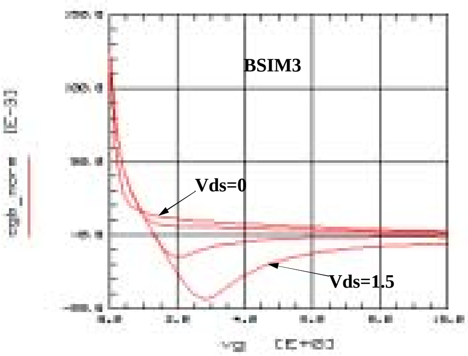

Figure 11: Cgb vs. Vg, BSIM3,N-ch,W/L=10000/10,Vbs=0,Vds=0 to 1.5v.

The EKV (and SP2001) Cgb vs. Vg curves have the correct shape and asymptotic dependence. The BSIM3 curves have completely incorrect shapes, and go negative. The asymptotic behavior approaches zero as they should, however.

4 SUMMARY

For all DC fitting, the SP2001 model is clearly superior to BSIM3. Gms/Is vs. log Is is debatable, although SP2001 seems somewhat more physical than BSIM3. The EKV model does not fit DC curves as well as SP2001 or BSIM3, but for a model with a small number of parameters it fits better than expected. In addition, EKV fits Gms/Is vs. log Is better than all the other models.

SP2001 and EKV are far better behaved than BSIM3. Typical Id vs. Vg and Id vs. Vd curves don't go ballistic as easily as BSIM3 can if one is not extremely careful.

The intrinsic capacitance models in BSIM3 are severely broken. Non-physical and just plain wrong behavior is seen in many areas of capacitance for BSIM3. Both SP2001 and EKV show none of these problems.

Due to the large number of parameters and strong correlation between many of them, the BSIM3 model is quite difficult to deal with for parameter extraction. It can take an experienced BSIM3 model builder about one week to extract a single model (one polarity only). SP2001 is easier to use than BSIM3, but it is by no means trivial to extract model parameters for SP2001 either. EKV is the easiest model to use.

And finally, due to printing restrictions, we have not covered other modeling areas such as Vth vs. L, model interpolation, and extension to future technologies. These will be covered in the live presentation. There it will be shown that SP2001 and EKV equal or surpass BSIM3 in all these areas.

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