New Parasitic Capacitance Modeling in *Hipex-C*

Introduction

In deep submicron technology, conduction layers have widths much smaller than their thicknesses (see Figure 1). This makes edge parasitic capacitance effects more dominant than plate capacitance.

In a multi-body system, neighboring conductors may capture some or all of the electrical fields lines emanating from a particular conductor. These field lines would otherwise terminate else where. This phenomenon is called charge sharing, which plays an important role in modeling parasitic capacitances.

This article presents new approaches to dealing with charge sharing and vertical shielding in Silvaco's parasitic capacitance extraction tool, *Hipex-C*. The three main
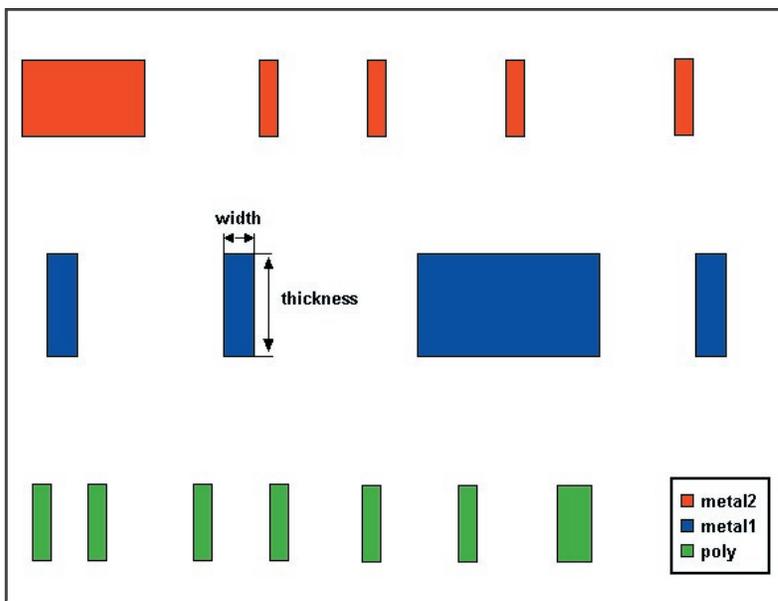

Figure 1. Cross-sectional view of a chip.

commands in *Hipex-C*, FRINGE, LATERAL and AREA, cover all of the capacitance calculation requirements that one would expect from a industry leading capacitance extraction tool. FRINGE enables edge-to-body, LATERAL enables edge-to-edge and AREA enables plate capacitance modeling.

All the commands allow one to specify different capacitance coefficients for different vertical configurations of the primary layers to account for charge sharing effects. The layers above or below or both the primary conductor(s) define the vertical configuration.
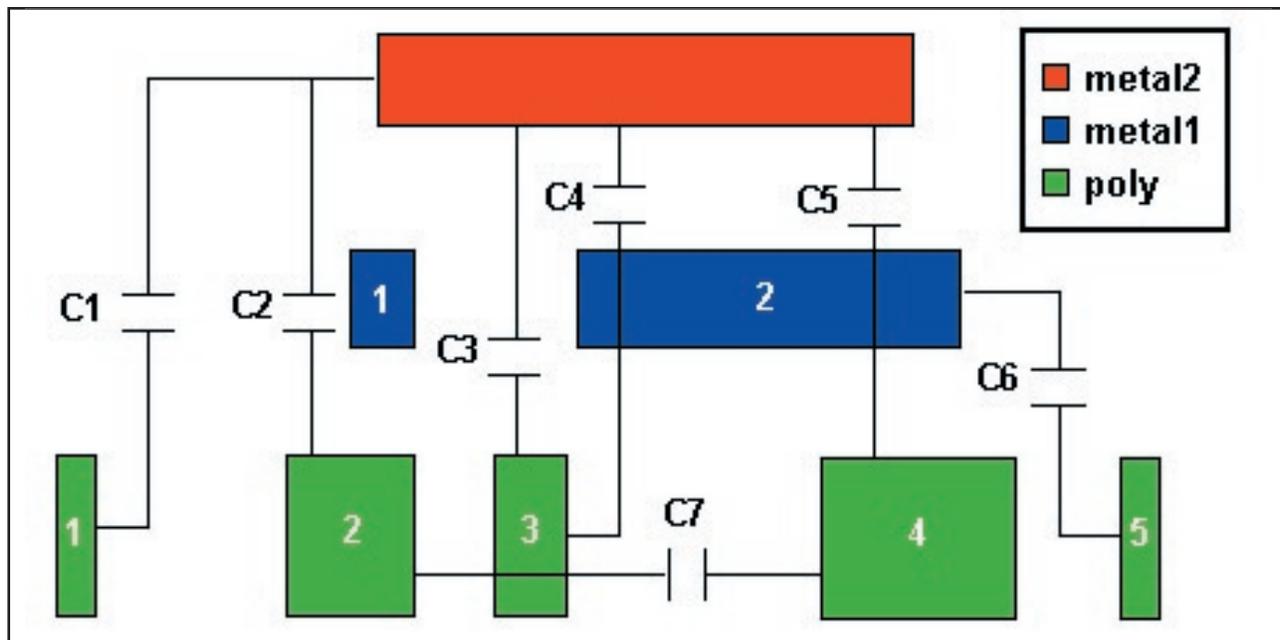

Figure 2. Vertical shielding example (cross-sectional view)

Vertical Shielding

Vertical shielding is caused by the vertical order of layers. When more than two conduction layers overlap, the inside layers shield the capacitance effects between the outer layers, Figure 2. demonstrates the effects of vertical shielding.

Note the following vertical shielding effects for primary layers `metal2` and `poly`:

- The first `metal1` shape is shielding the `metal2` edge from the edge of the first `poly` shape (lateral C1) and the body of the second `poly` shape (fringe C2)

- The second `metal1` shape is shielding the edge of the third poly shape from the `metal2` body (fringe C4) and the bodies of the `metal2` shape and the fourth `poly` shape from each other (area C5)

For lateral capacitance, a primary layer shape can shield another primary layer shape:

- The third `poly` shape is shielding the edges of the second and fourth `poly` shapes from each other (lateral C7)

- The fourth `poly` shape is shielding the `metal1` edge from the edge of the fifth `poly` shape (lateral C6)

The only capacitor, which is not shielded, is area C3.

In older versions of **Hipex-C**, the user has had to specify correct shielding layers in the `/INSIDE_LAYERS` option for each capacitance statement. For example,

```
CUP AREA met2 poly 1.08e-5 /INSIDE _ LAYERS=
met1;

CUP FRINGE met2 poly 1.2e-4 /INSIDE _ LAYERS=
met1;

CUP FRINGE poly met2 8.7e-5 /INSIDE _ LAYERS=
met1;

CUP LATERAL met2 poly /K=9.01e-6 /MAX _ DISTANCE=3
/INSIDE _ LAYERS=met1;
```

In the latest version of **Hipex-C**, we have introduced the new statement for specifying vertical order of conduction layers, `CUP ORDER`. It lists the layers from bottom to top.

For example,

```
CUP ORDER bulk, diff, poly, met1, met2, met3,
met4, met5, met6;
```

This statement determines shielding layers for a given pair of primary layers. In the example above, layers `met2` and `met3` are shielding layers for any type of capacitance associated with `met1` and `met4` layers. This kind of vertical shielding occurs automatically.

The `/INSIDE_LAYERS` option is also available for specifying extra shielding layers. This option is especially useful for lateral capacitance statements, in which a layer can be both primary and shielding layer at the same time (see capacitors C6 and C7 in Figure 2).

For example:

```
CUP  LATERAL  met1  /INSIDE _ LAYERS=met1  /
K=7.0526e-5 /MAX _ DISTANCE=1.245 /SHIELD _ FAC-
TOR=0.1;

CUP  LATERAL met2 met1 /INSIDE _ LAYERS=met2,
met1 /K=4.58e-6 /MAX _ DISTANCE=0.6 /SHIELD _
FACTOR=0.14;
```

The `/SHIELD_FACTOR` parameter controls the effect of shielding on lateral capacitances. The default value is zero, which avoids lateral capacitance when there is shielding. **Hipex-C** always avoids the shielded area and fringe capacitances.

Charge Sharing

In a multi-body system, any neighboring conductors can influence the capacitance associated with the two primary conductors. Older versions of **Hipex-C** as well as the latest version can model the charge sharing from a layer edge between another layer body and the same layer lateral edge. Figure 3. illustrates these charge sharing effects. As the distance D to lateral edge decreases, the lateral capacitance `C1` and `C4` increases, while the fringe capacitance `C2` and `C3` decreases.

The built-in lateral and fringe capacitance equations show these qualitative dependencies in the quantitative manner:

```
C _ lateral = n1 * L / (D + n2)^n3
C _ fringe  = n1 * L * (1 - exp(-n2 * (D + n3)))
```

Here, `L` is the length of an edge; `D` is the lateral distance; `n1`, `n2`, and `n3` are the specified non-negative constants.

The latest version of **Hipex-C** can effectively model the charge sharing effects caused by the presence of layers geometry above and below the primary layer(s). Using the `/OUTSIDE_LAYERS` option with the capacitance statements, you can specify different capacitance coefficients for each vertical configuration of the primary conductors. The layers above and below, if applicable, the primary conductors define the vertical configuration.
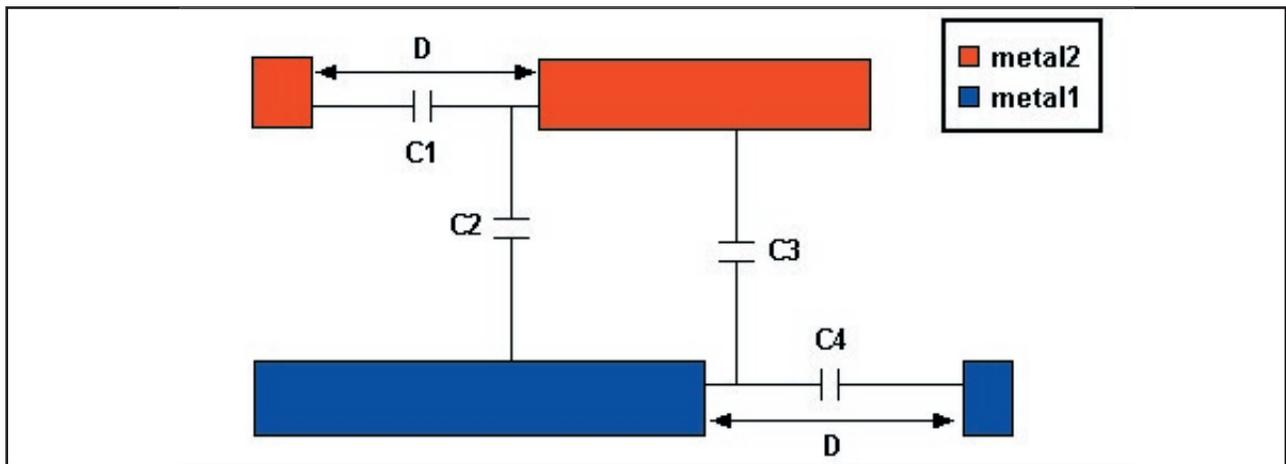
Figure 3. Charge sharing with lateral edge (cross-sectional view).

When *Hipex-C* encounters a capacitance for the primary layers, it first looks for a statement with the `/OUTSIDE_LAYERS` option that matches the surrounding layers. If the tool finds an exact match, then it uses the coefficients for the statement to compute the capacitance. If *Hipex-C* does not find a match, it uses the capacitance coefficients for a statement without an `/OUTSIDE_LAYERS` option. Therefore, statements without `/OUTSIDE_LAYERS` options provide the default coefficients for any vertical configuration of the primary layers.

For primary layers `layer1` and `layer2`, you can specify one or two outside layers:

`\OUTSIDE _ LAYERS = layer3`

`\OUTSIDE _ LAYERS = layer4`

`\OUTSIDE _ LAYERS = layer3, layer4`

Here, `layer3` is below `layer1` and `layer4` is above `layer1`. For a `LATERAL` statement, there might be only one primary layer, `layer1`.

Figure 4. demonstrates different vertical configurations of the two primary layers. Capacitance effects for the primary layers, `layer1` and `layer2`, are shown in red. Charge sharing effects with the outside layers, `layer3` and `layer4`, which lessen the capacitance effect, are shown in black.

The statements corresponding to the vertical configurations shown in Figure 4 are listed as follows:

a) `CUP FRINGE layer1 layer2 / OUTSIDE _ LAYERS= layer3`

b) `CUP FRINGE layer1 layer2 /OUTSIDE _ LAYERS= layer4`

c) `CUP FRINGE layer1 layer2 /OUTSIDE _ LAYERS= layer3, layer4`

d) `CUP LATERAL layer1 layer2 /OUTSIDE _ LAYERS= layer3, layer4`

e) `CUP LATERAL layer1 /OUTSIDE _ LAYERS=layer3, layer4`

Conclusion

New version of Silvaco's *Hipex-C* tool provides effective means for modeling vertical shielding and charge sharing effects. The user can account for different patterns of primary layers by specifying capacitance coefficients for each pattern.
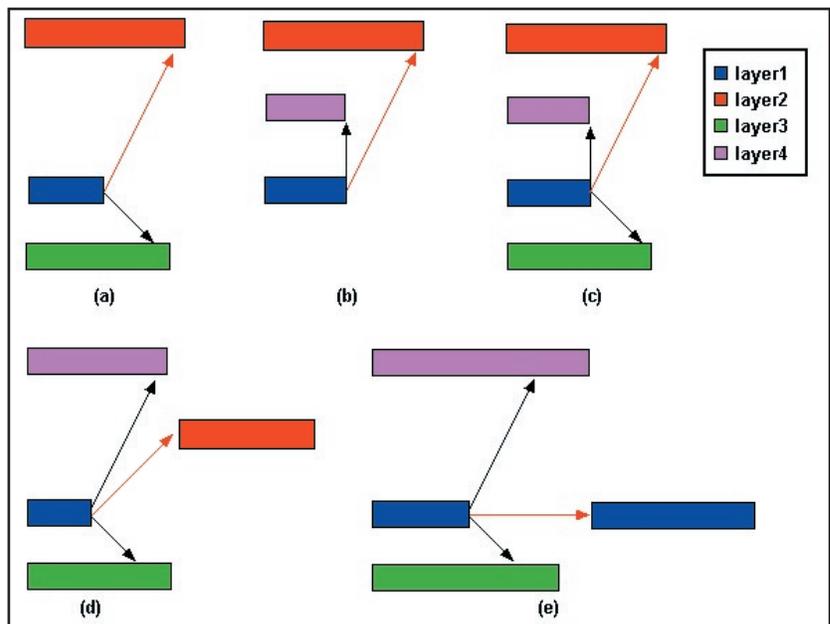

Figure 4. Charge sharing with outside layers geometry (cross-sectional view).