Implementation of background scattering variance reduction on the Rapid Nano particle scanner

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ABSTRACT

The background in simple dark field particle inspection shows a high scatter variance which cannot be distinguished from signals by small particles. According to our models, illumination from different azimuths can reduce the background variance. A multi-azimuth illumination has been successfully integrated on the Rapid Nano particle scanner. This illumination method reduces the variance of the background scattering on substrate roughness. It allows for a lower setting of the detection threshold, resulting in a more sensitive inspection system. By implementing this system the lower detection limit of the scanner was reduced from 59 nm to 42 nm LSE. A next improvement, a change of the inspection wavelength to 193 nm will bring the detection limit to sub 20 nm.

Keywords: particle inspection, dark-field microscopy, illumination, detection limit, Rapid Nano, EUVL, qualification

INTRODUCTION

The Rapid Nano is a dark-field particle inspection system developed by TNO [1]. The system was built for the purpose of particle qualification of reticle handling equipment [2-4]. In a qualification procedure a reticle blank is inspected before and after cycling in a handling system to determine the number of particles added by the handling system.

For a proper qualification the inspection system should be sensitive to all relevant particles. All particles larger than the maximum allowed defect size on a reticle, according to the requirements of the ITRS roadmap, should be detected. The Rapid Nano particle scanner does not have this sensitivity as it is able to detect particles from 59 nm in size. It is a general problem in particle qualifications that the sensitivity of the inspection equipment does not meet the size of the smallest relevant particle size [5-7].

We aim to increase the sensitivity of our scanner to match the requirements set by the ITRS roadmap. Here we describe the implementation of the first step towards this goal, the implementation of a new illumination system on the scanner.

In our recent papers [5, 6] we reported on our model of the inspection system that allowed us to optimize system parameters and predict the performance. Two main parameters were identified that could be used to increase the sensitivity. The first is multi-azimuth illumination aimed at reducing the variance of the background scatter. The second is a scaling of the inspection wavelength, which increase the signal to background ratio. Both steps will be implemented, dramatically increasing the scanners' sensitivity and allowing it to catch up with the requirements of the ITRS roadmap (Figure 1.1). Here we report on the successful implementation of the first step, an upgrade of the illumination system while preserving the inspection wavelength of 532 nm.

We described the theory of multi-azimuth illumination before [6]. Briefly, when sufficient light is used for the inspection the signal-to-noise ratio is dominated by scattering on the roughness of the sample surface. This scattering shows a speckle like statistic and has a large variance. If this variance can be reduced a lower detection threshold can be set to discriminate between the background and a detection of a particle.

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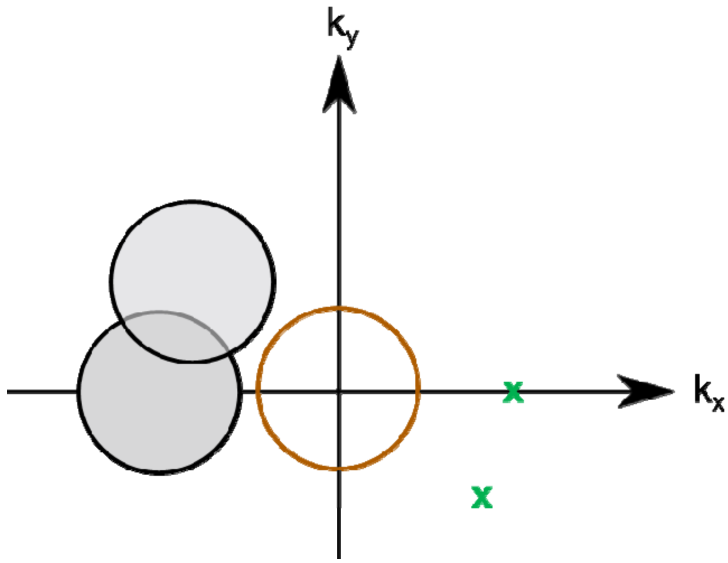

Figure 1: Frequency domain plot of the projected wave-vectors on the substrate surface for two different illumination azimuth angles (x) showing that a different set of roughness wave-vectors (gray circles) is involved in scattering towards the detection system (red circle)

The variance of the background speckle pattern can be reduced by adding multiple different realizations of this pattern. The variance is reduced by the number of independent patterns in the sum. Adding N independent realizations reduces the variance by a factor of N. To generate an independent speckle pattern a different sub-set of the wave-vectors in the surface roughness can be sampled. A different sub-set of the 2D wave-vectors is sampled by illumination with a different azimuth angle that is sufficiently separated from the original azimuth angle (see Figure 1.2).

Experiments on a breadboard setup with this technique showed that a reduction of the background variance near a factor of 9 was possible for the NA of our imaging system. Furthermore, it was found that the background speckle patterns of two sources separated by 180^{o} in azimuth angle correlate. To avoid exactly opposite positioned sources while having a uniform spacing of sources, an odd number of sources needs to be used. For these reason the Rapid Nano has been equipped with 9 illumination arms.

IMPLEMENTATION

The multi-azimuth illumination was implemented on the Rapid Nano particle scanner platform to increase its sensitivity. To get the highest possible reduction of the background variance the illumination arms need to be incoherent with respect to each other and have the same intensity across the image plane. These requirements were achieved by multiplexing the illumination in time and by adding beam-shaping optics to each arm.

To keep cost low the multi-azimuth system was implemented using the existing laser source on the scanner (Coherent Verdi 5). To make the illumination arms incoherent with respect to each other they were multiplexed in time. To be able to switch quickly between the sources and handle high power, while maintaining a speckle free beam-profile, a mechanical solution with rotating mirrors is used. The rotor consists of 16 mirror surfaces and two spaces (Figure 2.1). The spaces allow for transmission of the laser beam to a fixed mirror behind the rotor. In a full revolution of the rotor each arm is illuminated twice. This symmetrical design was chosen to keep the rotor in balance and allow the rotor to run at 1200 RPM, illuminating all arms each 25 ms.

The reflections from the rotor are sent to 9 identical illumination tubes via mirrors. At least two mirrors are between the rotor and each tube to allow for an independent alignment of the arms.

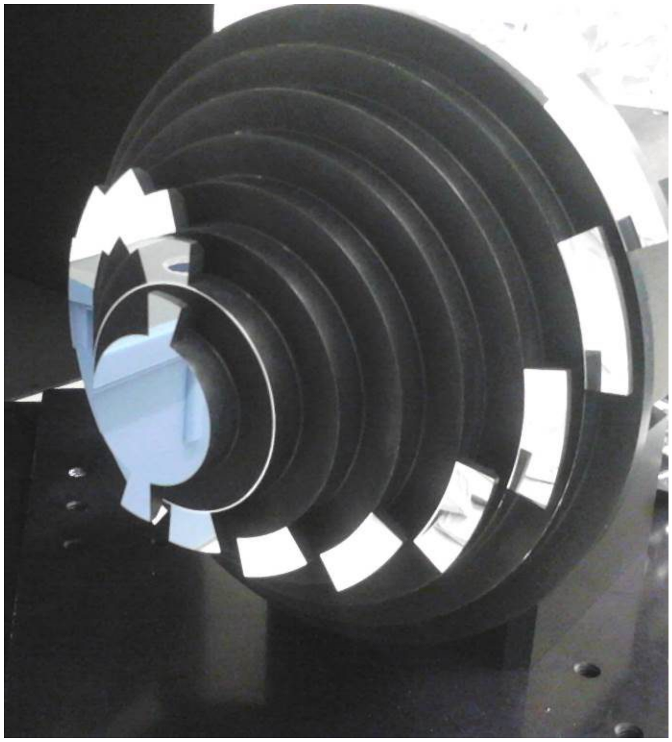

Figure 2.1: The rotor designed for time multiplexing the 9 illumination arms

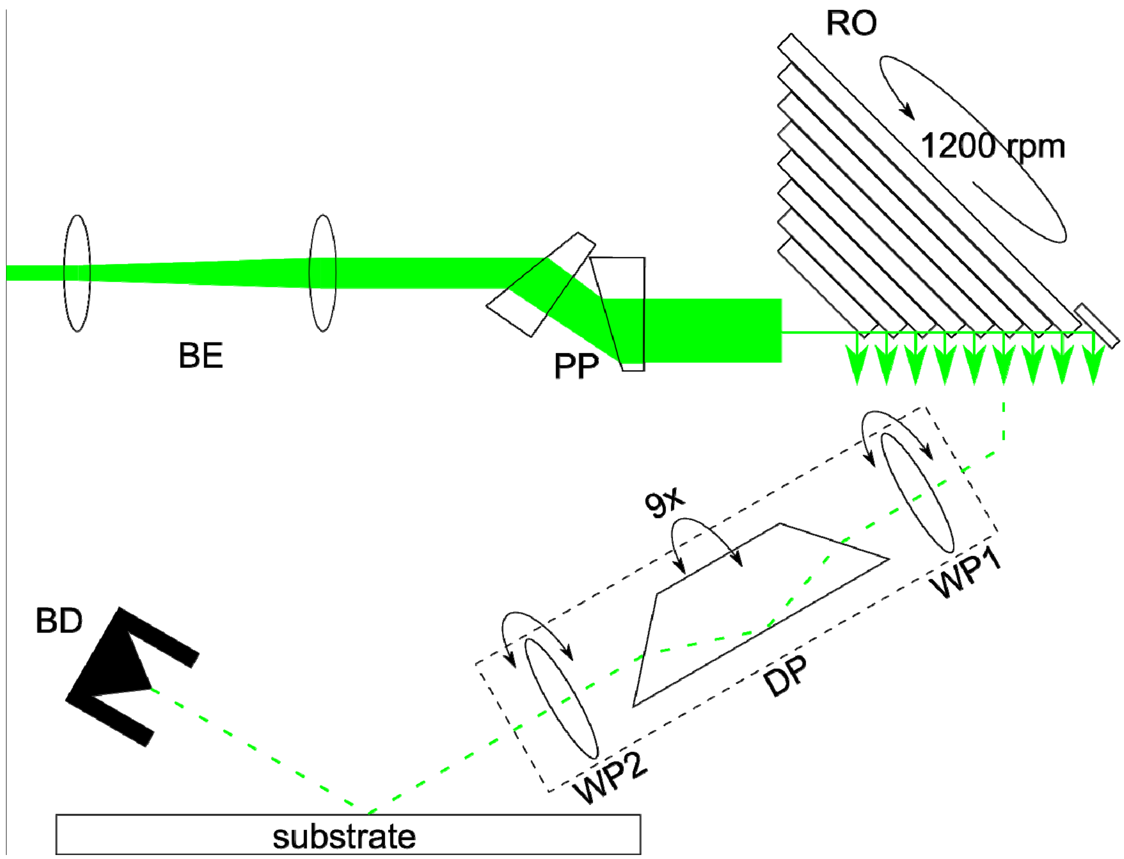

Figure 2.2: The Rapid Nano illumination system. BE beam expander, PP anamorphic prism pair, RO rotor, WP1/2 half-wave plates, DP dove prism and BD beam dump.

To have an optimal reduction of the background variance the mean intensity of the illumination arms should be the same at all positions in the image plane. Beam-shaping components were included in each arm such that it produces a circular symmetric intensity projection at the substrate. By overlapping the 9 illumination profiles each position in the image plane receives the same intensity out of each direction.
The illumination system is shown in Figure 2.2. The laser beam is first expanded to correspond to the size of the image field with a beam expander. An anamorphic prism pair is used to expand one axis of the beam profile by a further factor of 2. This aspect ratio produces a circular spot when projected in the correct orientation under an angle of 60^{o} from normal. The beam is distributed over the 9 illumination angles by the rotor. Mirrors (not shown) send the light to the illumination tubes. These tubes contain a dove prism and two half-wave plates. These three components can be independently rotated around the optical axis. The rotation of the dove prism rotates the beam profile. The prisms are adjusted to orient the beam-profile such that a circular projection on the substrate is produced. The first wave plate is used to rotate the polarization to be P-polarized through the dove prism to minimize reflection losses. The second wave plate after the dove prism is used to make the light P-polarized on the substrate. Finally, the reflection off the substrate is absorbed in a beam dump.

RESULTS

The background variance reduction of the multi-azimuth illumination system was checked by comparing the background distribution recorded with the rotor stationary (one illumination arm) and with the rotor spinning (9 illumination arms). The data was corrected for the illumination beam profile, which varied across the image field. The correction was done by determining the average background intensity at each image field position from 400 different substrate positions. Figure 3.1 (left) shows the background histograms for corrected images with and without spinning of the rotor. The histogram of the background with a spinning rotor has a 9 times lower variance than the histogram with a stationary rotor. This result means that the system is well aligned and that the intensities from the illumination arms are well equalized.

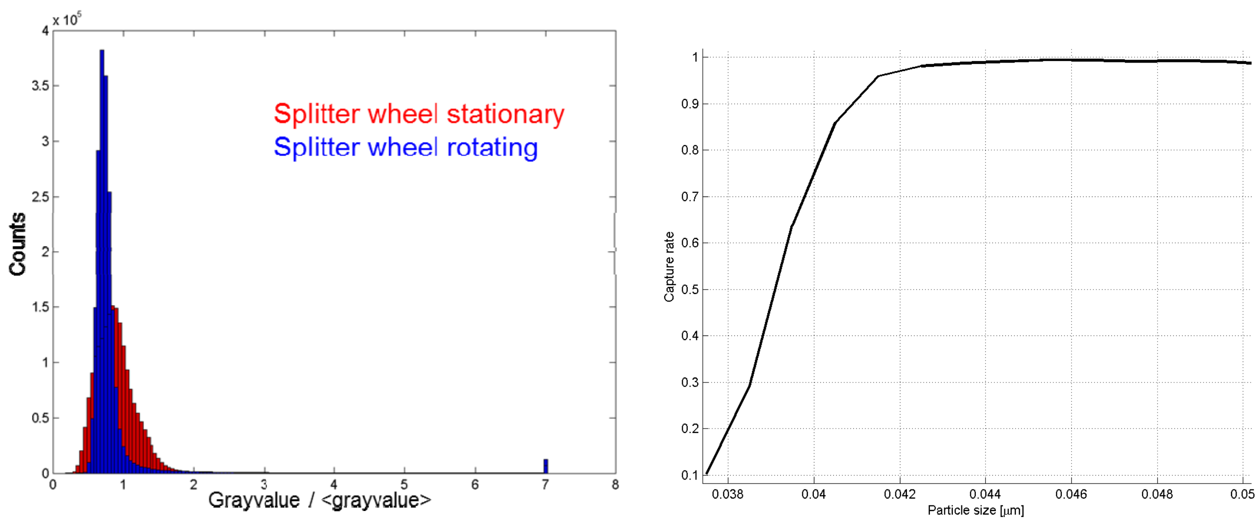

Figure 3: Histograms of the background intensity with the rotor stationary and rotating (left) and capture rate of the Rapid Nano with the upgraded illumination system (right)

The system was calibrated by scanning 4 samples with different known particle sizes deposited. PSL particles with an average size of 46, 59, 81 and 102 nm were used. From these data a calibration curve was constructed mapping detection intensity to an equivalent particle size.

The sample with 46 nm PSL particles was scanned 30 times according to the SEMI M50 procedure. The particle detections in each scan were matched to detections in all other scan by position. In this way for each particle the number of scans it was present is determined (N/30). This number gives the capture rate of an individual particle. A capture rate curve was constructed by placing particles in bins according to the average size it was detected at. This curve is shown in Figure 3.1 on the right. 42 nm particles are detected at 95% capture rate. This number corresponds well with the number predicted by our model.

CONCLUSION AND OUTLOOK

We have successfully integrated a multi-azimuth illumination system on the Rapid Nano particle scanner. This system illuminates a sample from 9 different azimuthal angles, reducing the variance in the background scattering. A mirrored rotor is used to distribute the light over the inspection arms, that each contain beam-shaping and polarizing optics.

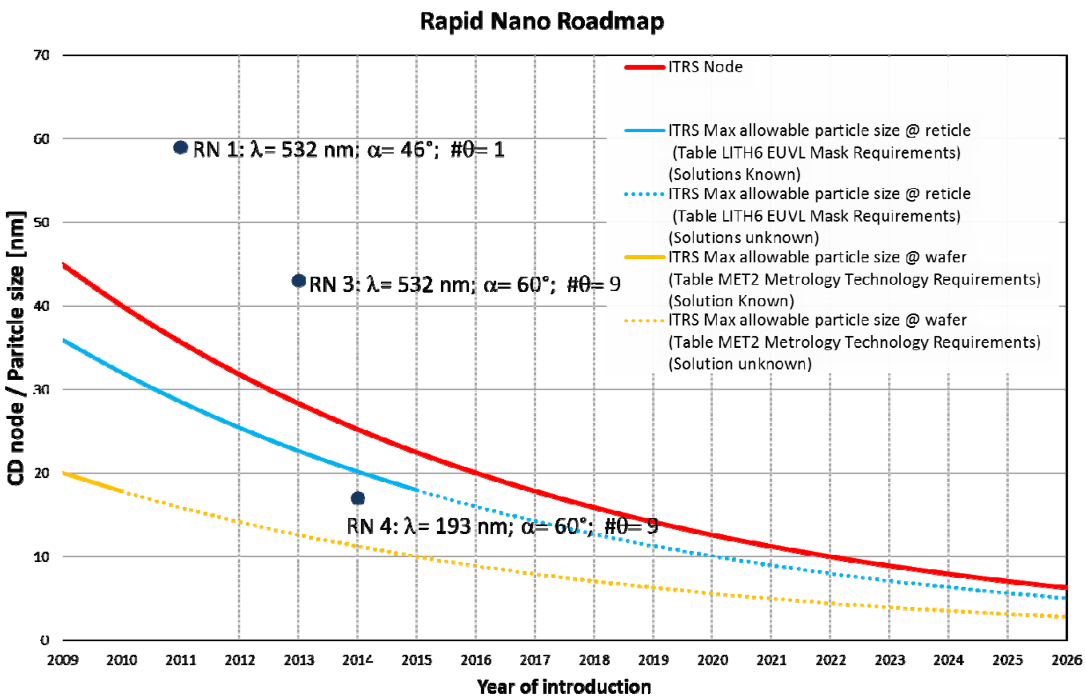

Figure 4: The roadmap for the Rapid Nano particle scanner plotted on the ITRS roadmap for maximum allowed particle sizes

The new illumination system has improved the sensitivity of the scanner from 59 nm to 42 nm LSE. Figure 3.3 shows the ITRS roadmap for allowable defect sizes and the sensitivity of the different generations of the Rapid Nano particle scanner. By demonstrating that the multi-azimuth illumination system achieves the predicted performance increase we have taken an important step in catching up with the requirements of the ITRS roadmap. The next step will be taken in the coming year with a scaling of the inspection wavelength to 193 nm with a predicted lower detection limit of 18 nm.

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