# A Non-Delta-Chrome OPC Methodology for Nonlinear Process Models

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Delta-chrome optical proximity correction (OPC) has been widely adopted in lithographic patterning for semiconductor manufacturing.[1–6] During each OPC iteration, a predetermined amount of chrome is added or subtracted from the mask pattern. The exposure intensity signal error (ISE) change or the edge placement error (EPE) change of printed contour is then calculated based on process models with Kirchhoff or thin mask transmission. Linear approximation is used to predict the proper chrome change to remove the correction error. This approximation can be very fast and effective, but must be performed iteratively to capture interactions between feature changes. As integrated circuit (IC) design shrinks to the deep sub-wavelength regime, previously ignored nonlinear process effects, especially three-dimensional (3D) or thick mask effects, become significant for accurate prediction and correction of proximity effects.[8] These nonlinearities challenge the delta-chrome OPC methodology. The model responses to the mask geometry perturbation by linear approximation are inaccurate, as shown in Fig. 1. A non-delta-chrome OPC methodology with ISE-based feedback compensation is proposed. It determines the proper chrome change based on ISE without intensive computation of mask perturbation response. Its effectiveness in improving patterning fidelity and runtime with the presence and absence of nonlinear effects is examined with a practical 50-nm circuit layout comprising of seven critical layers with a minimum pitch size of 125 nm. Despite the presence and the absence of nonlinear effects, our results show the proposed non-delta-chrome OPC outperforms the delta-chrome one in terms of patterning fidelity and runtime, as summarized in Table 1. The results also demonstrate that nonlinear process models limit the delta-chrome OPC methodology.

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[1] N. Cobb et al., Proc. SPIE **2621**, 534–545 (1995).
[2] N. Cobb et al., Proc. SPIE **4889**, 1281–1292 (2002).
[3] B. Painter et al., Proc. SPIE **5377**, 1198–1206 (2004).
[4] N. Cobb et al., Proc. SPIE **5853**, 693–702 (2005).
[5] S. Choi et al., Proc. SPIE **6154**, 61540P (2006).
[6] Y. Chen et al., Proc. SPIE **6520**, 65204C (2007).
[7] Y. Su et al., Proc. SPIE **6924**, 69243Z (2008).
[8] L. Melvin et al., Proc. SPIE **6792**, 6792D7 (2008).

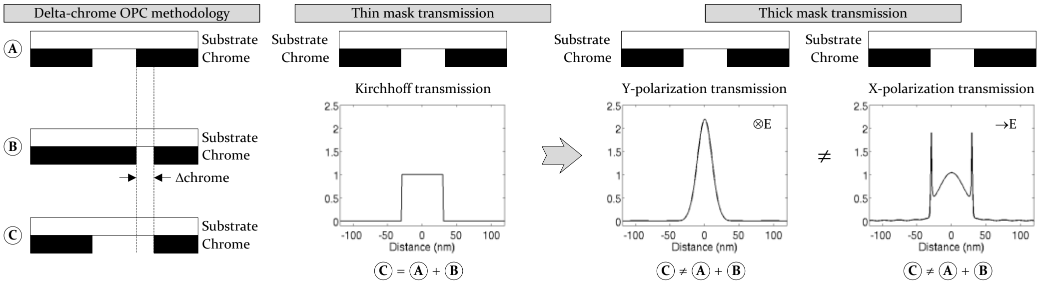

Fig. 1. Linear properties of delta-chrome OPC methodology for the cases of thin mask transmission: Ⓒ = Ⓐ + Ⓑ, and thick mask transmission: Ⓒ ≠ Ⓐ + Ⓑ. This implies that mask perturbation responses by linear approximation such as MEEF = ΔEPE / Δchrome or Slope = ΔISE / Δchrome are inaccurate, where MEEF is the mask error enhancement factor, EPE is the edge placement error, and ISE is the intensity signal error.

Table 1. OPC methodology comparison for 45-nm process model with thin mask transmission and 32-nm process model with thick mask transmission. "# Seg" columns denote the total number of segments assigned to each layer, "$\mu_{|EPE|}$" columns denote the mean of absolute EPEs, "$\sigma_{|EPE|}$" columns denote the standard deviation of absolute EPEs, "# OTS" columns denote the number of out-of-tolerance segments (|EPE| > 2 nm), "RT" columns denote the runtime, "# OTS Reduc" columns denote the reduction of out-of-tolerance segment numbers, and "RT Reduc" columns denotes the runtime reduction.

<table>
<tr><th colspan="12">52-nm half-pitch-equivalent process model with thin mask transmission</th></tr>
<tr><th rowspan="2">Layer #</th><th rowspan="2"># Seg</th><th colspan="4">Delta-chrome OPC</th><th colspan="4">Non-delta-chrome OPC</th><th rowspan="2"># OTS Reduc (%)</th><th rowspan="2">RT Reduc (%)</th></tr>
<tr><th>$\mu_{|EPE|}$ (nm)</th><th>$\sigma_{|EPE|}$ (nm)</th><th># OTS</th><th>RT (s)</th><th>$\mu_{|EPE|}$ (nm)</th><th>$\sigma_{|EPE|}$ (nm)</th><th># OTS</th><th>RT (s)</th></tr>
<tr><td>1:0</td><td>30702</td><td>0.32</td><td>0.35</td><td>8</td><td>36</td><td>0.32</td><td>0.34</td><td>7</td><td>31</td><td>0.00</td><td>13.89</td></tr>
<tr><td>2:0</td><td>59255</td><td>0.43</td><td>0.67</td><td>1559</td><td>58</td><td>0.42</td><td>0.70</td><td>997</td><td>52</td><td>0.95</td><td>10.34</td></tr>
<tr><td>3:0</td><td>14436</td><td>0.13</td><td>0.11</td><td>0</td><td>88</td><td>0.28</td><td>0.19</td><td>0</td><td>22</td><td>0.00</td><td>75.00</td></tr>
<tr><td>4:0</td><td>69894</td><td>0.57</td><td>0.80</td><td>2592</td><td>69</td><td>0.53</td><td>0.65</td><td>3235</td><td>55</td><td>–0.92</td><td>20.29</td></tr>
<tr><td>5:0</td><td>3448</td><td>0.12</td><td>0.11</td><td>0</td><td>33</td><td>0.24</td><td>0.17</td><td>0</td><td>16</td><td>0.00</td><td>51.52</td></tr>
<tr><td>6:0</td><td>26317</td><td>0.36</td><td>0.39</td><td>1</td><td>33</td><td>0.36</td><td>0.38</td><td>1</td><td>28</td><td>0.00</td><td>15.15</td></tr>
<tr><td>8:0</td><td>22641</td><td>0.43</td><td>0.41</td><td>1</td><td>31</td><td>0.45</td><td>0.38</td><td>4</td><td>28</td><td>–0.01</td><td>9.68</td></tr>
<tr><td colspan="2">Average</td><td>0.34</td><td>0.41</td><td></td><td></td><td>0.37</td><td>0.40</td><td></td><td></td><td>0.00</td><td>27.98</td></tr>
<tr><th colspan="12">40-nm half-pitch-equivalent process model with thick mask transmission</th></tr>
<tr><th rowspan="2">Layer #</th><th rowspan="2"># Seg</th><th colspan="4">Delta-chrome OPC</th><th colspan="4">Non-delta-chrome OPC</th><th rowspan="2"># OTS Reduc (%)</th><th rowspan="2">RT Reduc (%)</th></tr>
<tr><th>$\mu_{|EPE|}$ (nm)</th><th>$\sigma_{|EPE|}$ (nm)</th><th># OTS</th><th>RT (s)</th><th>$\mu_{|EPE|}$ (nm)</th><th>$\sigma_{|EPE|}$ (nm)</th><th># OTS</th><th>RT (s)</th></tr>
<tr><td>1:0</td><td>31096</td><td>26.0</td><td>81.8</td><td>31087</td><td>100</td><td>0.20</td><td>0.25</td><td>8</td><td>88</td><td>99.95</td><td>12.00</td></tr>
<tr><td>2:0</td><td>58866</td><td>1434.7</td><td>863.1</td><td>58524</td><td>132</td><td>0.20</td><td>0.24</td><td>5</td><td>103</td><td>99.41</td><td>21.97</td></tr>
<tr><td>3:0</td><td>14436</td><td>1964</td><td>0.0</td><td>14436</td><td>55</td><td>0.07</td><td>0.06</td><td>0</td><td>43</td><td>100.00</td><td>21.82</td></tr>
<tr><td>4:0</td><td>68938</td><td>16.4</td><td>72.7</td><td>64826</td><td>137</td><td>0.26</td><td>0.32</td><td>359</td><td>83</td><td>93.51</td><td>39.42</td></tr>
<tr><td>5:0</td><td>3448</td><td>1964</td><td>0.0</td><td>3448</td><td>36</td><td>0.07</td><td>0.05</td><td>0</td><td>33</td><td>100.00</td><td>8.33</td></tr>
<tr><td>6:0</td><td>26292</td><td>28.5</td><td>106.3</td><td>25781</td><td>61</td><td>0.18</td><td>0.17</td><td>0</td><td>54</td><td>98.06</td><td>11.48</td></tr>
<tr><td>8:0</td><td>22856</td><td>26.1</td><td>50.0</td><td>22841</td><td>86</td><td>0.15</td><td>0.19</td><td>15</td><td>75</td><td>99.87</td><td>12.79</td></tr>
<tr><td colspan="2">Average</td><td>779.9</td><td>167.7</td><td></td><td></td><td>0.16</td><td>0.18</td><td></td><td></td><td>98.69</td><td>18.26</td></tr>
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