PROVE, the next generation registration metrology tool, status report

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ABSTRACT

SEMATECH has identified the need for a high resolution photomask pattern placement metrology tool to support SEMATECH member companies' photomask production as well as research and development work. Performance measures of the tool are driven by double exposure/double patterning approaches that will help extend 193nm lithography according to *International Technology Roadmap for Semiconductors* (ITRS) requirements. Based on its superior and extendable concept, PROVE^{TM}, a new photomask registration and overlay metrology system from Carl Zeiss SMS, was chosen as the winning proposal for tool development by an evaluation team of mask makers and SEMATECH member companies. The scope of the PROVE^{TM} project is to design and build a photomask pattern placement metrology tool to serve the 32 nm node and below. The tool is designed for 193 nm illumination and imaging optics, which enable at-wavelength metrology for current photomask needs. The optical beam path offers registration and critical dimension (CD) metrology using transmitted or reflected light. The short wavelength together with an NA of 0.6 also allows sufficient resolution even at working distances compatible with the use of pellicles, hence enabling the tool for qualification of final masks. The open concept together with the use of 193 nm wavelength enables a higher NA for pellicle-free applications, including extreme ultraviolet (EUV) masks. This paper reports the current status of PROVE^{TM}, highlighting its resolution capabilities while measuring production features as well as key registration specifications.

Keywords: registration, pattern placement, metrology, resolution

1. INTRODUCTION

In 2005 SEMATECH investigated the need for a mask pattern placement and registration metrology tool that could support the needs of double patterning lithography and the pitch requirements of memory devices. SEMATECH issued a request for proposal to the mask tooling industry suppliers for a metrology tool that would meet the 32 nm half-pitch (HP) node specifications (ITRS 2006). Although the major emphasis would be for metrology on 193nm lithography masks, EUV masks would be an additional requirement. SEMATECH members and mask industry experts chose the Carl Zeiss tool proposal as the platform that would meet the 32 nm HP specifications. The project will soon be completed. This paper presents an update on the current capabilities of the tool. The platform includes an illumination technique that will improve the contrast for various mask features, giving the metrologist another parameter that can be adjusted to improve the quality of measurements on the mask. The resolution of the PROVE^{TM} system and its registration performance will allow for in-die metrology, a new requirement of lithography users, who want to perform in-die pattern placement and registration measurement on the mask to compare mask data to the design and resulting wafer printing.

2. SYSTEM DESCRIPTION

The development status of PROVE^{TM} has been reported continuously at all major mask making conferences starting at EMLC 2008. The community was introduced to the main tool concepts such as the design of the optical beam path, expected imaging performance, and stage calibration concepts [1-6]. PROVE^{TM} as a strategic project currently running at Carl Zeiss combines knowledge and expertise from various departments within Carl Zeiss SMT as well as external partners, M+W Group (environmental control) and HAP Dresden (handling system), both located in Germany. According to the development plan, the project was executed in different phases and work packages to ensure the timely fulfilment of critical system specifications. The project has now reached its final development stage and first beta and serial tools are being prepared for customer delivery.

Figure 1 shows the PROVE^{TM} alpha tool with full functionality for imaging tests on production pattern as well as for evaluation of registration performance. To achieve sub-nanometer precision, special care was taken to reduce the environmental influences such as ambient air variations and vibrations. The metrology unit is located in an environmental chamber that precisely controls temperature and humidity specifications. The precision stage, which is fully controlled in all 6 degrees of freedom by laser interferometers, is situated on a frame resting on an actively controlled damping device. To minimize the effect of the remaining temperature, humidity, and barometric pressure variations, an on-line wavelength tracking device, the Etalon, is used to compensate for refractive index fluctuations of the air in real time. The masks are loaded onto the stage by a fully automated handling system, which can also rotate and flip the mask if required. One key component of PROVE^{TM} is the 193 nm imaging optics that allow the resolution of production features even at the large working distances needed for different types of pellicles. For upcoming pellicle-free applications like extreme ultraviolet lithography (EUVL), the current 0.6 numerical aperture (NA) can be increased to 0.9, which will improve the inherent high resolution of the tool by 30%. The two illumination paths offer measurements in transmission and reflection. Further resolution enhancements can be achieved by variable illumination techniques.

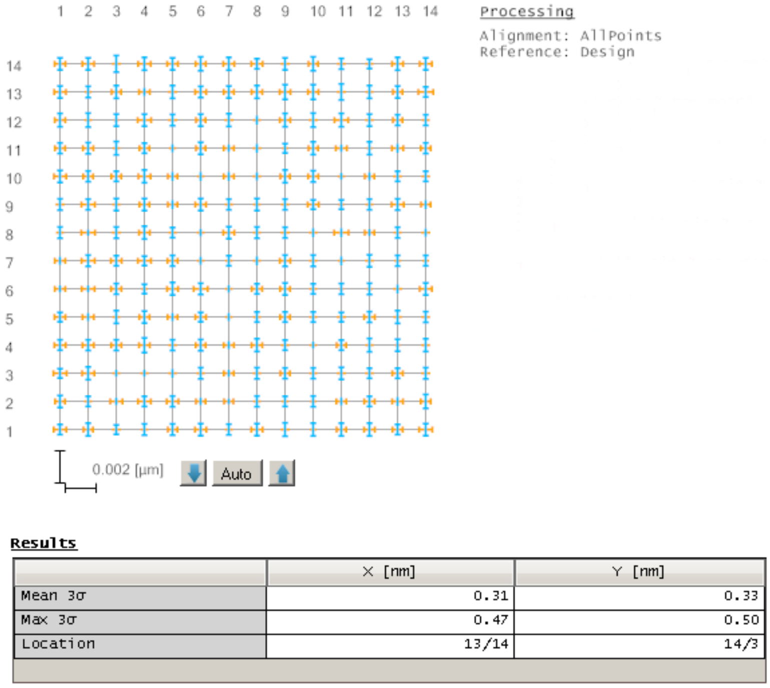
Fig. 1: View of PROVE^{TM} with Loadport and Operator Desk

The software concept for PROVE^{TM}, which has been finalized, aims for user friendliness and flexibility. This approach is maintained by four different applications, PROVE CONTROL, PROVE DATA, PROVE SERVICE, and PROVE MONITOR, supporting tool operation as well as data evaluation, tool monitoring, and service.

3. MEASUREMENT PERFORMANCE

3.1 Short-Term Repeatability

The stability of a registration metrology tool is usually described by the measurement repeatability. The short-term repeatability is defined as 3sigma over all measured positions using 20 measurement loops without unloading the substrate. The statistics evaluation in Figure 2 displays the mean 3sigma and the maximum 3sigma measured on a 6-inch opaque MoSi on glass (OMOG) mask as used for the 32 nm technology node. The measurement data indicate a random distribution over the measured grid of 14 x 14 sites. The results show a repeatability performance which meets the target specification of 0.5nm while the fine tuning of system parameters is still ongoing.



Processing

Alignment: AllPoints
Reference: Design

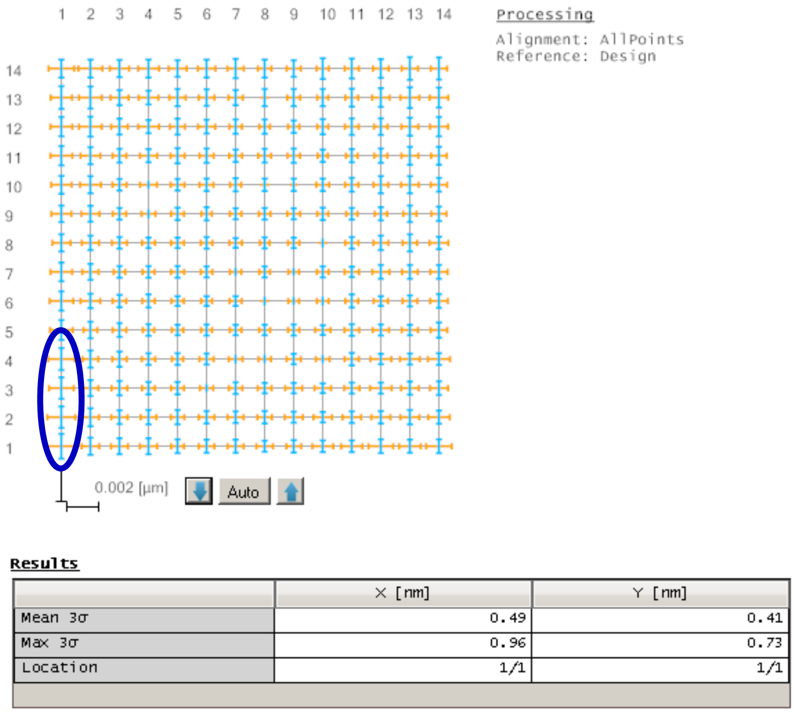
Results

	X [nm]	Y [nm]
Mean 3σ	0.31	0.33
Max 3σ	0.47	0.50
Location	13/14	14/3

Fig. 2: Short-term repeatability performance over 20 loops measured on a 6025 OMOG mask. The maximum 3sigma for the x-direction is 0.47 nm and 0.50 nm for the y-direction.

3.2 Dynamic Repeatability

The dynamic repeatability, including mask loading and unloading, is shown in Figure 3. The data have been obtained from 15 loading cycles over 5 days. Each cycle consists of three loops, resulting in a total of 45 measurement loops. The 3sigma was calculated for each feature site using the PROVE DATA analysis software. Despite the excellent stability over several days, the dynamical repeatability shows a first-loop effect at the beginning of each loop, in particular in the x-direction, which indicates a first-loop effect from insufficient thermalization. These first sites have a significant impact on the statistics results as shown in Figure 4. When removed from the evaluation, the dynamic repeatability performance improves to 0.79 nm in x-direction and 0.69 in y-direction. This observed thermalization effect is currently analyzed and will be improved in the ongoing fine tuning process.



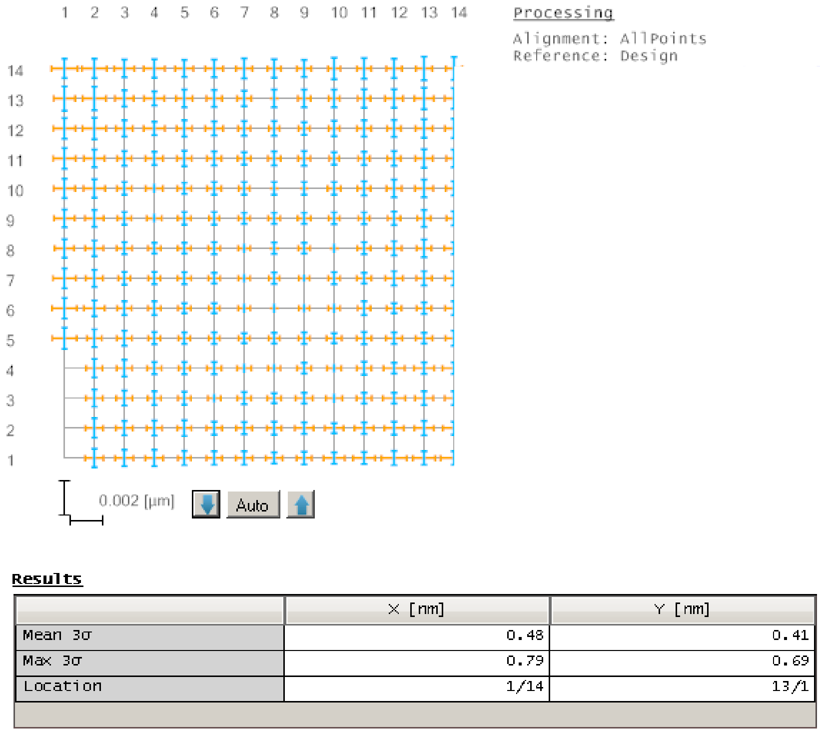
Processing

Alignment: AllPoints
Reference: Design

Results

	X [nm]	Y [nm]
Mean 3σ	0.49	0.41
Max 3σ	0.96	0.73
Location	1/1	1/1

Fig. 3: Dynamic repeatability performance evaluated over 5 consecutive days on a 14 x 14 grid. The maximum 3sigma for the x-direction is 0.96 nm and 0.73 nm for the y direction. The highlighted first four measurement sites indicate a first-loop effect from insufficient thermalization.



Processing

Alignment: AllPoints
Reference: Design

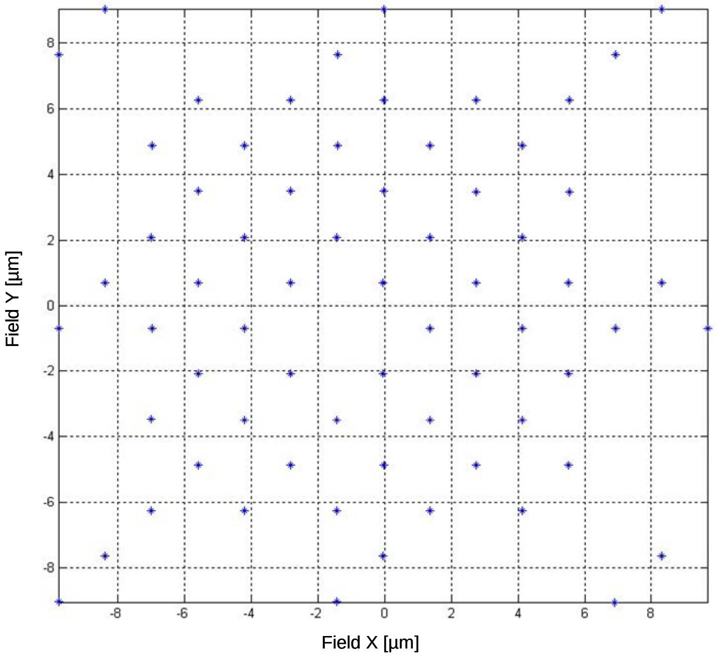
Results

	X [nm]	Y [nm]
Mean 3σ	0.48	0.41
Max 3σ	0.79	0.69
Location	1/14	13/1

Fig. 4: Dynamic repeatability performance without the first four measurement sites. The maximum 3sigma for the x-direction is now 0.79 nm and 0.69 nm for the y direction

3.3 Screen Linearity

A screen linearity evaluation was performed after an optics calibration for the complete field of view using dedicated test markers. Figure 5 displays the measurement results for 81 sites. The maximum deviation for all sites is well below 0.8 nm.



	X [nm]	Y [nm]
Max dev.	0.78	0.71
Max 3sigma	0.38	0.48

Fig. 5: Screen linearity evaluation over a 20 µm field of view with optics calibration. The graph displays the measurement sequence over 81 sites. The maximum deviation corresponds to 0.78 in x- and 0.71 in y-direction.

4. RESOLUTION ENHANCEMENTS

The imaging performance of the most advanced registration metrology tool depends on the interaction of different optical components, the illumination, the object to be imaged, and the imaging optic. The objects under investigation are various masks types such as standard chrome-on-glass (COG), opaque MoSi-on-glass (OMOG), or EUV, all that are to be measured in transmission or reflection. The benefit of a shorter illumination wavelength has already been discussed in [3]. Based on extensive optical simulations, it could be demonstrated that the chosen wavelength of 193 nm at a 0.6 NA enables superior resolution for different types of photomask and production features to be imaged and measured for registration. The benefits of this additional knob to increase contrast and resolution have been investigated experimentally and first results are shown in Figure 6.

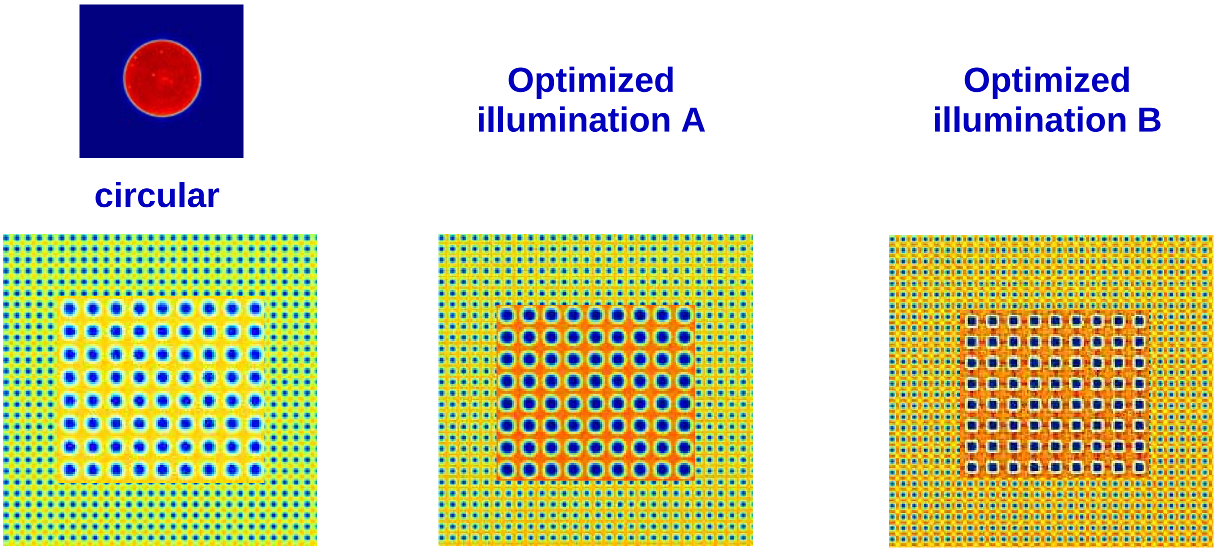


Fig. 6: Improved contrast by means of optimized illumination for 180nm dense contacts (COG mask). The inset displays a zoom into the measurement image.

While the dimension and shape of the structure under investigation affect the contrast, this can be partially compensated by adjusting the illumination properties. Figure 6 displays the benefit of optimized illumination methods for contrast enhancement on real images of 180nm dense contacts. The rectangular shape of the 180nm contacts can be imaged by illumination method B only, hence giving the registration tool the capability to evaluate the right edge position. This clearly shows that the adapted illumination can significantly help to achieve better performance, in particular for low contrast images at the resolution limit, where already slight improvements can reduce the impact of image noise on the registration error.

5. CONCLUSION

The paper presents the current status of the PROVE^{TM} tool's measurement capabilities. The first registration data show that the system offers the measurement performance required for the 32 nm HP requirements for mask pattern placement metrology. Although originally specified using the 2005 ITRS, the resolution is still consistent with 2009 ITRS requirements. This capability is necessary for the critical demands of current 193 nm lithography processing, including double patterning lithography, and of the tight pitch requirements for memory devices. These results would not be possible without the new state-of-the-art environmental control system and 193nm illumination. In addition, the illumination flexibility will provide better contrast for certain in-die mask features that need to be measured.

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