One platform, two products: How to turn Puma 9850 into a cutting-edge reticle blank inspector

Qiang Zhang, RAPID
Mick Giusti, RAPID
Garry Rose, RAPID
Tetsuya Yamamoto, RAPID

Abstract – This paper describes how WIN Puma 9850 patterned wafer inspector was selected as the common platform on which a cutting edge reticle blank inspector will be built, in order to break into a brand new market for KLA-Tencor that our competitor has exclusively dominated for over a decade. A list of technical challenges that we are facing to accomplish this task will be discussed. In particularly, we will focus on critical issues related to sensitivity modeling and validation, reticle damage risk, and automated defect classification (ADC) capability.

I. Introduction

As one of the key product offerings of KLA-Tencor, patterned reticle inspectors have a long history of development and evolution since the birth of the company. However, for over 30 years, one market area that K-T has not entered is the reticle blank inspection. The relatively small market size and low-end technical requirements associated with this market was the justification for such a decision.

As the semiconductor industry keeps pushing along the line that the Moore's Law predicts, the features sizes on both wafers and photomasks have shrunk steadily over the years. So are the sizes of the yield-impacting defects that blank suppliers and mask shop customers are trying to find, which has been driving the evolution of reticle blank inspection to using more and more advanced technologies. In addition, our competitor has started taking advantage of their success in the reticle blank inspection market and using it as a springboard to penetrate into some of the other market areas that K-T has traditionally dominated. As a result, it is a good time for K-T to reconsider the entry into this market for both technical and strategic reasons.

Obviously, in order to achieve this goal with the minimal development cost and the time-to-market, it makes perfect sense to utilize a K-T's existing product platform as oppose to develop a new one from scratch. Given the cost sensitivity and high throughput requirements, RAPID's current patterned reticle inspectors are not suited for this purpose. Instead, a couple of wafer inspection platforms were identified as promising candidates, including Surfscan's SP series and WIN's Puma series. Both platforms are based on dark-field detection technology and offer excellent sensitivity and throughput.

Between the two candidates, the Puma platform bears more resemblance to the patterned reticle inspector, hence a smoother conversion to a reticle blank inspector is expected. Puma is also more versatile by being capable of inspecting both blank and patterned reticles. Therefore, it could cover a wider range of customer use cases including process monitoring, tool qualification, and IQC, etc. As a result, RAPID launched program X-15. It chooses

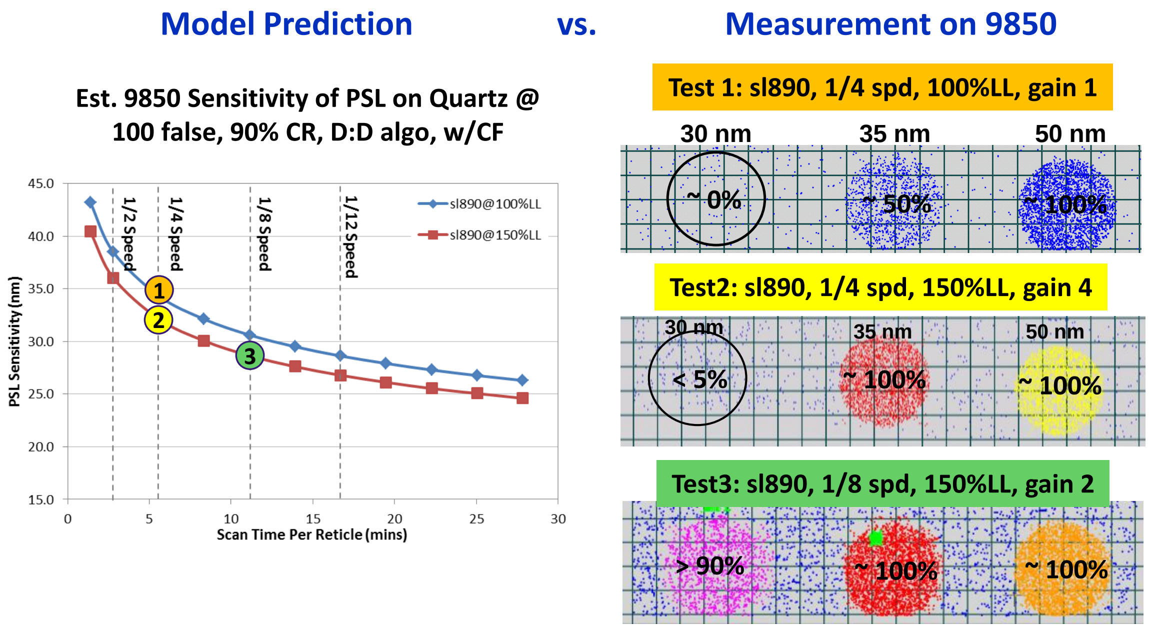

Fig. 1. Preliminary 9850 inspection data of three different sized PSL particles (30n, 35nm, 50nm) on the quartz reticle at various tool operating condition (light level, stage speed). The results agree favorably to the capturable PSL size predicted by the sensitivity model.

to adopt Puma 9850, the latest version of the Puma series, to be the platform of K-T's first reticle blank inspector targeting at N10 and N7 nodes.

As K-T is a new comer to the reticle blank inspection market, a number of technical challenges present which we need to address carefully in order to position us correctly against our competitor in this catch-up game. Herein, our discussion will be focused on a few critical issues related to sensitivity modeling and validation, reticle damage risk, and automated defect classification (ADC) capability.

II. Technical Discussions

A. *Sensitivity Modeling and Validation*

The most important performance metric of an inspection tool, undoubtedly, is its sensitivity. In the past, Puma 9850 has demonstrated excellent PSL particle sensitivity on blank Si wafers. But reticle blanks have significantly different optical properties and surface roughness from Si wafers. There is a need to reestablish an accurate sensitivity baseline for these new substrates for our development. For this purpose, we have built a new PSL sensitivity model and validated its accuracy by experimental verification.

The sensitivity model employs a Mie scattering calculator to rigorously simulate the optical scattering phenomena from a spherical PSL particle sitting on a reticle blank substrate for a given incident angle and polarization. The strength of the defect signal can be obtained by integrating the scattered power over each of the three detection channels of Puma in the angular space.

On the noise side, we took a straightforward yet accurate approach. Realistic noise data for various reticle blank substrates have been analyzed based on non-defective dark-field images collected at different illumination power levels from the 9850 tool. This allows us to separate the noise contributions from the tool detection system and from the reticle surface scattering (i.e. haze).

Combining the signal and noise analysis yields the signal-to-noise ratio (SNR), which is calculated for a range of particle sizes. Given the noise histogram distribution and the required false detection rate, we can then determine where the sensitivity threshold is in terms of the minimum capturable particle size at a certain chosen operating condition of the tool.

To validate our sensitivity model, preliminary

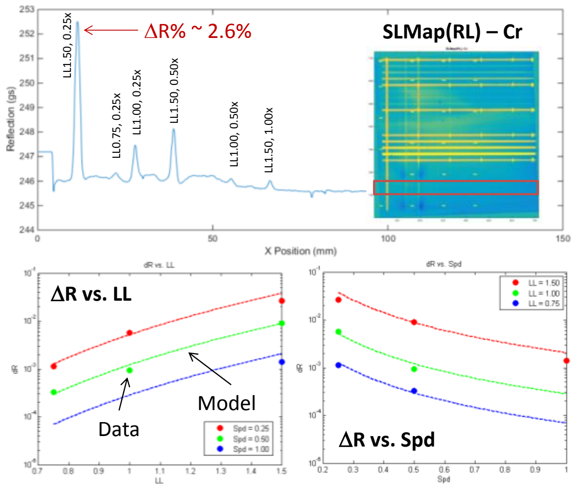

Fig. 2. Optical damage study of 9850 exposure on Cr reticle blank under various conditions. The reflectivity change at 193nm of the exposed reticle was measured with 6xx SLmap. An empirical model was constructed to fit the damage data as a function of light level, stage speed.

inspection on quartz reticle blank has been carried out on a 9850 engineering tool. The wafer chuck on the tool was swapped with a prototype reticle chuck, onto which the reticle could be loaded manually. Three different sizes of PSL particles were deposited on the quartz blank by VLSI, whose diameters were 30nm, 35nm and 50nm, respectively.

A typical blank wafer inspection recipe based on die to die comparison was used for the inspection, though a self-referencing based detection algorithm would be more ideal. Additionally, due to the lack of the Cal-Chip on the prototype reticle chuck, real time calibration of the tool has to be disabled which could have affected the focus accuracy and channel fusion performance.

Nevertheless, PSL particles as small as 30nm were successfully detected with nearly 90% capture rate at 1/8 speed and maximum light level in the 9850 sl890 mode. At this speed, we can still expect an inspection throughput more than twice as much as our competitor, whose sensitivity is limited to only 35nm. Additional inspections at faster speed (1/4 speed) and lower light level were also tested. The overall results are compared to our sensitivity model prediction, as shown in **Fig.1**. Excellent matching between the model and the experimental data

Substrate	Damage Evaluation			Recommended Setting for Max PSL Sensitivity		
	Risk	Method	Criteria	Light Level	Scan Speed	Sensitivity (nm)
Quartz	None	N/A	N/A	100%	1/8	28.5
CoG	Medium	6xx SLmap	ΔR < 0.5%	62%	1/8	32.1
EPSM	Low	6xx SLmap	ΔR < 0.1%	100%	1/8	28.3
OMOG	Low	6xx SLmap	ΔR < 0.1%	100%	1/8	N/A
Resist/CoG	High	WLI	Δh < 1nm	21%	1/4	42.6

Table 1. Summary of damage risk assessment for various types of reticle blank. Optimal inspection settings that minimize the damage risk are given. The maximum sensitivity at the damage threshold is estimated using the sensitivity model.

can be found at all operating conditions of the tool.

B. Damage Risk

Since Puma utilizes a pulsed multi-watt laser as the light source, in contrast to our competitor's CW laser with significantly less average power at the same wavelength, there were considerable concerns that Puma could cause optical damage in the inspected reticle blanks.

To evaluate such risk, we have performed extensive experimental damage study on a number of reticle blank types with various exposure conditions. Subsequent characterization of the exposed reticles with AFM, white-light interferometer and/or 6xx helps us to determine where the damage would reach the predefined threshold.

As one example, **Fig. 2** shows the damage analytical data on a chrome (Cr) reticle, one reticle type with relatively low damage threshold. Exposure swaths with different light level, stage speed and number of repeats were performed. The resulted damage was evaluated on 6xx using SLmap, which measures the minute change in the Cr reflectivity at 193nm caused by optical damage. The data was then fitted to an empirical model which in turn was used to predict the damage at an arbitrary exposure setting within its validity range. In the end, this helps us estimate the optimal operating condition of the tool that could maximize sensitivity without damage. The model was also useful in predicting the potential damage risk reduction if a pulse rate multiplexer had been implemented.

Similar exercises were carried out on other

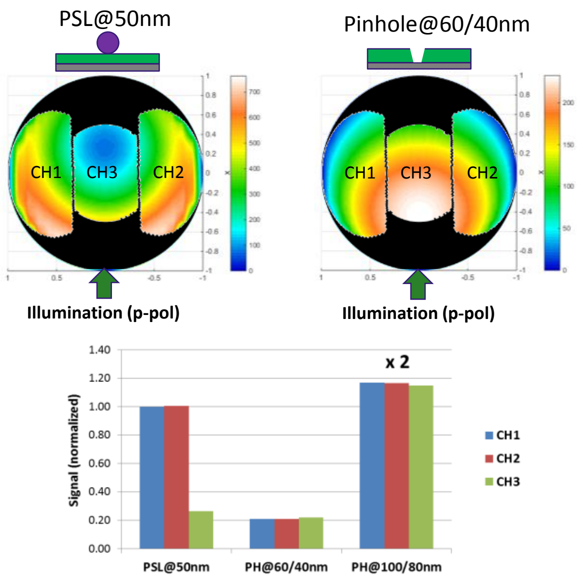

Fig. 3. Simulated optical scattering spectrum of a 50nm PSL particle sitting on EPSM blank and a 60nm(top)/40nm(bottom) pinhole in the EPSM film with the geometry of the 9850's three detection channels overlaid on top. The detected signal contrast among the three channels is also shown.

blank substrates, including EPSM, OMOG, and resisted-coated Cr reticles. Damage risk associated with each was evaluated and optimal inspection setting was recommended. The settings were then fed into the sensitivity model to estimate the practically achievable maximum sensitivity at the damage threshold. The results are summarized in **Table 1** (the sensitivity prediction for OMOG is currently unavailable due to the lack of knowledge of the optical properties of OMOG films at 355nm wavelength).

C. Automated Defect Classification (ADC)

In many reticle blank inspection use cases, the customers not only want to find small defects, but also demand the inspection tool to be able to distinguish what type of defect it is. This is largely because different defect types tend to have different yield impact. The strategy of how to deal with the found defect is very much hinged on the customer's knowledge about the nature of the defect.

Large extended defects, such as scratches and stains, have been commonly seen in Puma wafer inspection use cases. The existing defect classification capability of the tool should be able to adequately handle these defects. The key challenges are in classifying the defects which are near or beneath the resolution limit. Relevant defect types may include particles, pits/bumps in quartz substrate, pinholes in films, and voids in the resist. Traditionally, there was no strong motivation for Puma to distinguish these defects on wafer as long as they were properly captured.

We came to realize that the three detection channels that Puma is equipped with, including two side channels and one top channel, is potentially useful for ADC purpose if well calibrated. The reason is that different defect types tend to have a different scattering angular spectrum. To demonstrate such feasibility, we have performed optical simulation of a number of defect types and studied their signal contrast among the three channels.

Fig. 3 shows an example of the simulated scattering spectrum of a PSL particle sitting on EPSM blank and a pinhole in the EPSM film. The geometry of the three 9850 detection channels is overlaid on top. With the oblique incidence and p-polarization, it was observed that the particle scattering was strongly biased towards the side channels (CH1,CH2) as opposed to the top channel (CH3) by almost 4 times, while the pinhole scattering showed a much more balanced spread into all three channels. Furthermore, we were glad to find out that similar signature also existed for pit/bump defect in quartz and void defect in the resist. This would potentially allow us to efficiently separate particles from these types of defects.

III. Conclusion

Over many years since its introduction in 2005, the WIN's Puma platform has demonstrated its continued success in meeting customer's need in the wafer inspection. By adopting the same platform for reticle blank inspection, RAPID hopes to further extend Puma's success into a new market area that K-T has never entered before. The outcome will hold strategic importance in positioning RAPID against its competition.

Our preliminary but extensive study on 9850 inspection of reticle blanks showed promising results in sensitivity, reticle damage risk, and ADC capability. By engaging partnership with key customers, we fully expect the X-15 program to take off and become a formidable opponent to our competitor.

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