Slide 1

Handling Silicon substrate effects in EM simulators

franz.sischka@agilent.com
7.12.2004

Slide 2

Introduction:

difference between Substrate Loss Tangent and Substrate Conductivity with respect to device modeling

In Momentum, there are 2 ways to specify losses in the substrate:
- eps-r and Loss Tangent
- eps-r and Conductivity

Behind the two choices are two different equivalent schematics.
We begin with a little case study on a very simple structure: a piece of substrate between two ideal metal plates. Each metal plate serves as an S-parameter port. We apply here the Momentum Single Ports, which represent calibrated ports.

As a starting point, we get the Sxx and Sxy for eps-r=4 and no substrate losses. This will be the reference curves.
Specifying a loss tangent of 50m, we see that the starting point of $S_{xx}$ is not affected, but its end point towards infinite frequency is affected. This means that the underlying schematic is represented by a $C$ in series with a $R$. And $R$ represents the loss tangent.

Now, we investigate the effect of conductivity. To commence, we have conductivity=0 in the slide above.
Specifying conductivity = 200m, we see that the starting point of Sxx is now affected, but its end point for infinite frequency still tends towards 0 Ohm. This means that the underlying schematic is represented by a C in parallel with a R. And R represents the conductivity.

We can now overlay these two effects and end up with a silicon structure as shown above, and a resulting Sxx curve.
The slide above re-emphasizes the interpretation of the metal-SiO2-Si-metal schematic, from DC to infinite frequency, from a modeling engineer's standpoint.

Now, we bend the SiO2-Si structure and end up with the GSG-contacted (Ground-Signal-Ground) pad structure for Port1 and Port2 of typical on-wafer measurements.
We are now ready to discuss the right settings and optimization/tuning steps for the substrate parameters in Momentum. We will start with a typical OPEN Dummy structure as depicted above. 

Slide 12

**the following studies refer to this**

**GSG OPEN Dummy structure**

**top view**

pads: 150um x 150 um
As a first experiment, we check if there is an influence of a floating chuck (wafer) compared to a grounded chuck. Since the EM-fields are 'around' the GSG structure in metal1, and if we keep in mind that a typical wafer thickness is 0.5mm .. 0.8mm, and the SiO2 thickness is 0.5um .. 0.8um, it becomes clear that the ground contact of the chuck is negligible for our further considerations.

The substrate parameters shown above and the resulting Sxx and Sxy plots are the reference for our further investigations.
Varying the losses of the SiO2 does not exhibit an influence for small frequencies.

However, as expected, the losses (tangens delta) in the SiO2 show up for infinite frequencies.
As expected, the conductivity of the silicon wafer material determines the knee in the Sxx and Sxy plots.
The silicon wafer epsilon is responsible for the phase shift after the knee.

The SiO2 epsilon is responsible for the phase shift at low frequencies, below the knee.

Note: If there is no knee visible, both capacitors are in series and the smaller of them becomes the dominant one: the eps-r of the silicon wafer.
This slide wraps-up the results from before.

Slide 22
Application Example

- an OPEN Dummy structure was measured between 100Mhz and 10GHz

- only raw values for the eps-r were available, no good estimates on the Silicon conductivity and the tangens-delta of the SiO2

- a first Momentum simulation was executed, with the results below:

  the plots shows a mismatch
  - at f->0 (epsr-SiO2)
  - at the knee (conductivity Silicon)
  - f->10GHz (epsr_Silicon)

Application Example (cont'd)

following the relationship between the data and the substrate properties developed earlier, the substrate parameters were fine-tuned and the following result was obtained:
Conclusions

A good understanding of the physical meaning of the substrate specification parameters and a fine-tuning/optimization of their values gives very accurate, calibrated EM simulation results.
Appendix

lumped components modeling

as a side aspect, the Momentum simulation results were modeled with a lumped component schematic in ADS and the fitting was verified. The following slides depict the result.

Lumped Circuit Modeling Verification

Spar -> Ypar -> Zin, Ztrans, Zout

! visualization of impedance Zin = 1/Yin
! convert S -> Y
Y=TwoPort(S,"S","Y")
! calculation of input conductance
Yin=Y(11)-.5*(Y(12)+Y(21))
! return input impedance
RETURN Yin^-1

! visualization of impedance Ztrans = 1/Ytrans
! convert S -> Y
Y=TwoPort(S,"S","Y")
! calculation of input conductance
Ytrans=-.5*(Y(12)+Y(21))
! return input impedance
RETURN Ytrans^-1

! visualization of impedance Zout = 1/Yout
! convert S -> Y
Y=TwoPort(S,"S","Y")
! calculation of input conductance
Yout=Y(22)-.5*(Y(12)+Y(21))
! return input impedance
RETURN Yout^-1
Lumped Circuit Modeling Verification (2)

Momentum (M) vs. ADS Simulations (S)

Lumped Circuit Modeling Verification (3)

Momentum (M) vs. ADS Simulations (S)