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Impact of an etched EUV mask black border on imaging. Part II.

Natalia Davydova, Robert de Kruif, Dries van Gestel, and Dorothe Oorschot, ASML Netherlands B.V., De Run 6501, 5504 DR Veldhoven, The Netherlands

Hiroaki Morimoto, Yo Sakata, Jun Kotani, Norihito Fukugami, Shinpei Kondo, and Tomohiro Imoto, Toppan Printing Co., Ltd., Nobidome 7-21-33, Niiza, Saitama, 352-8562 Japan

Brid Connolly, Toppan Photomasks Inc., Rähnitzer Allee 9, 01109 Dresden, Germany

David Rio, ASML US inc., 4211 Burton Dr., Santa Clara, CA, 95054, USA

John Zimmerman and Noreen Harned, ASML Wilton, 77 Danbury Road, Wilton, CT 06897, USA

ABSTRACT

The image border is a pattern free dark area around the die on the photomask serving as transition area between the parts of the mask that is shielded from the exposure light by the Reticle Masking (ReMa) blades and the die. When printing a die at dense spacing on an EUV scanner, the reflection from its image border overlaps with the edges of neighboring dies affecting CD and contrast in this area. This is related to the fact that EUV absorber stack has 1-3% reflectance for actinic light. For a 55nm thick absorber the induced CD drop at the edges is found to be 4-5 nm for 27 nm dense lines.[1] In this work we will show an overview of the absorber reflection impact on CD at the edge of the field across EUV scanner generations, for several imaging nodes and multiple absorber heights.

Increasing spacing between dies on the wafer would prevent the unwanted exposure but results in an unacceptable loss of valuable wafer real estate thereby reducing the yield per wafer and is thus not a viable manufacturing solution. In order to mitigate the reflection from the image border one needs to create a so called black border. The most promising approach is removal of the absorber and the underlying multilayer down to the low reflective LTEM substrate by multilayer etching.[6] It was shown in the previous study[1] that the impact on CD was reduced essentially for 27 nm dense lines exposed on ASML NXE:3100.

In this work we will continue the study of a multilayer etched black border impact on
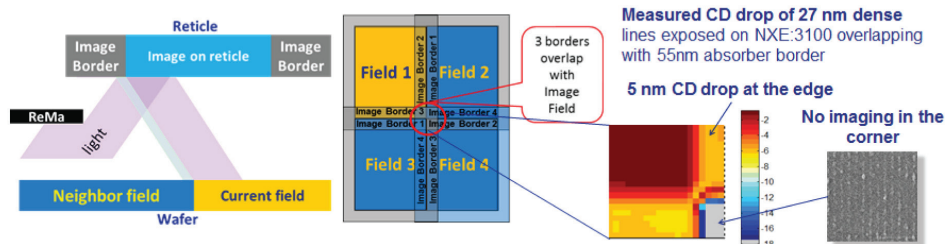

Figure 1. Die to die interactions on wafer. EUV light is reflected at the image border and impacts imaging in the neighboring die. In the corners of the dies reflections from the three neighboring image borders overlap with die area. It is shown in the experiment,[1] that 5 nm CD drop occurs for 27 nm dense lines at the edges of the field and no imaging is observed in the corners of the field if they overlap with 55 nm absorber border of the neighboring field.

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EDITORIAL

"EUV-Lithography - What Else"

Uwe Behringer, *UBC Microelectronics, Ammerbuch, Germany*

This provoking phrase was the title of the Panel Session of the European Mask and Lithography Conference, EMLC2013 held in June 2013 in Dresden, Germany. In contrast to some other panel discussions, this one was not preceded by presentations from the panelists, but immediately started with a series of questions and answers. Stefan Wurm from SEMATECH, Albany, NY, had collected, edited and sorted a list of tough questions submitted previously by the conference attendees and directed the answers excellently, giving the panelists quite a hard time. The participating panelists were F. Goodwin, SEMATECH, Albany, NY, USA; H. Morimoto, Toppan Printing Co., Japan; N. Hayashi, Dai Nippon Printing Co. Ltd., Saitama, Japan; H.J. Levinson, GLOBALFOUNDRIES Inc., Sunnyvale, CA, USA; J. Finders, ASML, Veldhoven, The Netherlands, and J.H. Peters, Carl Zeiss-SMS, Jena, Germany. One of the main results of this panel session for me were the statements by the two mask makers that they will be able to process EUV masks, as long as they get high quality substrates. Another important result was that mask makers see it difficult, but still doable, to write a 1X mask.

I proposed that title for the panel session to the EMLC program committee based on my personal opinion that most of the lithography and mask conferences nowadays suffer from too much attention to EUV and too little interest in other technologies. I think the reason is that most of the effort and money go to EUV, so that all the other important lithographic technologies do not get the support they need. Many technologists see these other technologies like Ar-immersion, e-beam multi-column, double patterning-double exposure…, just as a kind of backup for EUVL. However, looking back over the last years, EUV has been a technology, which promises us year by year the glorious technology breakthrough, but still has not solved the issues e.g., with the defect free reticle and the laser power. The CO_2 laser hitting a tin target in NXE 3100 or NXE 3300B systems needs 200 Watt and has actually 40 Watt. 50 Watt will allow to expose 39 three-hundred mm wafers, 80 Watt - about 58 wafers, and 125 Watt - about 80 wafers (Jan-Willem van der Horst, ASML, the Netherlands).

H. Levinson from GLOBALFOUNDRIES, USA, one of the EMLC2014 keynote speakers gave one of the best presentations I have ever attended. In "The Lithographer's Dilemma: Shrinking without Breaking the Bank" he showed the enormous cost increase of an exposure tool, starting in 2000 with about $10-15 M, increasing to $50M in 2010, still for optical tools, but topping with up to $100 M in 2015 for a EUV tool. Levinson stated that if one exposes 1000 wafers with 500 chips per wafer, the mask cost per die is increasing from $1 for the 130nm node to $8.5 for the 20nm node. Besides the tremendously increased tool cost, EUVL will stay throughput limited due to long times needed to expose the resist without substantial increases in source power. Because of shot noise, this limitation cannot be solved by extremely sensitive resists. His conclusion was that probably 500 W – 1kW sources may be actually needed to make EUV cost effective.

So it is a long and stony road to get EUVL into real production. Meanwhile, we have to live with what we have: ArF lithography with double etch (LE^2) → single spacer ← double spacer (SADP= self-aligned double pattering) and then, hopefully, EUVL.

My personal opinion is that we unfortunately have discarded some very sophisticated lithography technologies like X-Ray, E-beam Shadow printing, maskless lithography (both developed at IBM) and LEEPL (Low Energy Electron Projection Lithography, developed in Japan). These were all abandoned due to the use of 1X masks. 20 years ago, nobody believed in sufficient resolution, pattern placement accuracy, and defect control for 1X masks to work. Well proximity corrections will be very challenging at 1X and one is already having difficulties with defect inspection due to small defect size. But because we continue to research 1X imprint, I believe we should reconsider these "old" but highly sophisticated technologies. As an example, at Photomask 2013 this past September, a special session called "Big Glass: Will 9-inch Glass Return?" discussed the technical challenges of larger masks like 9" or even 12", a discussion we already had 20 years ago.
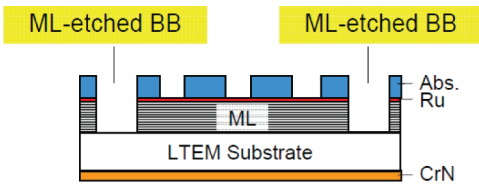

Figure 2. Absorber, ruthenium and multilayer are etched down to LTEM substrate to create the black border.

Table 1. Reflectance of the ML-etched black border is much lower than that of the standard absorber stack for EUV and DUV light.

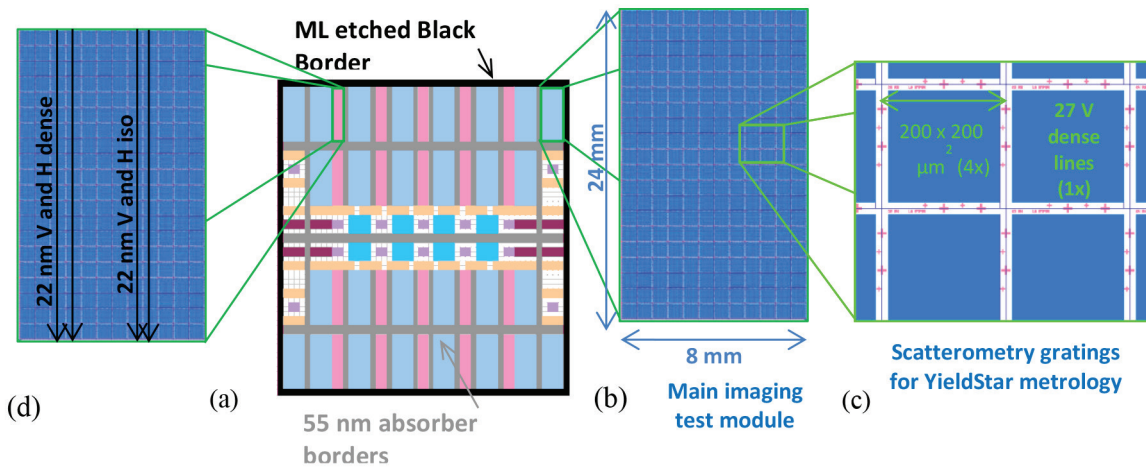| Function	Stack	Reflectance [%]		
		EUV 13.5nm	ArF 193nm	KrF 248nm
Absorber	55nm abs/Ru/ML/LTEM/CrN	2.7	20.8	9.6
Black Border	LTEM/CrN (etched ML)	< 0.05	5.9	5.2

Figure 3. (a) Mask layout of the test reticle with ML etched black border (black) around the full image field and standard absorber image borders (gray) allowing the exposure of smaller dies for comparison. The main imaging module (b) is a block 8x24 mm² (4x) consisting of scatterometry gratings (blue modules) 200x200 µm² containing (c) vertical dense lines targeted to 27 nm at wafer for ASML YieldStar metrology. Also 22 nm (wafer dimension) vertical and horizontal, dense and isolated lines are present on this reticle (d) in an array spanned in vertical and horizontal direction (pink and orange modules).

imaging. In particular, 22 nm lines/spaces imaging on ASML NXE:3300 EUV scanner will be investigated in the areas close to the black border as well as die to die effects. We will look closer into the CD uniformity impact by DUV Out-of-Band light reflected from black border and its mitigation. A possible OPC approach will also be evaluated.

1. Introduction

As EUV lithography matures and enters production phase, it should meet the requirements for high production yield and compatibility with the existing processes in terms of wafer layout, overlay and CD uniformity. The common practice is to place dies on the wafer very close to each other to utilize valuable wafer space and increase yield per wafer. In the initial stage EUVL will be used for critical layers mostly, while other layers will be exposed using conventional lithography (ArFi and larger wavelengths) and established processes. For EUVL this means that wafer layout should be the same as for conventional lithography and, in particular, no extra spacing is allowed between dies. It is known that dense spacing of dies

on wafer may result in unwanted die to die interactions, caused by EUV and DUV reflections of the absorber image border.

The EUV reflectivity of absorber image border is 1-3% depending on the absorber height.[1] The EUV reflectivity of the multilayer is roughly 60%. Therefore structures at the edge of the die receive 1.5-5% extra background light while in the corners this can be as much as 4.5-15%. As the CD sensitivity of 27-32 nm lines to the additional background light is around 1 nm/% this will result in an unacceptable CD drop at the edges of the adjacent dies and deterioration of imaging in the corners[2,3,8] (Figure 1). The contrast and process window of structures at the edges becomes worse also because of this parasitic exposure. In this work we will show the impact of the absorber reflections on 22 nm lines exposed on NXE:3300 AMSL EUV scanner and an overview of several imaging nodes from 32 to 22 nm exposed with 3 generations of EUV scanners and various absorber heights will be given.

A solution to this problem is to reduce EUV reflectivity of image border. Because of the presence of DUV OOB light in the current EUV exposure tools, the DUV reflectivity of the image

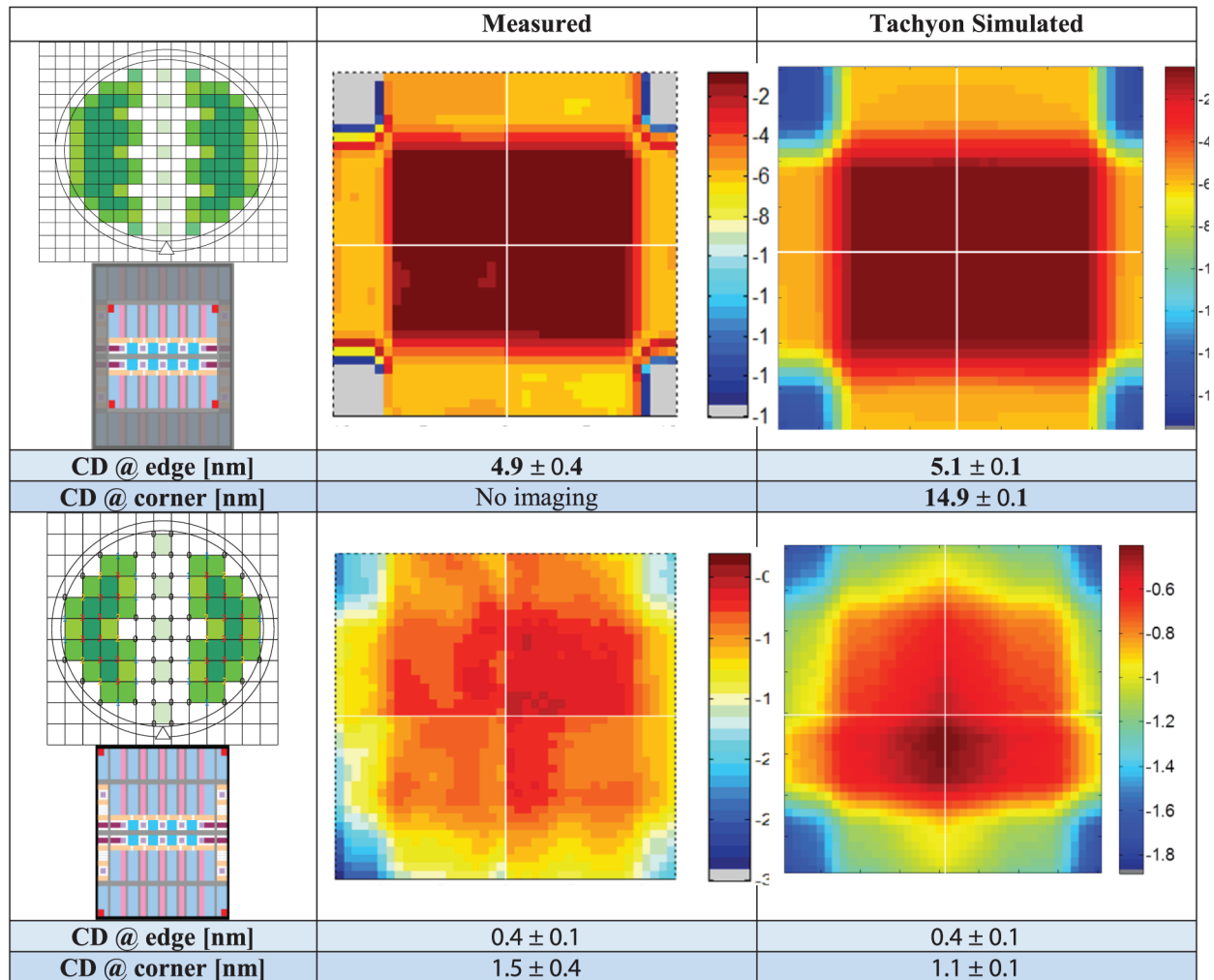|	Measured	Tachyon Simulated
CD @ edge [nm]	4.9 ± 0.4	5.1 ± 0.1
CD @ corner [nm]	No imaging	14.9 ± 0.1
CD @ edge [nm]	0.4 ± 0.1	0.4 ± 0.1
CD @ corner [nm]	1.5 ± 0.4	1.1 ± 0.1

Figure 4. Four 1x1 mm² corners measured and simulated delta CD map of field to field interactions with absorber border (upper plots) and ML etched black border (bottom plots).

border (100-300 nm wavelength) should also be controlled. One method to reduce the reflectivity in this region is the removal of the absorber and multilayer (ML) mirror by etching down to the glass substrate and creation of a low reflection trench around the image field[4,5,6] (Figure 2). The resulting EUV reflectivity of the LTEM substrate is below the lower measurement limit of 0.05% of the reflectometer and the DUV reflectivity is less than 6% for ArF and KrF light[6] (Table 1). The image border created by this process is very low reflective and we refer to it as the black border (BB).

In this paper we show new results of a reticle with the ML etched black border manufactured by the process described above.[6] This is a continuation of the study performed earlier.[1] In this work we will investigate die to die imaging performance of 22 nm and 27 nm lines by means of exposing wafers with this reticle on ASML NXE:3300 EUV lithography scanners. We will also investigate the impact of Out-of-Band DUV light on the imaging performance (CD and exposure latitude) near black border and evaluate whether this impact can be simulated (and thus corrected) in OPC tooling.

2. Reticle Layout and Manufacturing

2.1. Reticle layout
The EUV blank used for the test reticle is a commercial grade LTEM blank with a 280 nm 40-pair bilayer mirror, a 2.5 nm capping layer and a thin 55 nm absorber with an actinic reflectivity of 2.7%.[1]

The main test block of the reticle consists of repeating scatterometry gratings 200x200 µm² (4x) containing vertical dense lines targeted to 27 nm at wafer for ASML YieldStar metrology (Figure 3, blue modules) allowing extensive CD measurements. Also 22 nm (wafer dimension) vertical and horizontal, dense and isolated lines are present on this reticle in an array with 200 µm step spanned in vertical and horizontal direction from the field edge (Figure 3, pink and orange modules). The full image field of the reticle 104x132 mm² (mask dimension) is surrounded by a ML etched black border. There are also multiple absorber areas on the mask between the test blocks which can serve as standard absorber image border for image fields with a reduced size. They can be exposed for comparison to the full image with the black border.
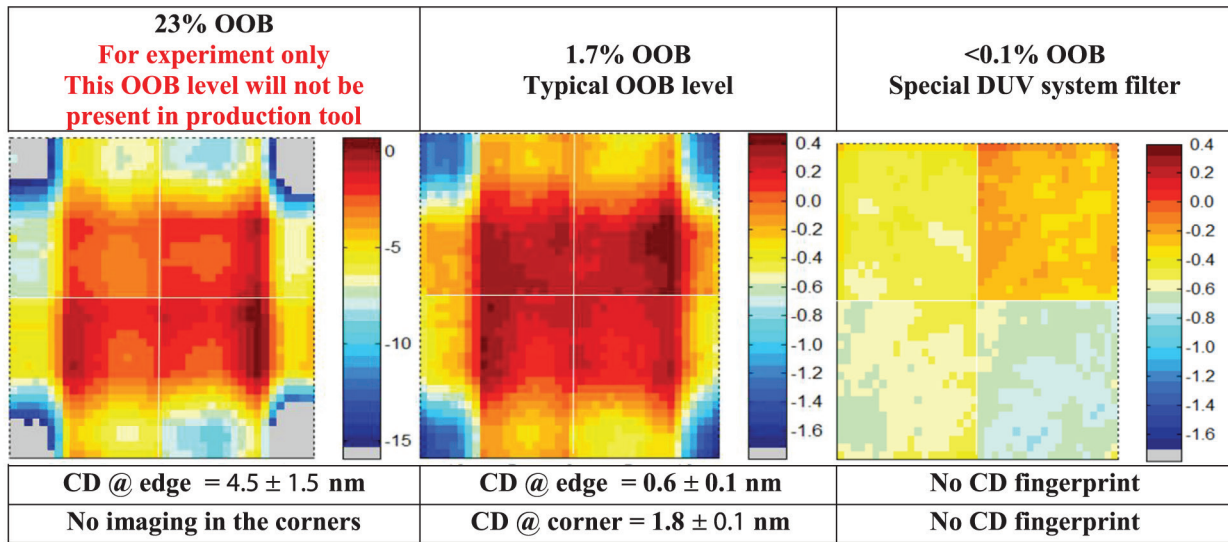
23% OOB **For experiment only** **This OOB level will not be** **present in production tool**	1.7% OOB **Typical OOB level**	<0.1% OOB **Special DUV system filter**
CD @ edge = 4.5 ± 1.5 nm	**CD @ edge = 0.6 ± 0.1 nm**	**No CD fingerprint**
No imaging in the corners	**CD @ corner = 1.8 ± 0.1 nm**	**No CD fingerprint**

Figure 5. Dense vertical lines 27 nm are measured in 4 corners 1x1 mm^2 of the field overlapping with 3 black borders of the neighboring fields. Field to field interaction delta CD maps are constructed: for high level of OOB CD drop is very large (5 nm at the edge); for typical OOB level the CD impact is reduced to 0.6 nm and no CD fingerprint is observed in OOB free system. Wafer and field layouts are the same as in Figure 4 (bottom).
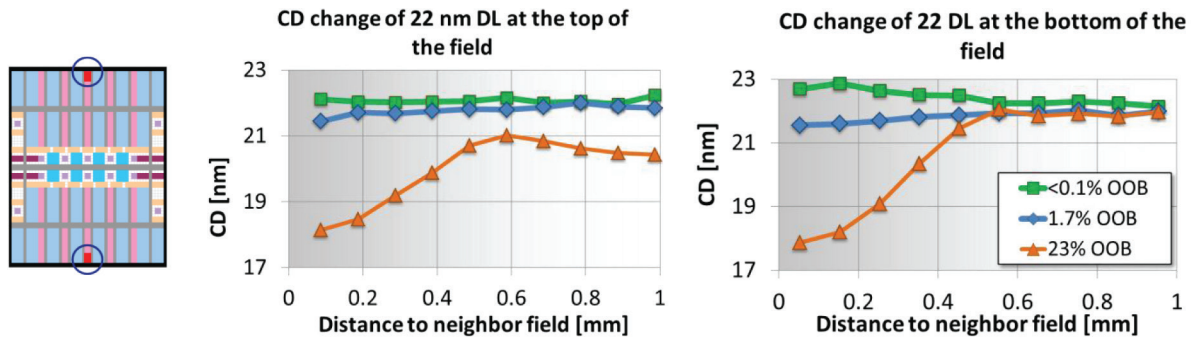

Figure 6. Dense lines 22 nm are measured at bottom and top of fields with neighbors. For high OOB level ~4 nm CD drop is observed. For the intermediate OOB level, CD drop is ~0.5 nm.

2.2. Black border manufacturing

The black border trench is etched in the image border area that encloses the full image field (Figure 3). The image border area measures 3 mm in scan (or Y) direction and 2 mm in slit (or X) direction at reticle level. The width of the black border was measured in 12 locations. It was found to be 2000.11µm in X direction with a variation of 0.13µm (3σ) in width and 3000.14µm in Y-direction with a variation of 0.11µm (3σ) which is considered as sufficient good quality.[1] The black border is etched after patterning of the image field/die.

## 3. Imaging of Black Border Reticle

3.1. Imaging and simulations of 27 nm dense lines exposed on NXE:3100 with the black border reticle

Initial wafers were exposed on the ASML NXE:3100 at imec, Leuven, Belgium. The purpose of this test was to compare field to field interaction for fields with the ML etched black border. The results of the test were detailed discussed in the previous study:[1] here we give a short summary and also simulation results.

Two exposure layouts were used: 1) Small Field exposure (Figure 4, top): only the central part 20.9x19.3 mm^2 of the mask surrounded by 55 nm absorber image border is exposed; 2) Full Field exposure (Figure 4, bottom): the full image field of the mask is surrounded by the ML etched black border is exposed. In both cases there is no spacing between fields and there are isolated reference fields and fields with different number of neighbors on the wafer. These two layouts serve for the comparison of ML etched black border and absorber image border impact on imaging of adjacent dies.

Detailed CD maps of 27 nm vertical dense lines are measured in 1x1 mm^2 corners of each field using ASML YieldStar S100 scatterometry tool. A field to field interaction map is obtained by the subtraction of CD's in the average isolated corner from
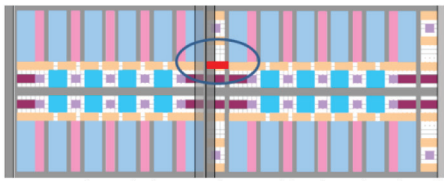
Measured module overlaps with absorber border
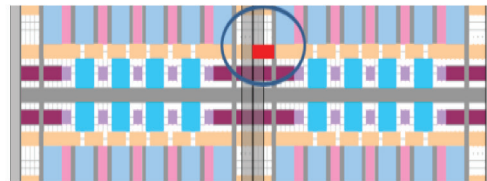
Measured module overlaps with black border

Legend: VD = Vertical Dense lines, HD = Horizontal Dense lines, VI = Vertical Isolated lines, HI = Horizontal Isolated lines
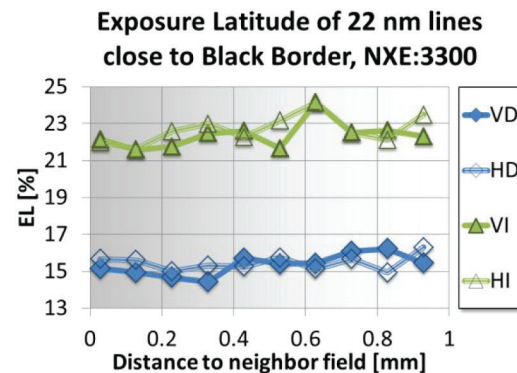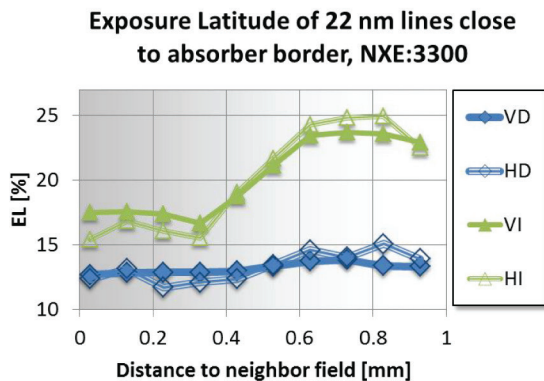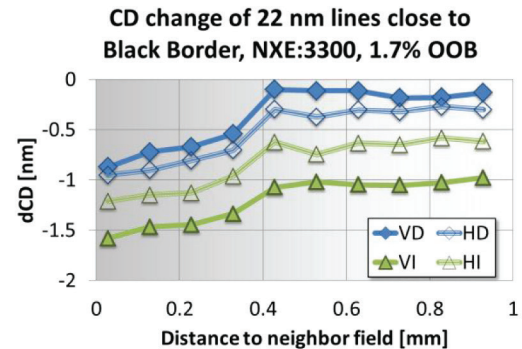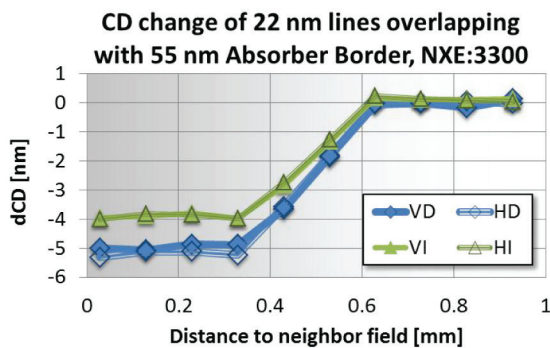

Figure 7. CD and exposure latitude change of 22 nm lines exposed on NXE:3300 at edge of the field and impacted by 55 nm absorber border reflection (left) and by the black border reflection (right) of the neighboring field.

CD's in the corner with three neighboring fields. The corners of the small field receive reflections from the absorber border and the corners of the full field receive reflections from the ML etched black border. A similar methodology was already used in our previous investigations of the field to field effect.[8]

The results of the experiment are simulated using Tachyon OPC software (ASML Brion). The software is able to simulate an EUV and DUV flare map for field to field interactions including impact of EUV and DUV reflection from image border, out-of-field EUV scattered light (flare), DUV reflection from ReMa (Reticle Masking) blades. Slightly asymmetric positions of ReMa blades are taken into account in the simulation.

In order to account for the DUV reflections, a measured value of out-of-band (OOB) DUV light in imec NXE:3100 is used.[10] It is measured using a high DUV reflective aluminum (Al) reticle specially designed for DUV OOB measurements[9] in the same resist which is used for the imaging experiment. As Al has a much higher DUV reflectivity than EUV mask stack, the OOB level was recalculated from the Al level to the mask ML level using the DUV reflectivity ratio of the ML (~55%) and Al (~85%): this value 1.43% is used as input for Tachyon simulations.

A very good match is obtained between the measurements and simulations. The model is calibrated separately for EUV and DUV light. A calibrated CD sensitivity to EUV light is -1 nm/% and to DUV light -1.4 nm/%. Similar CD sensitivity to OOB light can be deduced from OOB studies of imec:[10] 1.3 nm/% (this value is derived as the slope of CD versus relative OOB dose (Figure 7 in [10]), divided by OOB level for the resist D in question). The fact that the remaining CD impact can be modeled using measured OOB level and CD sensitivity, confirms the hypothesis that the root cause of this effect is OOB light reflected from the black border.

In addition, if CD change can be simulated, it can potentially be corrected using Tachyon NXE OPC+ software. The correction of the EUV absorber border effect would require a very high accuracy mechanics of ReMa blades which is not feasible. Moreover, the high level of the background light will reduce the contrast of the image (Section 3.3). The correction of the remaining OOB effect from the black border, on the contrary, is feasible and can be applied to the mask design in combination with flare and shadowing OPC.

Table 2. CD and exposure latitude drop at the edge of the field for 22 nm lines overlapping with 55 nm absorber border and with the black border.

Structure	CD change [nm]		EL change [%]	
	22 nm DL	22 nm IL	22 nm DL	22 nm IL
Absorber border	5.1±0.2	4.0±0.2	1.4±0.7	7.2±1.3
Black border	0.64±0.08	0.52±0.09	0.3±0.4	1.0±1.1

Table 3. Calculation of CD sensitivity to EUV/DUV reflection from absorber border.

Scanner type	Alpha Demo Tool		NXE:3100			NXE:3300	
Structure	32 nm DL	32 nm IL	30 nm DL	27 nm DL	27 nm DL	22 nm DL	22 nm IL
Absorber height	44 nm	44 nm	70 nm	55 nm	55 nm	55 nm	55 nm
Absorber stack reflectance to EUV	5%	5%	1.20%	2.70%	2.70%	2.70%	2.70%
Average Absorber stack reflectivity to DUV 140-300 nm	15%	15%	15%	15%	15%	15%	15%
DUV OOB level	<0.3%	<0.3%	<0.1%	<0.1%	1.4%	1.7%	1.7%
Relative EUV + DUV reflection	8.4%	8.4%	2.0%	4.5%	4.9%	5.0%	5.0%
CD drop, nm	8	7	2.3	4.3	5	5	4
CD sensitivity, nm/%	1.0	0.8	1.1	0.9	1.0	1.0	0.8

3.2. Impact of Out-of-Band DUV light on imaging of the reticle with black border

In order to verify the impact of OOB DUV light on imaging with the black border, the reticle is exposed on ASML NXE:3300 scanners with different levels of OOB light: 23%, 1.7% and <0.1%. The level of OOB light is measured using the earlier mentioned Al coated reticle[9] in resists used in the following imaging tests. The values are normalized to ML DUV reflectivity as described in the previous section. Since EUV mask absorber stack has lower DUV reflectivity (5-20%), the OOB level is a worse case estimate for a clear field mask.

The high level of OOB in the scanner was present in the initial state of the tool and was used for the purpose of this experiment only. This high level of OOB will not be present in the production scanner. The low level of OOB (<0.1%) was achieved by using a special DUV filter. However the DUV filter reduces not only DUV 1.7% is a typical amount which can be expected in the current NXE:3300 scanner.

Wafers with Full Field layout (Figure 4, bottom) were exposed on NXE:3300 scanners with the three levels of OOB light. Dense vertical lines 27 nm are measured in 4 corners 1x1 mm² using ASML YieldStar S100. Field to field interaction delta CD maps were constructed (Figure 5) in the same way as described above. For the high OOB level, the observed CD drop at the edge of the field is about 5 nm. There is no imaging in the corners; this situation is similar to the reflection from

the absorber border. For the intermediate level of OOB light, the CD drop at the edges is 0.6 nm and 1.8 nm in the corners; this shows that the impact in the corners is just 3x multiple of the impact at the edges. For the low OOB level no field to field fingerprint is observed. This proves that the remaining field to field interactions result from OOB light reflections from the black border.

3.3. Imaging of 22 nm lines on NXE:3300 with the black border reticle

The impact of OOB reflection is also measured for 22 nm dense lines at top and bottom part of the field (Figure 6) using a Hitachi CG-4000 SEM. For the high OOB level ~4 nm CD drop is observed at the bottom of the field. At the top of the field two effects can play a role: reflection from the black border resulting in ~4nm CD drop (~0.1 mm to the edge of the field) and, possibly, reflection from a ReMa blade resulting in 1-1.5 nm CD drop (0.6-1 mm from the edge of the field). For the intermediate OOB level, the CD drop is ~0.5 nm. For the low level of OOB the CD is actually flat at the top of the field, while there is some CD increase at the bottom of the field which is not yet understood (not reticle CD related). These CD changes are comparable to the values for 27 nm dense lines.

In order to compare the impact of the black border and standard absorber border performance for 22 nm lines, special wafer layouts were used where the measurement module is
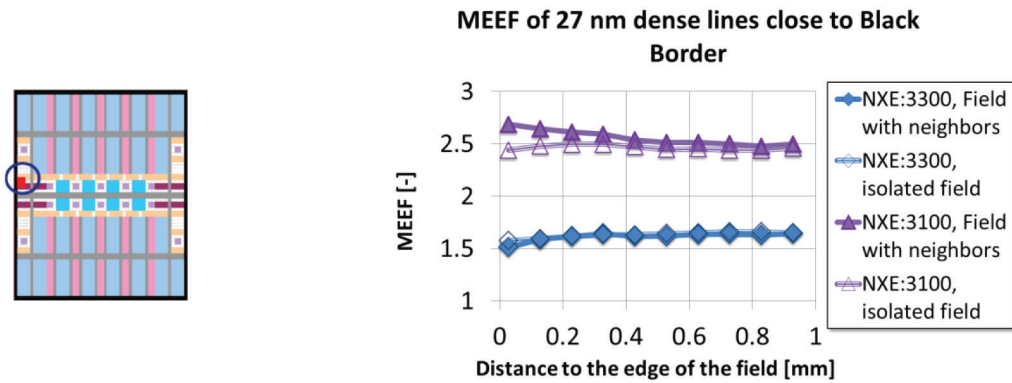
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Figure 8. MEEF of 27 nm dense lines measured at the edge of the field on NXE:3100 and NXE:3300 wafers.
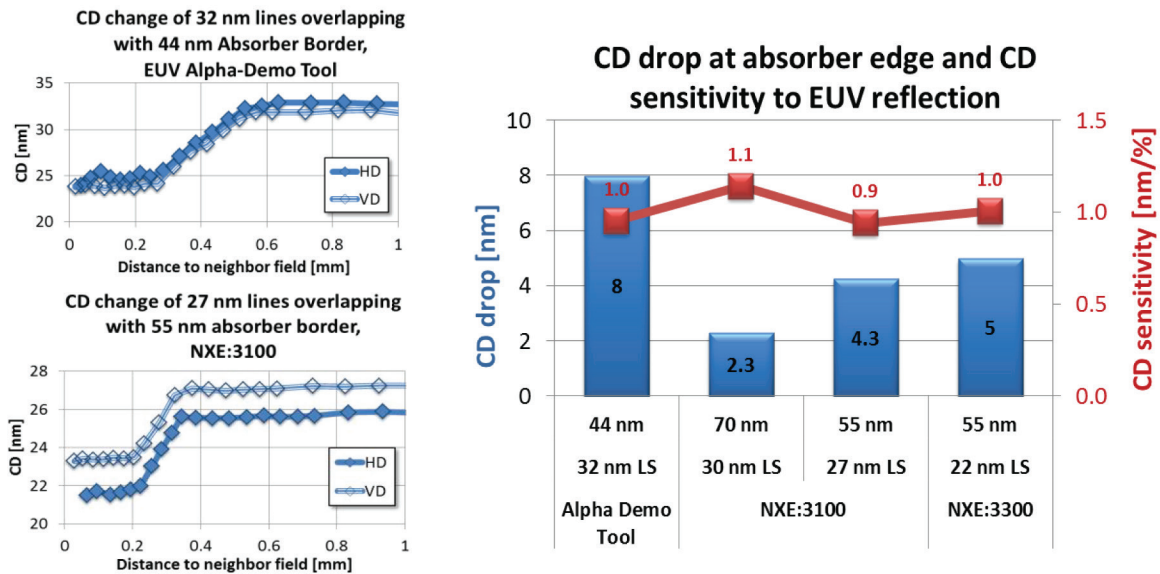

Figure 9. (Top left) CD profile at 44 nm absorber border for 32 nm lines exposed on ADT; (bottom left) CD profile at 55 nm absorber border for 27 nm lines exposed on NXE:3100; (right) CD drop and CD sensitivity to absorber border reflections for three scanner types, four imaging nodes and three absorber heights.

overlapped by absorber border (Figure 7, left) and by the black border of the neighboring field (Figure 7, right). A wafer with several dose steps (a so called dose meander) is exposed to determine (dose sensitivity based) exposure latitude at the edge of the field. The exposure latitude is a metric for image contrast. For the typical OOB level delta CD curves (difference between an average field with neighbors and an average isolated field) are constructed for the left part of the field for vertical and horizontal dense and isolated 22 nm lines.

The observed CD drop for 22 nm lines at the edge of the field is 4-5 nm for the absorber border and ~0.5 nm for the black border. For the absorber border we found an exposure latitude drop of~7% for isolated lines and 1.4% for dense lines. It is unclear why the contrast of dense lines is less sensitive to reflections from the image border.

At the black border the exposure latitude drop is marginal and do not exceed the measurement noise level. The stable expo-

sure latitude at the black border proves that there is (almost) no impact of black border OOB reflections on the contrast.

3.4. Impact of the black border on MEEF of 27 nm dense lines

Another metric which characterizes contrast is Mask Error Enhancement Factor (MEEF). MEEF is measured for 27 nm vertical dense lines at the left edge of isolated fields and fields with neighbors using NXE:3100 and NXE:3300 wafers exposed with an intermediate level of OOB light. (27 nm lines are chosen since no 22 nm MEEF modules were present on the reticle.)

MEEF on NXE:3300 is lower than that on NXE:3100. This is expected as NXE:3300 has higher NA and optical contrast. MEEF shows essentially a flat behavior as function of the distance from the edge. MEEF variation does not exceed 0.2. This proves that there is no impact of black border presence or field to field interactions on MEEF.

Table 4 Calculation of CD sensitivity to EUV/DUV reflection from the black border.

Scanner type	NXE:3300		
Structure	22 nm DL (left edge)	27 nm DL (slit center)	22 nm DL (right edge)
DUV reflectance of black border (LTEM + CrN)	<0.05%	<0.05%	<0.05%
DUV reflectance of black border	6%	6%	6%
DUV OOB level	22.1%	24.5%	28.1%
Relative EUV+DUV reflection	2.7%	3.0%	3.5%
CD drop, nm	4.0	4.1	5.0
CD sensitivity, nm/%	1.5	1.4	1.4

4. Discussion

4.1. Impact of absorber border on imaging through EUV scanner generations

Field to field interactions due to reflections from absorber border were investigated in a series of our previous work[2,3,8,7,1] as well as in the current work. The results allow to derivation of systematics of the CD response for multiple imaging nodes from 32 to 22 nm lines/spaces, for three scanner generations: starting from ASML EUVL Alpha-Demo Tool (ADT) to NXE:3100 to NXE:3300 and for three absorber heights used on reticles: 44 nm, 70 nm and 55 nm.

CD drop due to the absorber border reflections can vary from 2 to 8 nm (Figure 9, Table 3) depending on absorber height which is used on a particular reticle. The absorber stack reflectance to EUV light is determined by the absorber height,[11] while the reflectivity to DUV light is practically independent of the absorber height since the penetration length of DUV light into absorber is only a few nanometers. The absorber stack reflectivity has a certain spectrum[9] for 140-300 nm wavelengths with an average of ~15%. If we know the EUV and DUV reflectivities of the reticle and the OOB level in the scanner, it is possible to calculate a lumped relative EUV+DUV reflection from the absorber border using to the following equation:

$$Relative\ EUV + DUV\ reflection = \frac{R_{abs}^{EUV}}{R_{ML}^{EUV}} + OOB\ \frac{R_{abs}^{DUV}}{R_{ML}^{DUV}},$$

Where $R_{ML}^{EUV} = 60\%$ and $R_{ML}^{DUV} = 55\%$.. OOB is only a minor part of the background light coming from absorber. By dividing the CD drop by the found value, one can calculate CD sensitivity to the absorber reflection. For all cases the sensitivity was 1.0±0.1 nm/% background light for dense lines and slightly smaller ~0.8 nm/% for isolated lines.

The CD drop at the absorber border is mostly determined by the absorber thickness. The CD sensitivity to absorber border reflection does not depend on imaging node (and resist) and scanner type. Field to field interactions become therefore more important for future nodes because of tighter CD uniformity requirements.

4.2. CD sensitivity to black border reflection

The CD sensitivity to black border reflections can also be calculated as described above (Section 4.1) using measured black border reflectance's (Table 1). For this calculation we have only used the data from high OOB level exposures, since the obtained values are more reliable because of a better signal to noise ratio.

The sensitivities of 27 nm and 22 nm dense lines are determined. Imaging of 22 nm isolated lines was unsatisfactory for the high level of OOB. For the left, central and right location through scanner slit, different OOB levels are measured and also different CD drop is observed. However the sensitivity is close for 22 nm and 27 nm dense lines.

Most input parameters for the sensitivity calculation have a large error. For example, OOB level can be ~2-3% underestimated. This is related to the test design where a dose meander is exposed and a dose value for which the resist clears is used to determine OOB, while this dose value is higher than a real dose-to-clear of the resist. For smaller OOB values, the OOB level determination is much more accurate. Futhermore the CD drop variation is 0.5-1 nm at various edge positions. The error analysis results in 1.3±0.3 nm/% estimate of CD sensitivity to Black Border reflection which is 98% OOB DUV light in this case. This value is very close to 1.4 nm/% based on OPC model calibration (Section 3.1) and to the value 1.3 nm/% derived from imec work.[10] Notice that this sensitivity is higher than the sensitivity to EUV light reflected from the absorber border. The dependence of this value on a particular resist type is unclear so far since resist dependence is already taken into account in OOB level. We plan to perform more OOB sensitivity measurements in the future for several resists.

4.3. Reflectance requirements for black border

For a typical OOB level we have observed an impact of OOB reflection from the black border on CD which is 0.6 nm at the edges of the field and 1.8 nm in the corners. For the standard ASML CD uniformity (CDU) layout 13x7 field positions, the CD drop result in 1.3 nm CDU. This value is too high for the CDU budget of 1.4 nm targeting 16 nm dense lines on a ASML NXE:3350. In order to minimize the black border impact on CDU down to <5%, the OOB reflectivity from the black border should be reduced by 4x, a target value for the black border reflectance is then <1.5%.

A new type of black border which is currently under development already showed DUV reflectance reduction of more than 2x (at 193 nm light) compared to the current performance. Optimization work using simulations is ongoing.

5. Summary

CD changes at the edges and in the corners of adjacent fields occur, if a reticle with a standard absorber image border is exposed in a dense layout on the wafer. This CD change is independent of imaging node, resist and scanner in use; rather it depends on absorber thickness. For lines/spaces the CD sensitivity to EUV reflection from the absorber image border is 1 nm/% of relative background light. For 55 nm thick absorber the resulting CD drop at the edge of the field is ~5 nm, in particular, for 22 nm lines exposed on NXE:3300. For 22 nm isolated lines, exposure latitude drop of 6-7% is observed as a result of absorber border reflection.

This problem can be mitigated by creating a black border on the reticle. In this work a ML-etched type black border is evaluated. Its EUV reflectance does not exceed 0.05% and the DUV reflectance is less than 6%. Due to the presence of OOB DUV light in the scanner, field to field interactions are strongly reduced, but still observed. A CD drop of 0.5-0.6 nm is observed at the edges of the field and of 1.5-2 nm in the corners for a typical OOB level in an EUV scanner. The CD sensitivity of lines/spaces to OOB reflected light is ~1.3 nm/%. This effect can be simulated and therefore be corrected by Tachyon NXE OPC+ software. No essential impact of black border reflections on contrast metrics, such as exposure latitude and MEEF, is observed.

In order to mitigate the impact of OOB black border reflection on CDU, the DUV reflectance should be reduced to <1.5% (4x reduction of the current value). Optimization work is currently ongoing and 2x reduction of reflectance (for 193 nm wavelength) has already been achieved.

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EDITORIAL

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An EUV-tool with NA adequate for 10nm lithography and beyond will most likely need a 9" reticle. At the SEMICON Europa in Dresden this October, T. Heil, Director System Engineering, Carl Zeiss, Oberkochen, Germany, mentioned that a 9" reticle using a 6 X demagnification factor will allow to expose a full field chip (26 x 33) on the wafer. For a 6" reticle and 8 X reduction one only gets a quarter field and the data has to be stitched.

Closing my comments on this year's EMLC conference, I want to congratulate Natalia Davydowa from ASML, the Netherlands, for her excellent presentation "Experimental Approach to EUV Imaging Enhancement by Mask Absorber Height Optimization". The main conclusion of her paper was that thin EUV absorber (52 nm, 59 nm) is sufficient for good contrast and printability of dense structures in memory applications, and that thicker absorber layers (e.g., 66 nm) are more suitable for logic applications with varying pitches. This paper was selected for the Best Paper Award of the EMLC2013. She also received the Best Poster Award at Photomask 2013 for "Impact of an etched EUV mask black border on imaging and overlay, part II". So we will see her again as presenter at the EMLC2014; June 24th and 25th 2014 in Dresden, Germany.

There, I am looking forward to welcome you at the 30th European Mask and Lithography Conference, EMLC2014.

Industry Briefs

■ ASML and imec launch Advanced Patterning Center

ASML and Imec have launched The Advanced Patterning Centre, a semiconductor patterning facility, to be located at the Imec campus in Leuven, Belgium. It will offer the global semiconductor ecosystem patterning knowledge for sub-10nm technologies. It is hoped that this will tackle upcoming scaling challenges due to the chip industry's move towards single digit nanometer dimensions.

The Advanced Patterning Centre will use actual devices to analyze and optimize process steps as well as materials and device architecture choices, while applying integrated metrology. To guarantee critical dimension, uniformity, and overlay control, soon to be measured in fractions of 1nm, Imec and ASML will collaborate to investigate the practical interaction between all the different steps in the chip patterning process. ASML will support the Advanced Patterning Centre by making available its scanners, metrology systems and holistic lithography solutions, and by using the resources to optimize its offerings for the fab environment.

■ Microsoft to become a top-10 chip buyer on Nokia acquisition, says IHS

By **Jessie Shen,** DIGITIMES

With its upcoming acquisition of Nokia, Microsoft is set to become one of the world's top-10 original equipment manufacturer (OEM) semiconductor buyers, and will rank among the leading purchasers of microchips for wireless applications, according to IHS. In 2014, Microsoft is expected to become the eighth-largest OEM chip buyer, up from No. 13 in 2013 and 15th place in 2012.

Microsoft will spend an estimated US$5.9 billion in 2014 on semiconductors, up from US$3.55 billion in 2012 and from US$3.78 billion in 2013. (The 2012 and 2013 figures do not include spending generated by the Nokia buy, while 2014 presents post-acquisition purchasing. The Nokia deal will add about US$2 billion to what Microsoft would otherwise spend on semiconductors for 2014). Microsoft's new higher standing in 2014 also means it will be vying for fourth place in chip spending for wireless applications - along with a group of companies including ZTE, LG Electronics, TCL, and Ericsson. If Microsoft takes the No. 4 rank in wireless chip purchasing in 2014, it will still be behind market leaders Apple, Samsung Electronics and Huawei Technologies.

The Nokia acquisition will dramatically increase Microsoft's spending in the wireless segment. Prior to the deal, Microsoft purchased a relatively small quantity of semiconductors for its Surface line of tablets, some of which classified as wireless devices. The company spent just US$85 million in 2012 and will expend US$110 million in 2013 on wireless chips. The majority of the company's chip spending in recent years was related to its Xbox 360 video game console, regarded as a consumer electronics device. Approximately 37% of its US$5.9 billion spend in 2014, i.e., US$2.2 billion, Microsoft will spent on chips for wireless devices like smartphones and tablets.

■ SK Hynix starts full-scale mass production of 16nm NAND flash

By **Jessie Shen,** DIGITIMES, Taipei

In June, SK Hynix has started full-scale, mass production of 16nm 64-gigabit (Gb) MLC NAND flash chips, according to the South Korea-based memory chipmaker. It has recently started to mass produce the second version, more cost competitive due to its smaller chip size, the company said. SK Hynix has also developed 128Gb (16-gigabytes, 16GB) MLC chips based on the specification and endurance of 16nm 64Gb MLC, with mass production scheduled for early 2014, the company noted.

Generally, the thinner process technology shrinks, the more frequent interferences among cells occur, but SK Hynix applied up-to-date Air-Gap technology to overcome the interferences among the cells. The Air-Gap technology builds insulation shield with vacuum holes between circuits not with insulating substances. "After the company developed and started to mass produce the industry's thinnest 16nm product then, now prepared high density NAND flash product portfolio," said Jin Woong Kim, senior VP and head of SK Hynix' flash tech development.

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