EUROPEAN COMMISSION - Seventh FRAMEWORK PROGRAMME

Semiconductor
Equipment
Assessment
Leveraging Innovation

Deliverable 2.2.3, Report
SP02 HamaTech EUV MaskTrack*Pro*
Verification of performance of optimized recipes

Contract Number:	257379
Project Acronym:	SEAL
Project Title:	Semiconductor Equipment Assessment Leveraging Innovation

Document Identifier:	SEAL_SP02_D223_final.pdf
Status:	Final

Title of Document:	Deliverable D2.2.3, SP2.2, Report
Dissemination Level:	Public (PU)

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Approved by: (PMB and/or SC)	

Created on:	April 23rd, 2012
Last update:	12th June 2012

Document history

When	Who	Comments
23rd April 2012	R.J.	Write the first draft of the document
26th April 2012	P.D.	Review feedback to Rik Jonckheere and approval after suggested changes
27th April 2012	R.J.	Further update based on feedback Peter Dress
1st May 2012	R.C.	Approval of the document
2nd May 2012	P.D.	Preparation of final document version and send document to SEAL project leader
12th June 2012	R.Ö., S.M.	Minor corrections by the reviewers were accepted

Project Management Board and/or Steering Committee Review

	Reviewer 1: Wolfgang Arden			Reviewer 2: Yoram Uziel		
	Answer	Comments	Type*	Answer	Comments	Type*
1. Is the deliverable in accordance with						
(i) the Description of Work?	☒ Yes ☐ No		☐ M ☐ m ☐ a	☒ Yes ☐ No		☐ M ☐ m ☐ a
(ii) the international State of the Art?	☒ Yes ☐ No		☐ M ☐ m ☐ a	☒ Yes ☐ No		☐ M ☐ m ☐ a
2. Is the quality of the deliverable in a status						
(i) that allows to send it to EC?	☒ Yes ☐ No		☐ M ☐ m ☐ a	☒ Yes ☐ No		☐ M ☐ m ☐ a
(ii) that needs improvement of the writing by the originator of the deliverable?	☐ Yes ☒ No	Very detailed report, only a few words were corrected	☐ M ☒ m ☐ a	☐ Yes ☒ No		☐ M ☐ m ☐ a
(iii) that needs further work by the partners responsible for the deliverable?	☐ Yes ☒ No		☐ M ☐ m ☐ a	☐ Yes ☒ No		☐ M ☐ m ☐ a

* Type of comments: M = Major comment; m = minor comment; a = advice

Abstract

In this deliverable the main results are brought together that qualify the two optimized cleaning recipes on the MTP to assure maximum cleanliness of the back-side of EUV reticles at the wafer fab, before use on the EUV scanner.

This deliverable further reports on an ADDITIONAL accomplishment beyond the original project targets; as now a back-side inspection capability has been incorporated in the previously combined cleaner and automation module. This additional achievement has been possible thanks to the success of a cross-cutting activity with SP10 IMDI.

Together with the previously established automated handling of EUV reticles via Dual Pods (see D2.1.3 and D2.1.4) the overall project outcome combines EUV mask cleaning, automated handling and in-situ back-side inspection into one tool. Thereby any need for manual handling, originally considered the main reason for reticle back-side cleaning at the wafer fab, is (virtually) totally overcome.

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1. Introduction

D2.2.1 described that thick particles present on the back-side of an EUV reticle can cause overlay issues on the printed wafer. As discussed in this deliverable, which was still based on the experience with imec's first EUV scanner, i.e., the ASML Alpha Demo Tool (ADT), the main origin for such particles was determined to be the manual handling to reload the reticles, upon receiving them from the mask shop, into the ADT-dedicated Reticle Storage Boxes (RSB's).Yet also the fact that they were not protected from fall-on particles during shipment was considered to contribute a lot.

D2.2.2 has reported the obtained results of back-side cleaning in this scenario. Through the frequent use of these ADT reticles, without being able to minimize the manual handling, gradually major "particle" contamination of the back-side of ADT reticles could not be avoided. It is considered that over time repeated clamping on the reticle stage without satisfactory avoidance of backside particles has evolved into non-recoverable damage of the backside of the reticle in the form of scratches and indentations. Not only were the reported cleaning recipes on the MTP limited in reaching a similar cleaning efficiency as a champion process established at INTEL (see D2.2.2), also a major part of these back-side "particles" were not even considered cleanable anymore.

Meanwhile imec has installed the pre-production EUV scanner from ASML, i.e., the NXE3100. As discussed under state-of-the-art, this scanner uses the Dual Pods that are being standardized (SEMI E152).

For other reasons than discussed here, the recipe in use for cleaning ADT reticles has also evolved towards reduced aggressiveness to the front-side (see for example the appendix in D2.1.4). The efficiency of cleaning the back-side had been tested quantitatively for the first time when preparing for D2.2.2.

While major progress has been achieved on realizing a fully automated handling of Dual Pods (see mainly D2.1.3 and D2.1.4), the main origin for back-side particles, i.e., manual handling, has been gradually reduced. While shipping of reticles in such Dual Pods remains a challenging target for the EUV community, the partners have seen a major benefit in using the SMIF pod (RSP200, for which the original MTP Cleaner already had an interface) as an intermediate measure for shipping reticles. In this way it has been possible to test the updated cleaning recipes in more typical circumstances where the cleaning plays even more the role as a measure to *avoid* that overlay-critical back-side particles can remain on the back-side of the NXE3100 reticle at the time of loading it onto the scanner, rather than trying to *heal* the effects of such "particles" after the reticle has been extensively used on the scanner without proper precaution.

Because this deliverable is of public nature, the details of the experiments and experimental results are not included.

2. State of the Art

The state-of-the-art has evolved quite a bit during the running time of subproject SP02:

At the start of the project the ADT was in use at imec as one of the only two customer sites with an EUV scanner. While Sematech was already leading a standardization initiative for the so-called Dual Pods, reporting on their superiority for shipping, as they actually are a removable hard pellicle, the reticle handling in the ADT environment still took place via the specific Reticle Storage Boxes. Although the MTP was equipped to interface with the cleaner to minimize the manual handling of the reticle itself, it was not fully successful. Meanwhile it became clear that the dual pods were selected for interfacing to the next generation EUV

scanner, i.e., ASML's NXE3100. Up to then the demonstration of SÜSS's SPM-free (*) cleaning had been hampered by the limitation of the reticle handling using the manual reload from shipping boxes. As imec installed this scanner during the run-time of SP02, replacing the ADT, the project could make even further developments, preparing a more pre-production oriented EUV scanner environment.
(*) SPM = Sulphuric acid / hydrogen Peroxide Mixture

Thanks to parallel interactions and projects (mainly imec's Advanced Lithography Program and Catrene EXEPT), as well as the cross-cutting opportunities that emerged among the SEAL sub-projects, the SP02 subproject team has been able not only to close to gap to the state-of-the-art: The integrated tool as now in place at imec actually has become a world-wide unique infrastructure where cleaning, handling and back-side inspection have been combined, while minimizing the particle adders that are mainly due to manual handling and shipping.

Shipping of reticle in Dual pods remains a required development for the whole EUV community, but the integrated infrastructure set-up at imec is fully prepared for this further work (beyond the scope of this project).

3. Results and Analysis

The results have been obtained stepwise. The main outcome of this qualification (= the original goal of this deliverable) is reported in section 3.2 below. First (section 3.1) the experimental aspects are discussed. The qualification results are obtained via the blank inspection equipment in use at INTEL, as originally intended. Further (in section 3.3) some example results are shown for the realization of back-side inspection on the SPARK.

3.1 Experimental

D2.1.4 already described the methodology of testing the in-situ cleanliness of the MTP including InSync, and the use of RSP200 for shipping. Whereas assuring correct orientation and visual cleanliness check at first still required manually opening the RSP200 before a reticle could be used on the NXE scanner, we have gradually worked towards using features of the InSync and SPARK (see further) to eliminate this step, and fully exploit the automated interfacing, hence avoiding adders by manual handling.

The cleaning recipe as available at the time of D2.2.2 has been further tuned to become less aggressive for the front-side (beyond the scope of this project), as to avoid damage to the multilayer mirror and capping layer. Combining this with the same back-side clean as before, established a first recipe (named "EUVBSNO9d") to be qualified in this new situation of virtually fully automated handling.

In a second cleaning recipe the plans discussed under Further Plan in D2.2.2 have been realized and combined into one aggressive recipe "MildFSAggrBS". While this recipe is also qualified for back-side cleaning efficiency in the present work, it should be noted that it has not been confirmed by dedicated testing that it is free of unacceptable impact on the pattern side. This aspect is considered beyond the scope of this project. Yet its analysis was inspired by the interest to investigate what cleaning virtually could achieve to *heal* masks that already have evidence of damages due to the lack of *avoidance* of back-side particles. Possible impact of too repeated cleans of the reticle in view of possible impact on the pattern side has been the main reason why, until today, this clean is not applied as default before every use on the scanner.

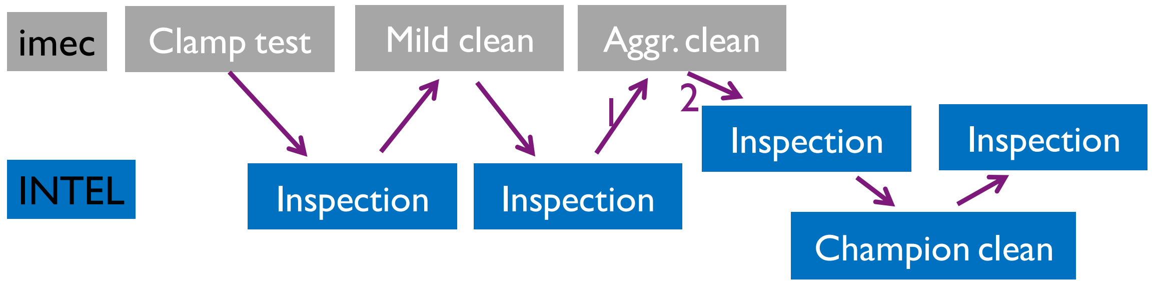


Figure 1: Total sequence used for cleaning recipe qualification in terms of cleaning efficiency (explanation see text). Labels 1 and 2 will be explained in section 3.3.

For the qualification of the recipes for back-side cleaning, we used dedicated tests with new reticles. The total sequence is explained in Figure 1. The qualification results are obtained via the blank inspection equipment in use at INTEL, as originally intended. Prior to the cleaning experiments the test reticles were cycled 20 times between the clamped state on the reticle stage and the EUV pod on the loadport, and back. Thereafter the test reticles were sent to Intel for inspection. After this qualification and shipping the reticles back to imec, they were cleaned at imec using the mild back-side clean. This was followed by a similar sequence of off-site inspection and shipping back, followed by the aggressive BS clean. Upon receiving the reticles again and inspection, Intel made an additional clean with a champion SPM-based clean, as described in D2.2.2, considered capable to remove all removable particle contamination. Based on this we could determine the cleaning efficiency of the mild, as well as the subsequent mild + aggressive clean. With a second set of test masks the performance of the aggressive clean was assessed separately.

In a third set of experiments we started to use a clean before such clamping test, but this qualification is only done on-site via the SPARK (see 3.3).

3.2 Results and discussion

Table 1 summarizes the cleaning efficiency of the 2 cleaning recipes for the two sets of test masks. The results illustrate that the mild BS clean has a CLE of about 80%, whereas the aggressive clean reaches about 90%.

	# removable defects	Removed by mild clean	Removed by aggr. clean	PRE mild	PRE (mild +) aggr.
total	158	123	18	78%	89%
.2 – 1 um	120	93	14	78%	95%
>1um	37	29	5	78%	89%
total	61	NA	55	NA	90%
.2 – 1 um	51	NA	46	NA	90%
>1um	10	NA	9	NA	90%

Table 1: Calculated particle removal efficiency (PRE) for two sets of experiments. The upper half corresponds to the first set, explained in figure 1. The second set (in grey shadow) did not include the mild clean in the sequence. The number of removable defects was determined based on the set of total removed particles (sum of all MT-Pro cleans + champion clean at INTEL). PRE is calculated for the individual/combined MTP recipe as shown.

The results reported here are still based on inspections run at INTEL for the reticle handling tests and cleaning test executed at imec. Although the RSP200 was used for shipping, which in principle already allows for automated handling both at INTEL and at imec, this means that adders during shipment may blur the overall cleanliness results. In other words, as the test reticles were NOT kept al all time during the experiment at imec while only using automated handling, over time these test reticles are expected to have gathered particle contamination faster than in principle avoidable. The reader is reminded that the intermediate result as reported in deliverable D2.2.2 was about 75%. A further improvement is now reported, to about 90%.

Needing off-site metrology or back-side inspection is therefore found an important flaw. It neither was an attractive method to assure that all reticles in use on the NXE are at all times maximum clean on the back-side. Exactly this is the reason why the next step was made in the further development of the infrastructure: the incorporation of back-side inspection.

3.3 Realization of integrated inspection

The incorporation of a back-side inspection capability in the InSync tool established was realized as a clear cross-cutting activity, because the SPARK tool (cfr. SP10 IMDI) of Nanda Technologies, now part of Nanometrics, has been selected.

Gradually during the dedicated tests described under section 3.1, we started to run parallel back-side inspection on the SPARK tool integrated into the InSync before shipping the reticle to Intel for off-site inspection, or after receiving the reticle back from Intel before clamping tests or before cleaning on the MTP.

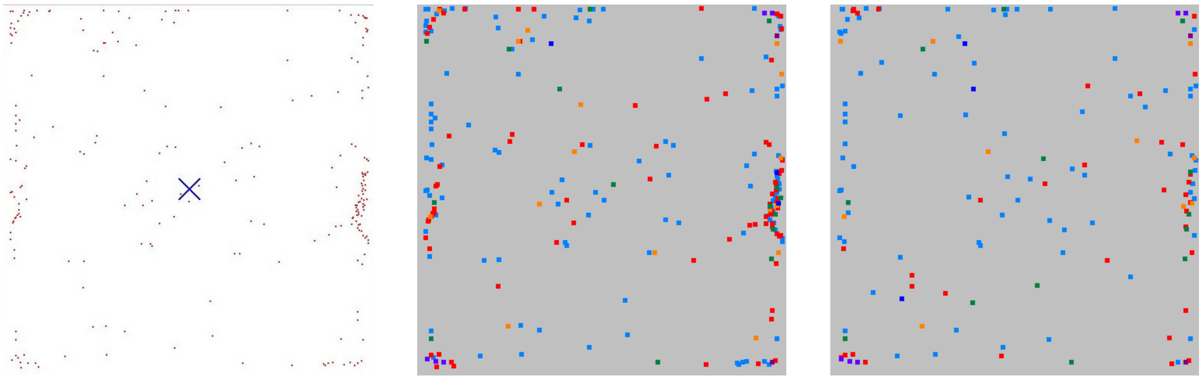


Figure 2: SPARK data obtained at imec before (left and center) and after (right) the aggressive clean in figure 1 (in between marks 1 and 2). Left illustrates the raw SPARK output. Center and right show the inspection results after size binning (colors assigned to sizes). Note these SPARK inspections (at imec) are not shown in the experimental flow of figure 1.

Figure 2 demonstrates the capability of the SPARK at imec by illustration as a defect map, for an example case (see caption).

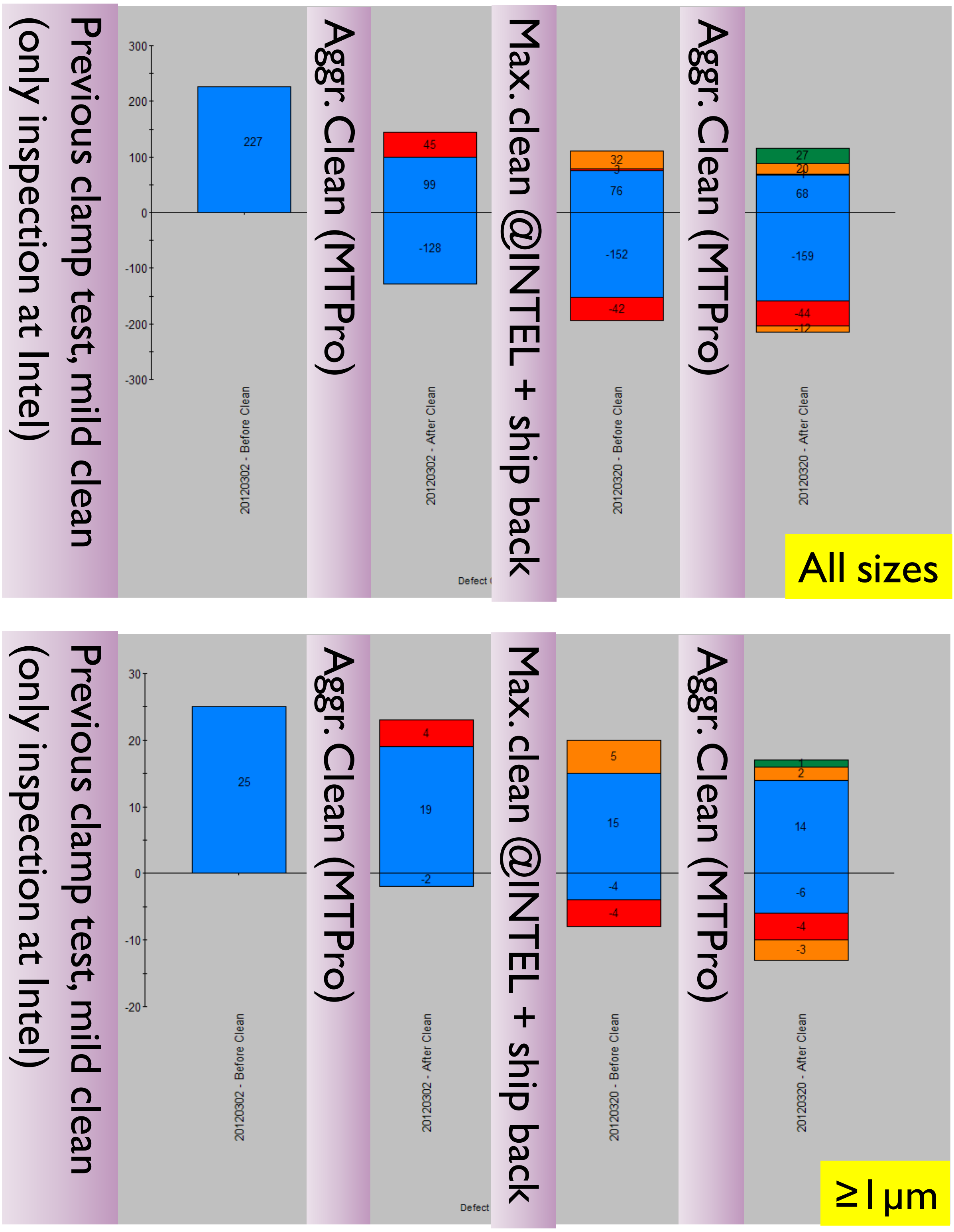


Figure 3: Illustration of the capability of the on-site inspection at imec (based on SPARK) to follow the evolution of the number of particles through an experimental sequence. In this example we start at label 1 in figure 1, and included an additional clean after receiving the reticle back at imec, to be added to the far right in figure 1. The top figure shows all detections; bottom only the detections above 1 micron. Explanation to the bar chart (top as example): in the first step 227 detections were made. In the second step 99 of those were still present, while 128 were removed. Yet 45 new detections were made. In the third step only 76 out of the original 227 remained, 162 had been removed. Of the 45 added in the second step, 42 were removed in the third step. The third step added 32 new ones, etc.

Figure 3 expands on the SPARK results obtained during the qualification of the second set of clamping tests discussed under Section 3.2, and demonstrates that it becomes possible to compare the defect inspection results at a given point in the sequence to another one.

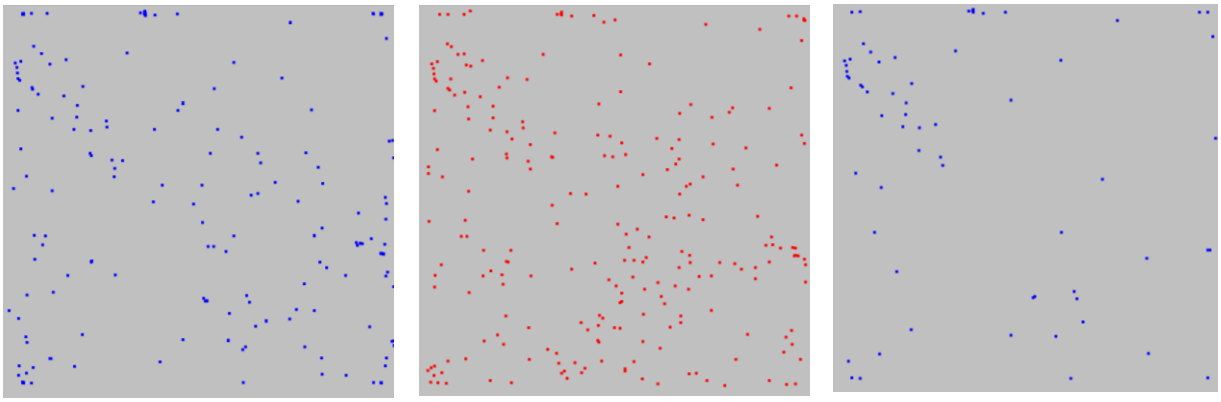
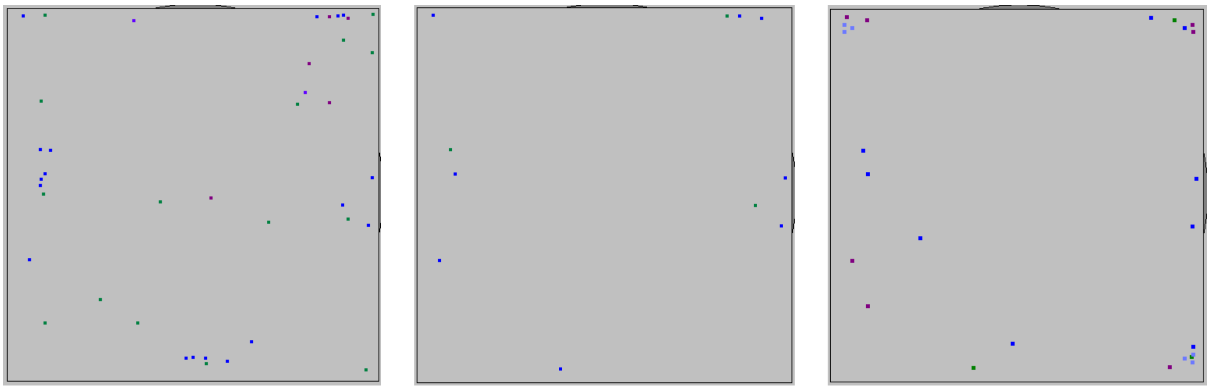


Figure 4: Comparison of back-side inspection made at Intel (left, only detections >200nm) and on SPARK (mid, all detections). The defect map on the right shows the common detections.

Figure 4 compares the detections made during inspection at Intel and on SPARK qualification before, resp. after the shipment indicated by label 2 in figure 1, as an example case.



Total counts >1µm: 40	**Total counts >1µm: 11 (including 4 adders)**	**Total counts >1µm: 25 (including adder-detections by clamping that were not removed by post-clean)**

Figure 5: Evolution of the cleanliness of an NXE reticle illustrating the role of on-site back-side cleaning. Only detections > 1µm are shown, because these are the ones that, according to new insights (beyond the scope of this project, can have potential impact on the overlay performance of the reticle upon printing. Left: Defect map of a dedicated test plate, without history of clamping and hence potential damage due to crunched particles qualified as received at imec. The detections are considered to consist of i) residual adders during shipment and automated handling and ii) defects on the mask backside during mask fabrication or blank manufacturing. Center: Defect map obtained after a clean to *avoid* particles critical upon use of the reticle on the NXE3100. Right: Defect map after reticle clamping on the NXE3100, together with a post-clean to *heal* any effects of the clamping. Below the plots the number of defects >1µm are mentioned and commented.

Figure 5 shows the result for a third set of tests fully evaluated by SPARK inspection only, independent from INTEL inspection support. In this sequence a reticle was used that had not been previously clamped. A clean was given, followed by a clamping test and finally another clean was given, all while shipping and manual handling was avoided, and inspection was purely done based on SPARK. Because according to ASML input only particles above 1 micron are virtually critical, only these SPARK detections are shown. The bottom row in figure 5 shows the net result of the cleaning runs before and after use of the reticle on the scanner: as a result, the number of detections can be kept low. The results show that, although back-side cleaning and in-situ inspection are available, detailed analysis would be required to understand each of the detections made, including the adders, during each of the steps (handling, cleaning, use on the scanner, and even the inspection itself). This is beyond the scope of this document, but illustrates the next steps to be done now that this unique infrastructure has been realized.

4. Summary and Outlook

In this deliverable not only the performance of the back-side cleaning recipes defined on the MTP were qualified, as it was the original target of the document. A step forward was realized relative to the status described in D2.2.2, as now 90% cleaning efficiency was achieved.

This report also summarizes the performance of the unique infrastructure for integrated cleaning, handling and back-side inspection of NXE3100 reticle, established at imec as a final outcome of SP02. With the integration of the MaskTrack*Pro* Cleaner, MT*Pro* InSync and SPARK a unique EUV mask infrastructure has been established at imec, in direct neighborhood of the NXE3100 EUV scanner, that combines EUV mask cleaning, automated handling and in-situ back-side inspection into one tool, through which fully automated handling starting from shipment from the mask shop to the wafer fab is assured, once shippable EUV pods become state-of-the-art.

Before this can be fully exploited further steps must be made within the EUV community before the use of fully particle-free EUV reticles on the EUV scanner can be reached, amongst other this includes the proof of particle-free handling inside the scanner and realization of a shippable EUV pod.

Yet, the established infrastructure facilitates that virtually every EUV reticle can now be inspected (on-site!) before use on the scanner, and cleaned if a certain cleanliness criterion is not met.

Overall, this subproject SP02 has been clearly successful, as the targets for cleaning and automation have been met, and additionally an in-situ quality check (in the form of the integrated backside inspection) has been established. This is considered largely compensating for the delay from which the project has suffered, as the overall project outcome clearly exceeds what was originally planned.