# Introducing 157nm Full Field Lithography

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157nm lithography is currently considered as the main technology for the manufacturing of critical 65nm node layers and beyond. After a number of potential show stoppers of 157nm have been removed in the last three years, the final phase of development will now start based on the first full-field step and scan exposure systems. This paper describes the status and progress of the IMEC 157nm program, that is aiming to remove the remaining 157nm engineering challenges. The first full field scanner (ASML Micrascan VII) is currently under installation at IMEC. The investigation on a number of full-field issues already started. Results on 157nm resist full field patterning, on reticle handling including vacuum ultra violet cleaning, and on hard pellicle printing are discussed in this paper.

**Keywords : $F_2$ lithography, 157 nm resists, integration, hard pellicles, VUV cleaning**

## 1. Introduction

157 nm lithography is considered the leading candidate for semiconductor device manufacturing at the 65 nm technology node. Early on, a number of critical issues have been identified, that could eventually become show stoppers for the commercialization of 157nm lithography [1-3]. Besides the identification of a suitable reticle substrate material, also the absorption of all existing resist chemistries had to be decreased significantly at 157nm. Moreover the quality and required quantity of $CaF_2$, the main optical material for manufacturing the projection and illumination lenses was a high risk. Along the development path of 157nm lithography, a new critical issue was discovered by NIST [3]: the intrinsic birefringence of $CaF_2$.
After the 3rd International Symposium on 157nm lithography, organized in Antwerp in September 2002, it was concluded that all potential showstoppers for 157nm lithography were removed [4-8]. Nevertheless, serious engineering challenges remained to be solved, as there are : optical path stability and contamination mitigation in full field scanners; reticle substrate transmission under typical handling in wafer fab, due to organic contamination; hard pellicle imaging quality; and last but not least 157nm transparent resist patterning for 65nm critical layers. The IMEC 157nm lithography development program is designed to address the remaining challenges. Most of these challenges require the availability of a full-field step and scan exposure system, in order to be tackled efficiently. The first 157nm full field scanner (ASML Micrascan VII) has been shipped to IMEC in April 2003 and is currently under installation. Despite the fact that the Micrascan VII is not yet fully operational at IMEC at this current time, the work on several of the remaining technical challenges has been started. This paper is giving an update on the status of these projects: 157nm resist process development, 157nm reticle handling and hard pellicle imaging.

## 2. 157nm resist status

Each new wavelength has required the development of new photoresist chemistries, the main challenges being to combine transparency at the imaging wavelength with good lithographic performance and dry-etch resistance. The typical polymers used in 248nm and 193nm resists are far too absorbing to be used in 157nm. Early in 2001, when applying 248nm-based chemistries, resist materials with absorbances in the order of 6-7/µm were supplied. These materials required films no thicker than 70nm and, moreover, they could only be patterned on reflective substrates (Fig. 2a). For imaging in 150 to 200nm film thickness with good profile and CD control, the resist absorbance must be reduced to below 1/µm. The two main approaches [9-14] to reduce absorption have involved incorporation of fluorine and/or silicon into the polymer. By fluorine incorporation in the side chain of the polymer, absorbances between 2 and 3/µm could be achieved. A further reduction of absorbance below 2/µm requires the incorporation of fluorine atoms into the polymer backbones, such as in tetrafluoroethylene [13] and monocyclic monomers [9,10]. A breakthrough in resist transparency was realized in 2002 with the introduction of a new fluoropolymer by Asahi Glass Co. Ltd. [10]. Formulated resists based on this polymer could achieve the absorption target of <1/µm [10, 12]. The trend of decreased absorbance has been continued in 2003 and recently high transparent resist materials with good imaging performance have been reported by several researchers [15-21]. Main issue still to tackle is the trade-off between absorbance and etch resistance. The trend of decreased absorbance is shown in Fig 1 for formulated resist materials from commercial suppliers. State of the art 157nm resist nowadays have reached absorbances of 1/µm and below.

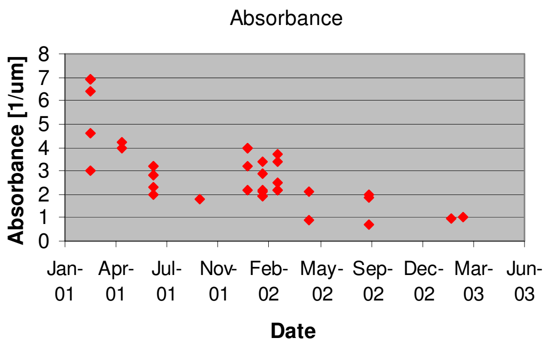


**Fig. 1:** Absorbance (log10) of 157nm resist from commercial suppliers versus time.

As such, the latest advanced resists are capable of imaging on anti-reflective layers (organic anti-reflective coating (ARC) or inorganic ARC such as SiON) in a thickness of well over 150nm (Fig. 2b). The feasibility of the resolution capability for the 65nm node was demonstrated by exposures on a 0.85NA (numerical aperture) stepper (Fig. 2b). An ultimate resolution of 55nm lines has been reported [21].

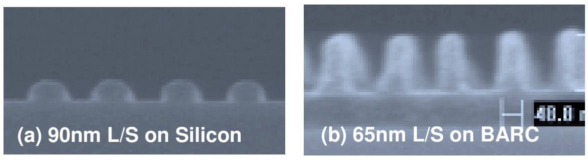


**Fig. 2:** (a) 90nm L/S (lines and spaces) exposed on a 0.60NA micro-stepper with alternating PSM in 67nm thick UTR (ultra-thin resist) resist, (b) 65nm L/S exposed on a 0.85 NA microstepper with PSM in 150nm thick transparent fluoropolymer resist.

In summary, tremendous progress has been made in the resist development: 157nm resist technology is moving out of the basic chemistry stage into a stage of formulation and process development. All resist materials have been evaluated on micro-stepper up to now. The next step is to look at the performance of resists on full field 157nm scanners and to work on integration issues, such as delay stability, line-edge roughness and etch resistance.

## 3. 157nm resist full field patterning

### 3.1 Introduction

Before the availability of 157nm full field scanners, resist development and benchmarking [6] of resist materials from commercial suppliers is being carried out on microsteppers (as they are installed at International Sematech and at Selete). From the development of 193nm resists, it has become clear that resists, developed on microsteppers, can sometimes perform quite differently on a number of aspects when exposed on full-field scanners. Moreover, also the more resist integration related aspects such as CD uniformity, delay stability, pattern transer can only be effectively optimised and tested on full field scanners. For those 157nm resists, performing well on the 157nm microsteppers, and showing reasonable performance at 193nm as well, a number of full-field properties have been investigated through 193nm exposures before the 157nm full-field scanners are available. In this way, it is our belief that a number of less promising full-field properties of those 157nm resists can be discovered and fed back to the resist manufacturers early on.

## 3.2 Integration of 157nm resist chemistry

Based on resist screening experiments on micro-steppers at Sematech and at Selete, 2 resist materials have been selected to check the full field patterning properties using the 193nm litho-cell at IMEC. Both resists A and B showed good imaging quality at 157nm (Fig.3), exposed on a 157nm micro-stepper. Resist A has an optical absorption at 157nm of 2.2/µm. The resist is applied at a thickness of 110nm. Resist B is more transparent at 157nm, having an absorption of 0.9/µm. Resist B could be applied at a thickness of 200nm for exposure at 157nm.

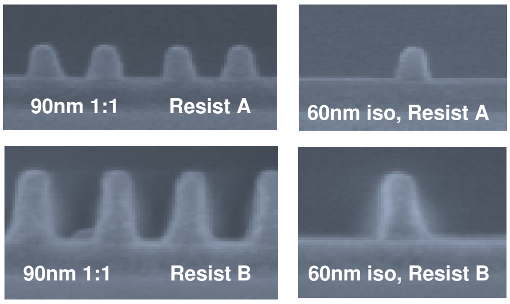


**Fig. 3 :** Profiles of 90nm dense and 60nm isolated lines in resist A and B, printed on the ISMT microstepper at 0.60 NA using an alternating PSM.

Both resist show good resolution, but improvements of LER is still required. Line-edge roughness for 157nm resists A and B is respectively 8nm and 12nm on 100nm L/S exposed at 0.75NA with a BIM at 157nm. The higher LER for resist B is illustrated in Fig. 4.

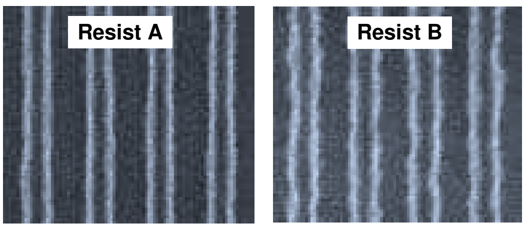


**Fig. 4 :** Top/down pictures of 100nm L/S exposed with a BIM and 0.75NA on the ISMT 157nm micro-stepper.

Metrology and inspection is a challenge for these 157nm resists due to the shrinkage of the resist material by exposure with the e-beam. This line width slimming as a function of inspection time is illustrated in Fig. 5 for two different 157nm resists. Resist shrinkage will remain part of our benchmarking work of 157nm resists on the ASML MSVII. Typical CD SEM shrinkage for 157nm resists is 4 to 9% as exposed on 157nm microsteppers [22].

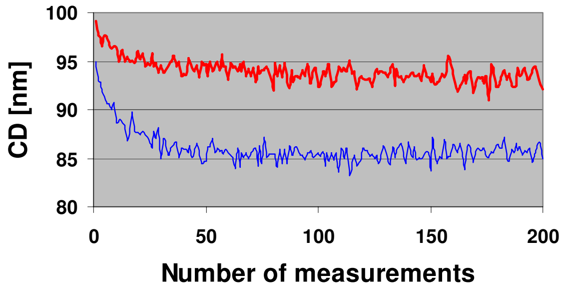


**Fig. 5 :** CD SEM shrinkage on nominally 100nm lines for 2 different 157nm resists.

Using the 193nm litho-cell at IMEC (ASML PAS5500/1100 interfaced to a TEL Clean Track ACT8), a number of patterning experiments have been carried out to check the full-field patterning properties of these two 157nm (semi-) transparent resists. Since both resists have a similar optical absorption of about 1/µm at 193nm, they were applied at a thickness of 200nm for the ArF experiments. The experience in 193nm learned us that the early 193nm resists developed on the micro-steppers, in some cases, showed a very high sensitivity to small levels of stray light (flare) when exposed on the early full-field scanners. After a while, resist companies could reduce that sensitivity. Also 157nm resists have been tested almost exclusively at 157nm micro-steppers to date. We exposed resist A and B using various mask tonalities and line widths on the 193nm litho-cluster (Fig. 6).

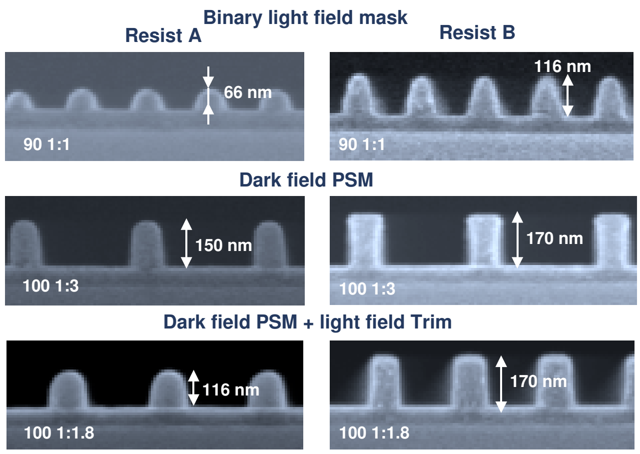


**Fig. 6 :** Profiles of 90nm and 100nm lines exposed in resist A and resist B using various reticles (BIM, PSM) and reticle tonalities.

The resist thickness for both materials was 200nm after coating and soft bake. When exposing resist A with a light field binary mask (0.75 NA), the remaining resist height that can be observed after

development is much below 200nm for 90nm 1:1 L/S : about 66nm. Exposing this same resist with a dark field alternating PSM, the profiles improve significantly and also the resist thickness loss is limited. When performing a second exposure with a light field trim mask, as is often done, again the resist thickness is reduced to approximately 116nm. Given that the flare level in the 193nm litho-cell are very low (long range flare, as measured with the disappearing box technique, is 1%), this indicates the extreme sensitivity of resist A to this effect.
Resist B is shown on the right hand side in figure 6. When exposing 90nm 1:1 lines with a BIM, resist thickness loss is about 80nm, which is much less than for resist A.. When exposed with the dark field alternating PSM without and with a second light field trim mask exposure, resist thickness loss is limited to about 30nm in both cases. Obviously this resist B is already much less sensitive to straylight and mask tonality effects. Nevertheless also a small difference in profile can be observed; more rounded tops in case of the light field mask.

The CD control for 157nm resist has been investigated. One of the most explored routes to improve the optical transparency of 157nm photoresists, is the incorporation of fluorine (F) in the resist polymer. It is well known that higher F-content will also increase the hydrophobicity of the polymer. As a consequence, one could expect difficulties in puddle formation during the development step, and hence a degraded CD uniformity within the wafer. The intra-wafer CD uniformity has been tested using both Fluoropolymer resists A and B. A batch of 10 wafers was spin-coated, exposed and developed. Since the available quantity of such resists is not high yet, it was impossible to plug the resists on the track. Instead, the semi-automatic dispense unit in the coating module of the TEL ACT 8 track was used. Figure 7 shows the results of the obtained CD uniformity for resist B. A typical average intra-wafer CDU of 5nm (3σ) was found, and a wafer to wafer variation of less than 3nm. These numbers are very comparable with the numbers obtained for the current state-of-the-art thin193nm resists, when coated on the semi-automatic dispense unit. As a result, it was concluded that the presence of fluorine in the 157nm resist polymer was not detrimental for the development uniformity of these resists.

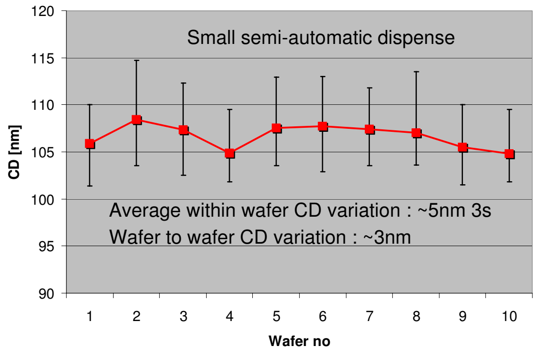


**Fig. 7** : CD uniformity of resist B, exposed on the 193nm litho-cell.

Important parameters on CD control are the post-exposure bake (PEB) sensitivity and the contamination sensitivity and/or Post-exposure delay (PED) stability.
The post-exposure bake temperature resist sensitivity was measured for resists A and B on 100nm L/S, when exposed at 193nm. For both resists very low values for PEB sensitivities were measured (Fig. 8) : 1.2nm/C for resist A and 0.3nm/C for resist B. This property is better than or at least as good as current state-of-the-art 193nm resists.

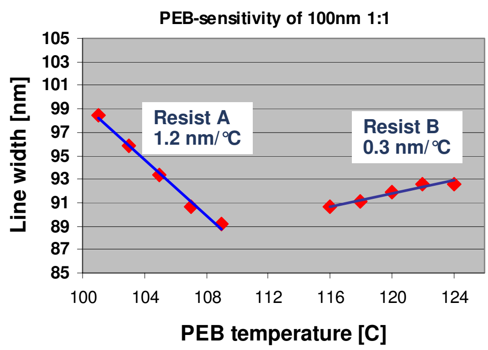


**Fig. 8 :** PEB sensitivity of resist A and resist B as exposed on the 193nm litho cell.

The post-exposure delay (PED) stability for both resists has been measured as well. The wafers were kept in the interface of the TEL track for times up to 30 min. The ammonia levels as measured in the track were 0.5ppb. In figure 9 and 10, the CD is plotted as a function of PED time. A very good PED stability for both resist was measured in an interfaced litho-cell at low amine levels. In both cases, no evidence of T-topping is seen, and the CD changes are as low as 0.013nm/min for resist B and 0.028nm/min for resist A. At slightly higher amine levels, e.g. at 0.8ppb in the stepper interface a CD change of 0.13nm/min for resist B and 0.30nm/min for resist A has been measured.

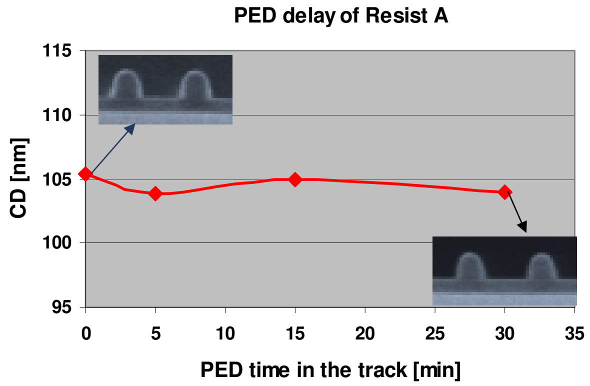


**Fig. 9 :** CD as a function of PED delay for resist A.

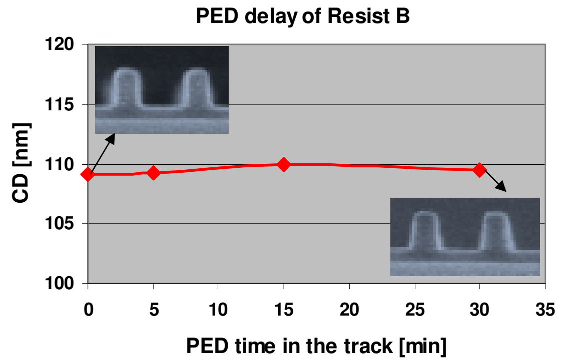


**Fig. 10** : CD as a function of PED delay for resist B

## 3.3 Pattern transfer

Pattern transfer has been tested for gate and for a contact holes stack, making use of 193nm exposures at IMEC (ASML PAS5500/1100 interfaced to a TEL Clean Track ACT8).

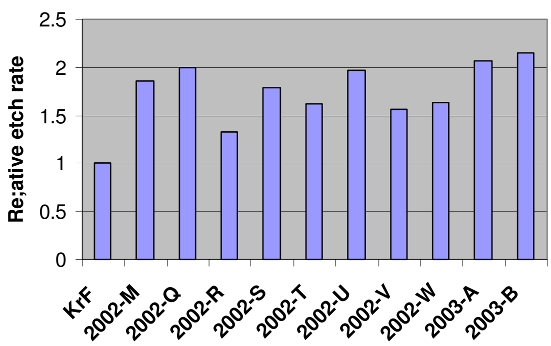


**Fig. 11:** Relative etch rate of the latest 157nm resists in a $CF_4$ plasma in a Lam 2300 Versys etch module.

First the etch rate of several resists has been tested in fluorine chemistry in a 2300 Versys. etch module from Lam Research. Figure 11 illustrates the etch rate for the new transparent resists normalized to the etch rate of a 248nm DUV resist (ESCAP chemistry). Typically the etch rate of 157nm is a factor 1.4 to 2.1 times faster than DUV resists.

Using a gate stack of 100nm poly-Si with an SiON hardmask/anti-reflective layer (ARC) on top, the development of a gate etch process was started for resists A and B exposed on the full-field 193nm litho-cell. Gate etching was performed in a 2300 Versys™ etch module from Lam Research. The total stack was etched using a single recipe, without intermediate resist removal. Typically, a fluorine based chemistry was used for the hardmask opening, while the bulk silicon etch was done using a sequence of process steps with $HBr/Cl_2/O_2$ chemistry, and fluorine-addition for appropriate sidewall passivation. For both resists, acceptable poly-Si profiles could be reached after poly etch and strip (figure 12).

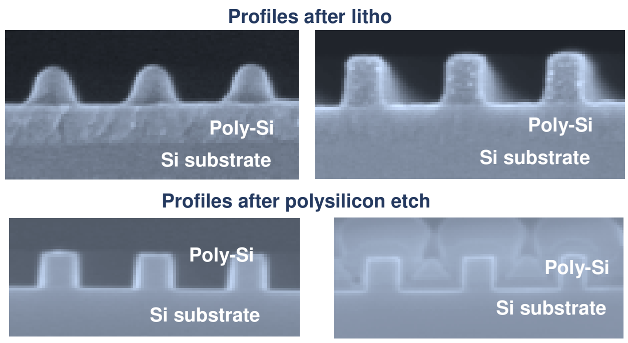


**Fig. 12 :** 100nm gates after litho (top) and after polysilicon etch and strip (bottom) using resist A (left) and resist B (right).

Using a dielectric stack of 300nm silicon oxide on a SiC liner/ARC layer, the development of a contact etch process was started for resists A and B exposed on the full-field 193nm litho-cell. The oxide etch chemistry was performed in a LAM ExelanHP chamber and based on a $C_4F_6/Ar/O_2$ plasma, which has been proven to be less aggressive for ArF 193nm. For both resists, the etch into the oxide down to the liner left about 100nm of resist on the wafer (figure 13), what, unexpectedly, indicates a relatively high oxide:resist selectivity. However, the sloped profiles in both cases could be caused by the resist facetting and erosion during etch.

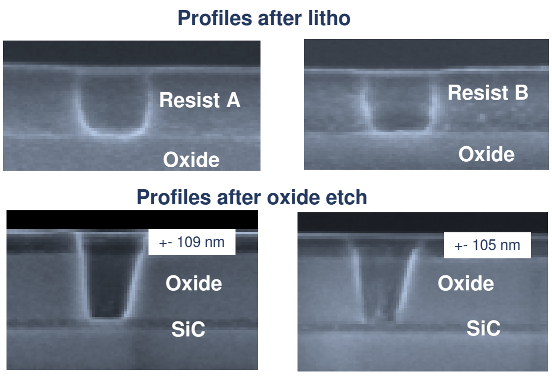


**Fig.13** : X-section of 120nm isolated contact holes after litho and after oxide etch in resist A and resist B, after stopping on the SiC liner and before resist strip.

Therefore, an alternative route was explored, using the same stack of 300nm oxide on a SiC liner but with an additional SiC layer as a top hard mask. In this case the SiC was first etched with a $Ar/N_2/CF_4/CHF_3$ plasma, the resist was stripped and the SiC was used as a hard mask for further etching into the oxide. This resulted in clearly improved contact profiles, as can be seen in figure 14.

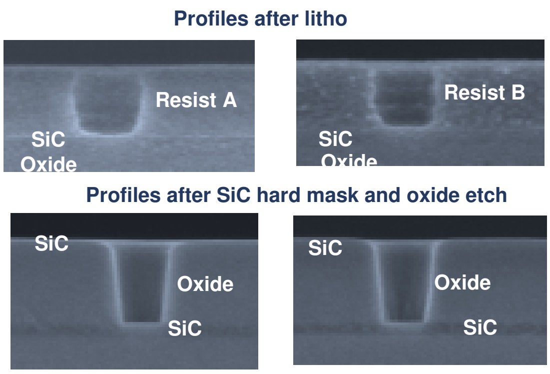


**Fig. 14 :** X-section of 120nm isolated contact holes after litho and after oxide etch in resist A and resist B, using a top SiC hard mask approach.

### 3.4 Imaging performance on a full field 157nm scanner

The ASML Micrascan VII is the first in a generation of 157 nm full-field, step-and-scan exposure systems. This system is currently under installation at IMEC. It has an optical numerical aperture (NA) of 0.75 and uses an all-calcium-fluoride catadioptric projection optics system. An un-narrowed fluorine laser provides the 157 nm illumination. The system is capable of exposing 200 mm or 300 mm wafers. Alignment is achieved using an off-axis system. The exposed field size measures 26 mm by 32 mm, and the optics reduction ratio is 4x.

Initial exposures have been carried on the ASML MSVII 157nm scanner during the factory acceptance test at ASML. Figure 15 shows 100nm L/S in resist A as exposed on the micro-stepper at ISMT and on the ASML MSVII full field scanner using an NA of 0.75, annular illumination with a Binary Mask (BIM). The profiles are sloped due to the still relatively high absorbance (A=2.16/um) of resist A at 157nm. Profiles on the micro-stepper and on the full field scanner are rather similar although it should be mentioned that the reticle used for the MSVII exposures is more dark field than the one used for the micro-stepper exposures. Exposures with a dark field mask in a more transparent resist (resist C with an absorbance of 0.97/um) is illustrated in Fig. 16 for both a BIM and a PSM. A detailed study of the effect of reticle tonality and the sensitivity of the resist profiles to flare on full field scanner is planned as soon as the 157nm scanner is fully operational at IMEC.

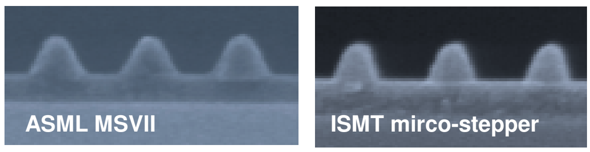


**Fig. 15 :** 100nm L/S in resist A exposed with annular illumination at an NA of 0.75 using a BIM on the ASML full field scanner (left) and the ISMT micro-stepper (right).

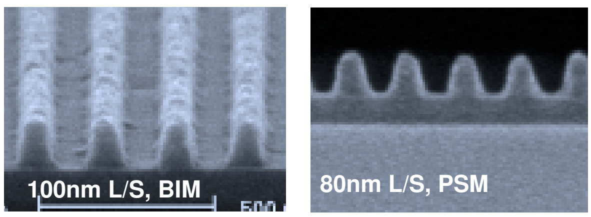


**Fig. 16 :** 100nm L/S in resist C exposed with annular illumination using a BIM (left) and 80nm L/S exposed with conventional illumination using an alternating PSM (right) on the ASML MSVII full field scanner.

## 4. Reticle handling

The expected transmission degradation at 157nm due to organic contamination of both reticle surfaces has been reported a few years ago [23]. It has also been demonstrated that these organic monolayers can be removed by a process of ozone cleaning [24], by illuminating the mask substrates with deep-UV light (e.g. 172nm light from a Xeradex light bulb) in presence of a few ppm of oxygen. In that way, the oxygen is forming

ozone, which forms free radicals upon exposure with sufficient energy to break organic bonds with a binding energy below a given amount.
Based on this principle, ASML Wilton has designed a cleaning module for implementation in the scanner. A stand-alone version of this module has been installed in the IMEC clean room. For measuring the effectiveness of the cleaning process, IMEC has invested in a Sopra purged ultra-violet (PUV) ellipsometer. This system can not only measure the optical parameters (n and k) of materials at wavelengths down to 157nm, but also measure the reticle transmission at 157nm, mapped across the reticle surface. During the present phase of the project in which the MS-VII tool is not yet in operation at IMEC, the evaluation of reticle contamination has been done based on transmission measurements, rather than CD control on exposed wafers. The first cleaning results with the UVO cleaner, measured by the Sopra PUV have proven that the issue is a small effect: transmission can be restored by about 1-2%, in line with published literature reports [23].
Although it is a small effect, a 1% variation in transmission, definitely if it shows up as a uniformity issue, can consume a considerable portion of the overall lithography CD budget. Relative to a typical exposure latitude of 10% (total range), for a CD of 65nm, a ±1% transmission variation will cause an effect around 1nm in CD, whereas the required CD control is also just a few nm.

## 5. Hard pellicle imaging

Due to the fact that no soft pellicle material has been identified with sufficient transparency at 157nm and at the same time a long durability upon 157nm exposure [25], the industry is currently focusing on the development of a so-called "thick" or "hard" pellicle. This hard pellicle is a 800µm modified fused silica plate, which is mounted on a reticle and serves to protect the reticle pattern against particle contamination. Due to the thickness of this parallel plate, this element has to be treated as a critical optical element in the optical path. The work on understanding the imaging contributions of hard pellicles has been started using 193nm step and scan systems. This work is carried out in close collaboration with ASML and the International Sematech Hard Pellicle Working Group. The main optical effects of introducing a hard pellicle to a reticle is (*i*) a defocus of the image, due to the non-negligible thickness of the parallel plate (Fig. 17 ) and (*ii*) a number of low order aberrations like spherical. The first effect can be easily compensated for by adjusting the height of the reticle stage in the step and scan tools. The low order aberration effects however need to be understood first and can be compensated by introducing new elements in the projection lens, provided that the effects can be made sufficiently reproducible. It is the goal of the hard pellicle working group to reach such a situation, so as to render the net effect of hard pellicles negligibly small.

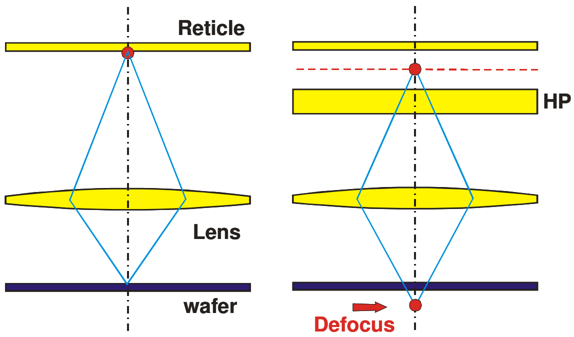


**Fig 17** : Optical effect of introducing a hard pellicle

In order to illustrate our current status, a simple distortion test was carried out and reported The introduction of a hard pellicle in the optical path of a step-and-scan system (experiment carried out in 248nm here) causes distortion vectors as large as 400-450nm. With all the currently existing and known correction mechanisms in a projection lens, the residual distortion can be brought back to about 12nm. From exposures without hard pellicle however, we know that we should reach distortion numbers of about 6-8nm. Hence the remaining 5nm distortion needs to be taken out by additional manipulators or by improving the mounting characteristics of the hard pellicles (with, as main requirement, the reduction of the local tilt [26]).

## 6. Conclusions

This paper has given an update on the status of the IMEC 157nm lithography program, aimed at tackling the remaining full-field technical challenges of 157nm lithography. The first 157nm full field exposure system (ASML Micrascan VII) is under installation at IMEC and will become fully operational in July 2003.

It has been shown that the infrastructure and methodologies are in place at IMEC to study 157nm reticle handling procedures, including VUV cleaning, as well as hard pellicle imaging. With respect to the full field patterning properties of 157nm resists developed today, promising results have been obtained with respect to CD uniformity, PEB sensitivity, delay stability, gate and contact patterning. Critical issues with 157nm resist is still methods to reduce shrinkage and line-edge roughness. Initial imaging on 157nm full field scanner has been demonstrated, process optimisation yet has to start.

## 7. Acknowledgements

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