Chemical Trimming Overcoat: An Enhancing Composition and Process for 193nm Lithography

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ABSTRACT

As the critical dimension of devices is approaching the resolution limit of 193nm photo lithography, multiple patterning processes have been developed to print smaller CD and pitch. Multiple patterning and other advanced lithographic processes often require the formation of isolated features such as lines or posts by direct lithographic printing. The formation of isolated features with an acceptable process window, however, can pose a challenge as a result of poor aerial image contrast at defocus. Herein we report a novel Chemical Trimming Overcoat (CTO) as an extra step after lithography that allows us to achieve smaller feature size and better process window.

Keywords: Chemical Trimming Overcoat, double patterning, 193 photolithography, positive tone photoresist, process window, 2D pattern, defect, LWR

1. INTRODUCTION

As the critical dimension (CD) of devices continue to shrink, the semiconductor industry is looking for means to extend 193nm immersion lithography before next generation lithography is ready. Under this circumstance, multiple patterning has emerged as the solution.[1] Self-Aligned Double Patterning (SADP)[2] and Litho-Etch-Litho-Etch[3,4] are the two main multiple patterning processes being used by advanced semiconductor manufacturers. CD trimming is a critical step in these advanced patterning processes. Among the available CD trimming methods, etch trim is versatile and widely used.[5] However, one drawback of etch trim step is that it adds extra complexity and cost. In comparison to etch trim, spin-on chemical trim, Chemical Trimming Overcoat (CTO), can simplify the advanced patterning process and reduce cost of ownership.[6-10] A typical CTO process is shown in Figure 1. CTO is coated over a positive tone developed ArF resist pattern. The wafer is then heated and developed. The process results in smaller feature size with pitch maintained. All the steps involved in CTO are done in track.

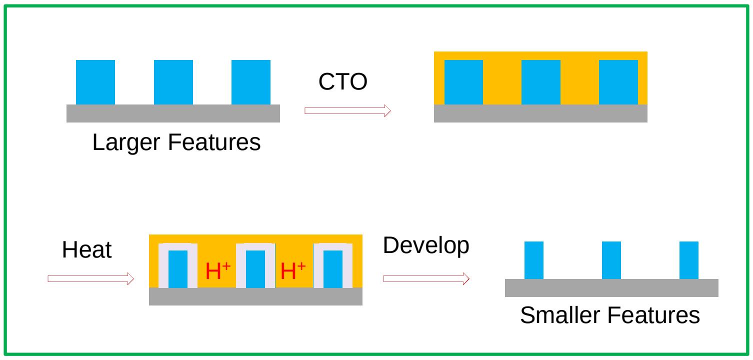

Figure 1. Typical CTO Process

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We have developed a spin-on CTO formulation. In this report, the lithographic performance with and without the CTO are compared. CTO has shown advantages in various lithographic parameters including DOF, LWR, CDU and defect.

2. EXPERIMENTAL

General

All the CTO, photoresists and other coating formulations used in this study were prepared by Dow Electronic Materials using proprietary materials.

All wafers were coated on TEL CLEAN TRACK^{TM}. Photoresist patterns for CTO test were obtained from one of the three exposure tools: 1) ASML 1900i, 2) ASML 1100 and 3) Nikon 610S.

CTO process was done on TEL CLEAN TRACK^{TM}: CTO film was spin coated on a photoresist pattern; the wafer was baked on a hotplate and developed with 2.38% TMAH developer to give a trimmed photoresist pattern.

CD data was collected on Hitachi 9380 and Hitachi CG4000 scanning electron microscope(s) (SEM). Cross section SEM (XSEM) images were collected on a Hitachi S4800. Defect was checked on KLA2800.

Experiment 1

A 90nm 1:1 L/S pattern of photoresist A was obtained on ASML1100. On top of the pattern, a 600Å CTO film was spin coated at 1500rpm. The wafer was baked for 60s and developed with 2.38% TMAH developer. The line CDs of the trimmed patterns were measured. The test was repeated with different bake temperatures (±2 and ±5°C) and the line CDs were measured on Hitachi 9380.

Table 1. Bake temperature effect on CD trimming

CTO Bake Temperature (Delta to center)	-5°C	-2°C	0	+2°C	+5°C
CD after Trim (nm)	72.2	69.9	68.6	66.3	62.6
ΔCD (nm)	16.5	18.8	20.0	22.3	26.1

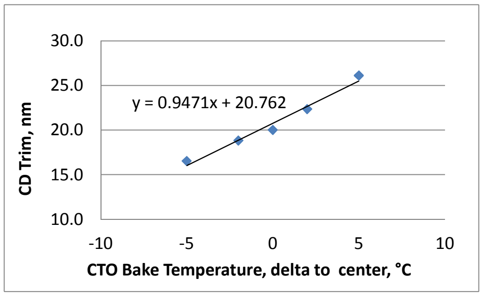


Figure 2. Bake temperature effect on CD trimming

Experiment 2

A 90nm 1:1 L/S pattern of photoresist A was obtained on ASML1100. On top of the pattern, a 600Å CTO film was spin coated at 1500rpm. The wafer was baked for 90s and developed with 2.38% TMAH developer. The line CDs of the trimmed patterns were measured. The test was repeated with different bake times (100s, 110s, 120s, 130s, 140s and 150s) and the line CDs were measured on Hitachi 9380.

Table 2. Bake time effect on CD trimming

CTO Bake Time	90s	100s	110s	120s	130s	140s	150s
CD after Trim (nm)	71.4	71.0	70.9	69.9	70.0	69.3	69.1
CD Trim (ΔCD), nm	16.2	16.6	16.8	17.7	17.7	18.4	18.5

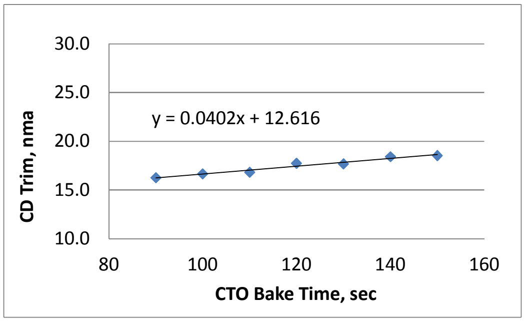


Figure 3. Bake time effect on CD trimming

Experiment 3

A 90nm 1:1 L/S pattern of photoresist A was obtained on ASML1100. On top of the pattern, a 600Å CTO film was spin coated at 1500rpm without delay. The wafer was baked for 120s and developed with 2.38% TMAH developer (process a). In process b), a 5-hour delay was inserted before CTO coat. In process c), a 100°C hard bake step was inserted before CTO coat. In process d), both a 5-hour delay and a 100°C hard bake step were inserted before CTO coat. The line CDs were measured on Hitachi 9380 after each process.

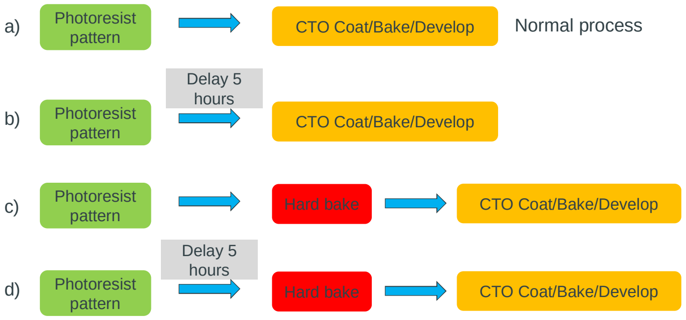


Figure 4. CTO process flow involving delay and hard bake.

Table 3. Effect of delay and hard bake on CD trimming.

	CD Trim (ΔCD), nm		Change in CD Trim, nm
	No Delay	5 Hour Delay	
No Hardbake	20.1	17.6	2.5
100°C Hardbake	14.5	14.5	0

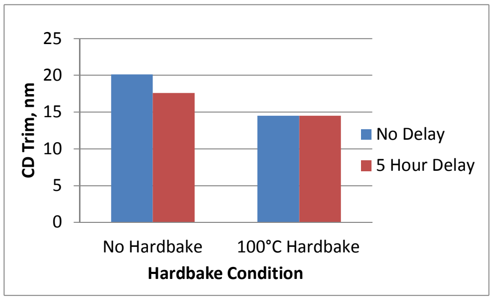


Figure 5. Effect of use delay and hard bake on CD trimming.

Experiment 4

A 90nm 1:1 L/S pattern of photoresist A was obtained on ASML1100. On top of the pattern, a 600Å CTO film was spin coated at 1500rpm. The wafer was baked for 120s and developed with 2.38% TMAH developer. The test was repeated with varied delay time (15min, 30min, 60min and 120min) before the development step. The resulting line CDs were measured on Hitachi 9380.

Table 4. Effect of CTO develop delay on CD trimming.

Delay Time before CTO Develop	0min	15min	30min	60min	120min
CD after Trim (nm)	71.4	70.5	71.2	69.3	69.7
CD Trim (ΔCD), nm	17.3	18.3	17.6	19.4	19.0

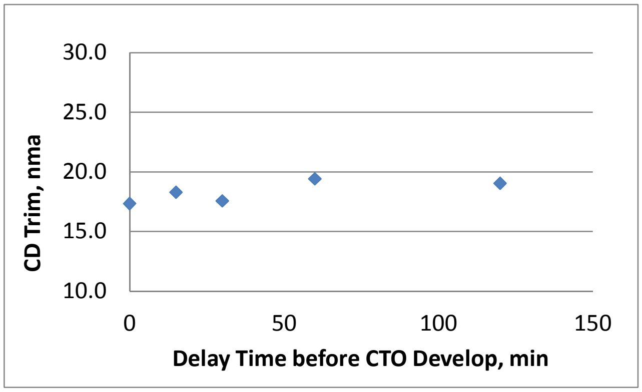


Figure 6. Effect of CTO develop delay on CD trimming.

Experiment 5

A 45nm 1:1 L/S pattern of photoresist C was obtained on ASML1900i. On top of the pattern, a 600Å CTO film was spin coated at 1500rpm. The wafer was baked for 120s and developed with 2.38% TMAH developer. The resulting line CDs were measured on Hitachi CG4000. The results are summarized in Figure 7.

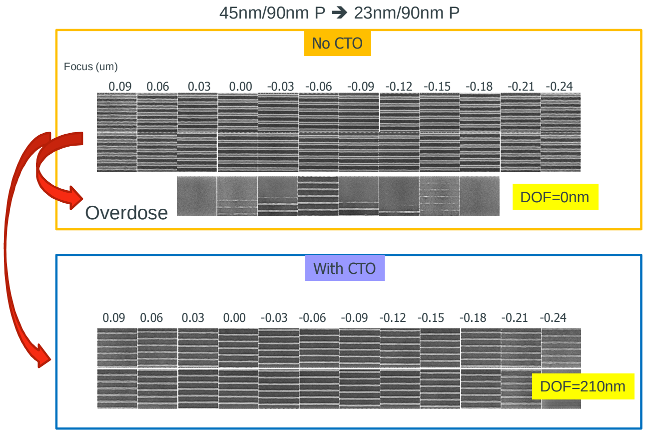


Figure 7. DOF comparison with and without CTO

Experiment 6

A 70/128pitch (x-direction)/200/1485pitch (y-direction) post pattern of photoresist D was obtained on Nikon S610C. On top of the pattern, a 600Å CTO film was spin coated at 1500rpm. The wafer was baked for 60s and developed with 2.38% TMAH developer. The resulting post CDs were measured on Hitachi CG4000. The results are summarized in Figure 8.

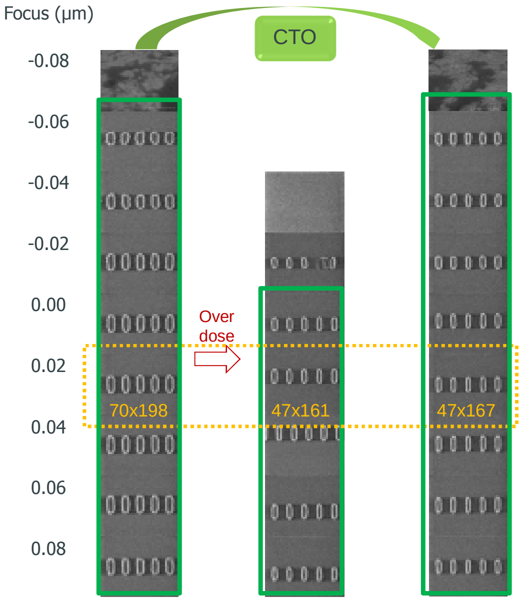
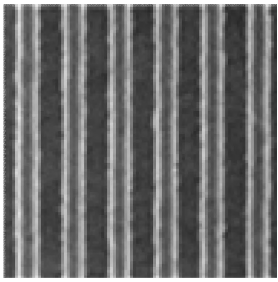
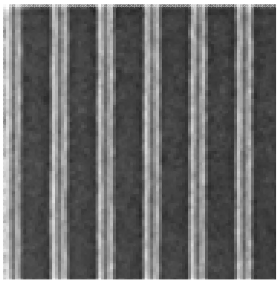
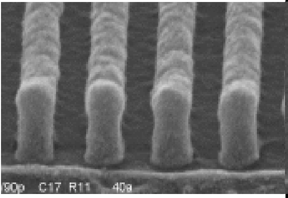
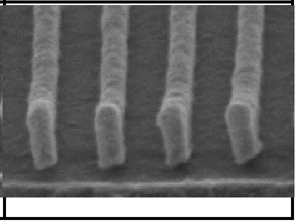


Figure 8. DOF comparison with and without CTO

Experiment 7

A 45nm 1:1 L/S pattern of photoresist B was obtained on ASML 1900i. On top of the pattern, a 600Å CTO film was spin coated at 1500rpm. The wafer was baked for 60s and developed with 2.38% TMAH developer. The resulting line CDs and LWRs were measured on Hitachi CG4000. Cross section SEM (XSEM) images were collected on a Hitachi S4800.

Table 5. Lithographic performance comparison with and without CTO

	Without CTO	With CTO
Average Line CD	46.3 nm	30.4 nm
CDU Sigma	0.42 nm	0.24 nm
LWR	3.5 nm	2.6 nm
Topdown Image at Esize		
Vertical SEM Image at Esize		

Experiment 8

A 45nm 1:1 L/S pattern of photoresist E was obtained on ASML 1900i. On top of the pattern, a 600Å CTO film was spin coated at 1500rpm. The wafer was baked for 120s and developed with 2.38% TMAH developer. The resulting line CDs and LWRs were measured on Hitachi CG4000. LWR before and after CTO were analyzed by the Roughness Power Spectral Densities (PSD) using SuMMIT software. The results are summarized in figure 9.

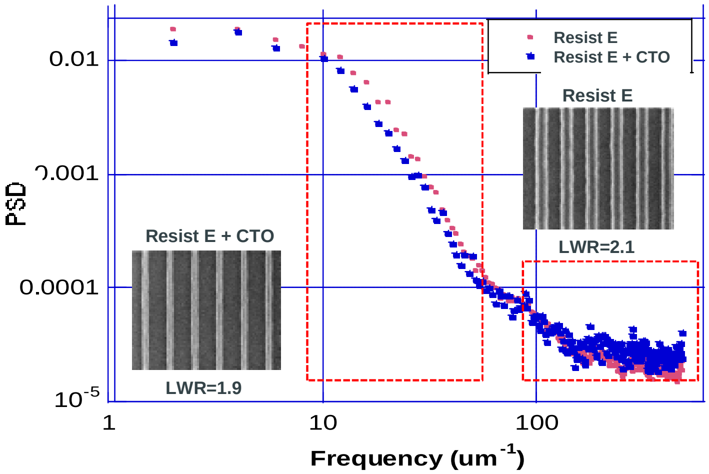


Figure 9. Averaged PSDs with and without CTO.

Experiment 9

L/S pattern of photoresist B were printed on Nikon S610C, using masks with varied pitches. On top of the pattern, a 600Å CTO film was spin coated at 1500rpm. The wafer was baked for 120s and developed with 2.38% TMAH developer. The resulting line CDs were measured on Hitachi CG4000.

Table 6. Pitch effect on CD trimming.

Pattern (line/pitch)	90/180	90/260	90/360	90/550	90/700
CD before Trim (nm)	97.2	69	57.9	50.7	52.1
CD after Trim (nm)	71.5	43.7	32.8	25.9	26.2
CD Trim (ΔCD), nm	25.7	25.3	25.1	24.8	25.9

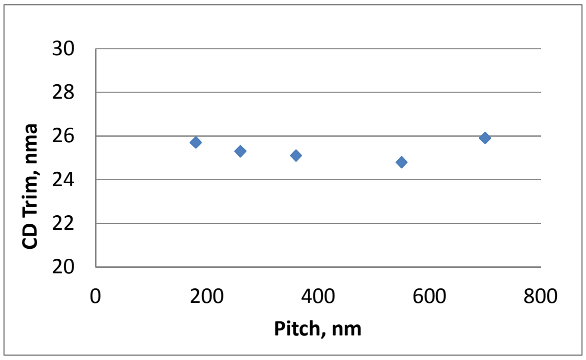
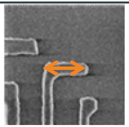
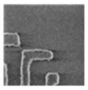
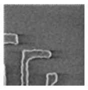
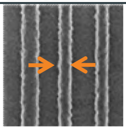
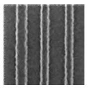
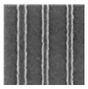
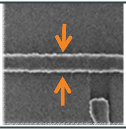
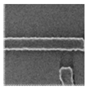
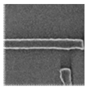
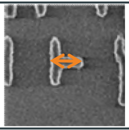
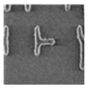
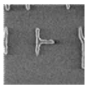
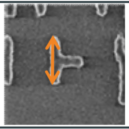
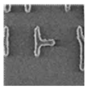
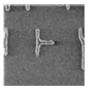


Figure 10. Pitch effect on CD trimming.

Experiment 10

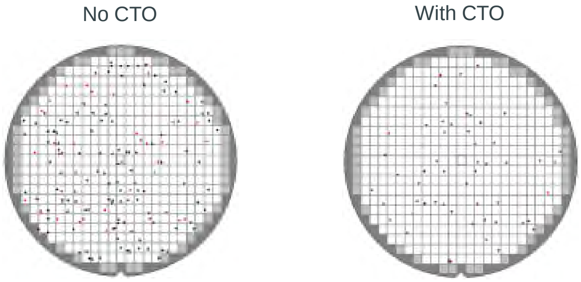
A variety of 2D patterns of photoresist D was obtained on ASML1900i. On top of the pattern, a 600Å CTO film was spin coated at 1500rpm. The wafer was baked for 120s and developed with 2.38% TMAH developer. The CDs of the resulting patterns were measured on Hitachi CG4000.

Table 7. CD trim on 2D patterns with CTO.

	Measurement Features	No CTO	With CTO
Feature 1		 340.9nm	 ΔCD=24.0
Feature 2		 94.27nm	 ΔCD=21.8
Feature 3		 137.6nm	 ΔCD=26.6
Feature 4		 210.7nm	 ΔCD=28.1
Feature 5		 313.3nm	 ΔCD=26.3

Experiment 11

A 90nm 1:1 L/S pattern of photoresist B was obtained on ASML 1100. On top of the pattern, a 600Å CTO film was spin coated at 1500rpm. The wafer was baked for 120s and developed with 2.38% TMAH developer. The defect of the resulting pattern was checked on KLA2800. A 90nm 1:1 L/S pattern of photoresist B without subsequent CTO process was used as control in this experiment.



Sample	Bridging Defect Density (/cm2)	Total Defect Density (/cm2)
No CTO	1.76, 1.65	1.76, 1.73
With CTO	0.04, 0.01	0.56, 0.61

Figure 11. 90nm 1:1 L/S pattern defect with and without CTO

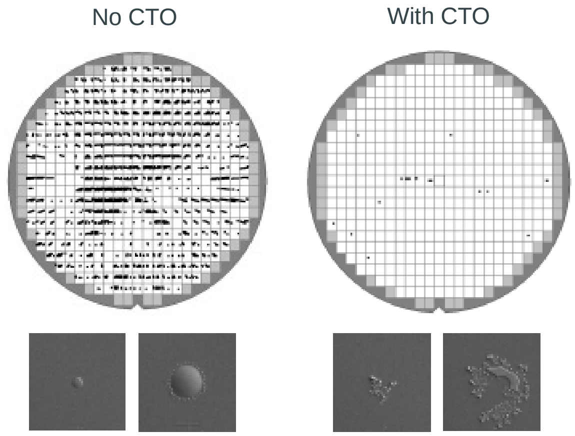


Figure 12. Defect with and without CTO in the bulk exposed areas between die.

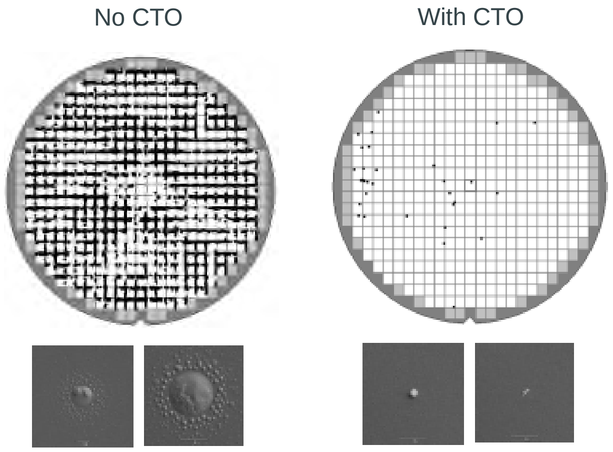


Figure 13. Defect with and without CTO in the bulk unexposed areas between die.

3. RESULTS AND DISCUSSIONS

Impact of Process Parameters on Trim Performances

The CD trim amount can be easily tuned by adjusting bake temperature and time and spin speed. Higher bake temperatures led to more CD trim (Table 1 and Figure 2). The bake temperature sensitivities are generally less than 1nm/°C. Longer bake time led to more CD trim as well (Table 2 and Figure 3). The bake time sensitivity in this case is observed to be 0.04nm/sec. Among these process parameters, bake temperature appears to be the most significant factor in adjusting CD trim amount.

The impacts of CTO use delay and additional hardbake were studied. Figure 3 shows the experiment process flow where additional delay and hardbake are optionally inserted in the normal process. A five-hour delay of CTO use led to observable decrease of CD trim amount (Table 3 and Figure 5). This CD trim amount drop may be caused by water absorption at the resist pattern surface during the delay. The addition of a hardbake step before CTO use reduced the overall trim amount but stabilized the CD over the five-hour delay. In comparison to the CTO use delay, the CTO develop delay over a two-hour period did not lead to appreciable CD trim change (Table 4 and Figure 6).

Lithographic Performances with CTO

CTO enables large depth-of-focus. As shown in figure 7, there was no DOF when 45nm 1:1 L/S patterns were overexposed for targeting 23nm 1:3 patterns. In comparison, treatment of the original 45nm 1:1 L/S patterns with CTO process afforded 23nm 1:3

patterns and 210nm DOF. Similarly, in figure 8, overexposure on an elongated post pattern led to significantly degraded DOF. However, the DOF was maintained with CTO process and similar feature size was obtained as compared to the overexposure.

CTO process improves LWR and CDU while trimming down the CD. As can be seen in table 6, 14.9nm CD trim, 0.9nm LWR improvement and 0.18nm CDU improvement were achieved at the same time. Vertical SEM images were shown in table 5. The profile was largely maintained after CTO. It is also worth pointing out that the space areas were also cleaner and there was less scum next to the lines.

The Power Spectral Density (PSD) is used to look at the frequency content of roughness. The PSD is the edge or CD variation per spatial frequency up the line. A L/S pattern of resist E has LWR of 2.1. After the CTO process, the LWR improves to 1.9. Comparison of the PSDs suggested a possible improvement in medium to low frequency LWR ranges (figure 8).

The CD trim amounts with CTO at pitches ranges from 180nm to 700nm were measured and there was no significant difference of CD trim amount observed. (Table 6 and Figure 10). The minimum through-pitch proximity bias on certain photoresist patterns is an important benefit of CTO. However, the bias may vary depending on the resists used.

CTO was applied to a variety of 2-D features and successfully trimmed the CDs with reasonably low CD variation (Table 7). The CD trim amounts of the labeled positions range between 21.8nm and 28.1nm.

Defect Test

A defect test was run with 90nm 1:1 L/S patterns and showed significant improvement in both bridging defect and total defect. It is believed that CTO both helps to modify the pattern profiles to disfavor bridging formation and helps to remove residues that fail to develop away during the previous patterning steps (figure 11). CTO also significantly improves defectivity in the bulk exposed and unexposed areas between die (figures 12 and 13).

4. CONCLUSIONS

We have developed a Chemical Trimming Overcoat (CTO) formulation and process. The CD trim amount is adjustable by common track process parameters, such as bake temperature and bake time. Hardbake before CTO use can also reduce the CD trim fluctuation of CTO. CTO improves process window, LWR and CDU. PSD analysis suggested a possible improvement in medium to low frequency LWR ranges with CTO. Minimum through pitch proximity bias was achieved with CTO. CTO is also capable of trimming CD of a variety of 2D patterns and improving defectivity at after-develop check.

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