Nanoparticle detection limits of TNO's Rapid Nano: modeling and experimental results

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Introduction

The lack of a suitable pellicle material for EUV lithography makes EUV reticles very sensitive to deposited particles. For this reason, EUV reticle handling equipment should have strict requirements on number of added particles per reticle pass (PRP). Before being taken into production, such equipment should undergo particle tests and qualification.

TNO has developed the Rapid Nano reticle blank scanner as a tool to aid in the particle qualification of reticle handling equipment [1-3]. Due to the very strict requirements on PRP, much tool-time is required on the equipment to be qualified [4]. The inspection equipment should add the minimum possible number of particles to the test blanks, as introducing extra background noise increases the required tool-time even more. The Rapid Nano was designed specifically with particle cleanliness in mind [5].

Here, we present an end-to-end model of the detection sensitivity of our scanner. All illumination, collection, substrate, particle and noise parameters are included in this model. The outcome of the model is a capture rate curve for a given particle type on a given substrate. The model correctly predicts the current performance and it can be used to make accurate predictions of future generations of the scanner.

Modeling

Our model describes the probability distribution of the pixel values on the camera. The cases of background only, and with a particle present are considered. Sensitivity is mainly limited by the variation in the background signal.

The mean value of the background signal is determined from the surface roughness power-spectral-density, using a well known perturbation method [6]. The variation around this mean value is determined using speckle theory [7] and some parameters from the imaging optics. The model correctly predicts the experimentally observed background distribution as shown in Figure 1.

For the description of the scattering by a particle we used a model developed by Bobbert and Vlieger [8]. This model treats the scattering of a sphere near a flat substrate by solving Mie scattering and Fresnel reflections self-consistently. We used a freely available implementation of this model [9].

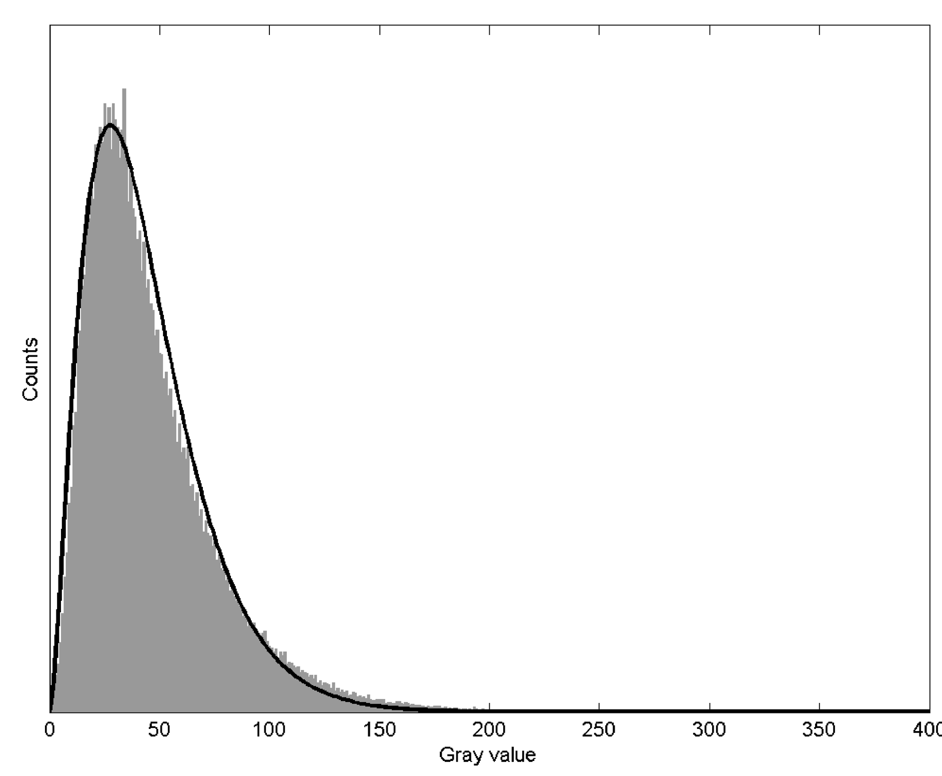

Figure 1: A typical background histogram (gray) and the distribution predicted by the model for this substrate (solid line).

Results

The model was used to optimize the sensitivity of the scanner. Furthermore, the results were extrapolated to shorter illumination wavelengths. Reduction of the wavelength has a large effect on the sensitivity for two reasons. First, higher spatial frequency roughness of the substrate is sampled. Generally the roughness of a substrate reduces toward higher spatial frequency following a power-law dependence. Therefore the signal to background ratio is increased by decreasing the illumination wavelength. Second, the refractive index of the particles increases for most materials at shorter wavelength, increasing the intensity of the scattered light.

Illumination Configuration	PSL on Si [nm]	Al on Si [nm]	PSL on CrN [nm]	Al on CrN [nm]
532 nm, current system	59 Expt: 59	35 Expt: 35	72 Expt: ~75	48
532 nm, optimized	43	25	56	37
405 nm	35	20	44	28
355 nm	32	18	40	27
266 nm	20	18	28	25

Table 1: Model predictions for the particle size at 95% capture rate for different system configurations, particle materials and substrates.

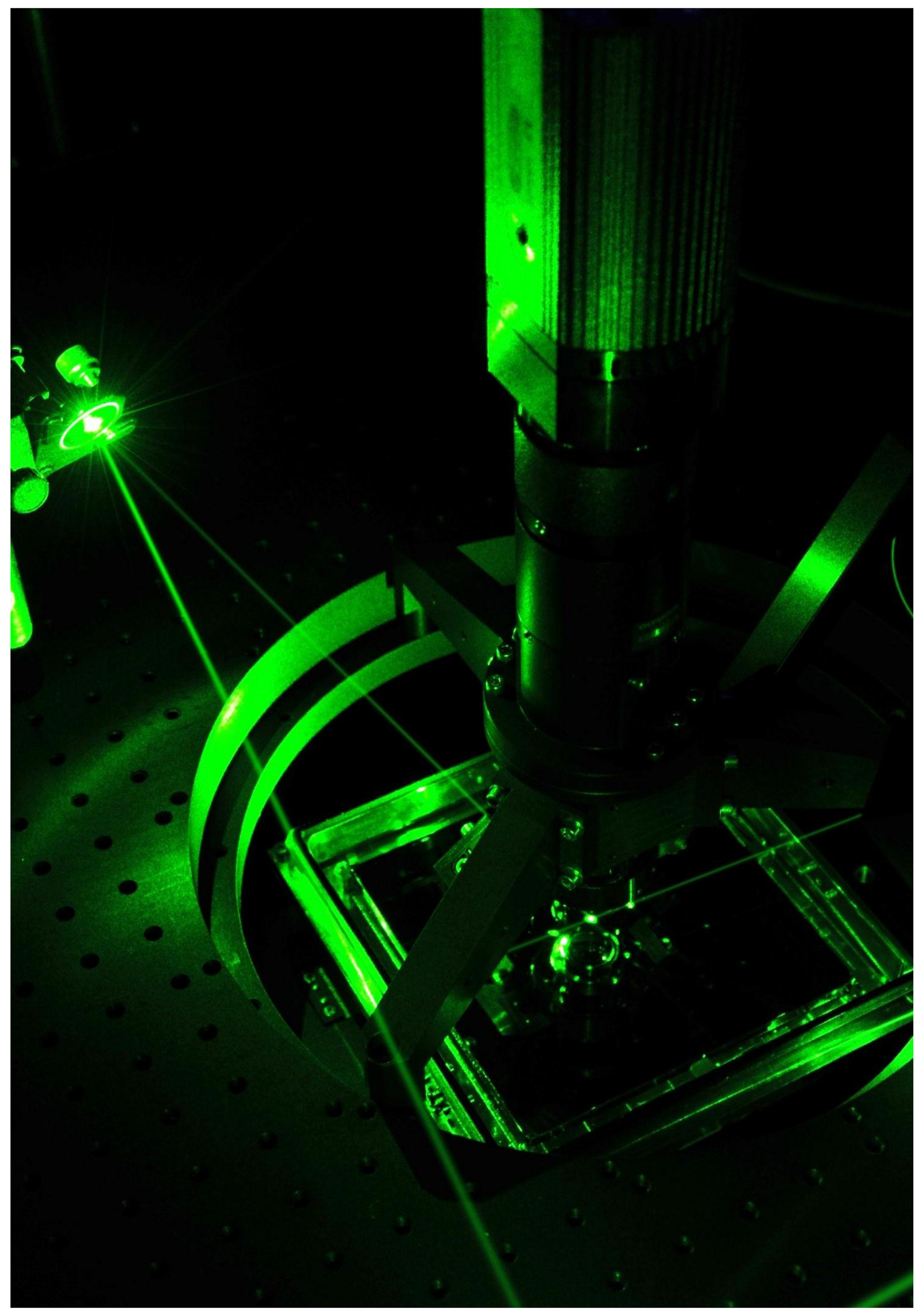

Figure 2: Inside view of the Rapid Nano during inspection. The green 532 nm inspection laser is visible.

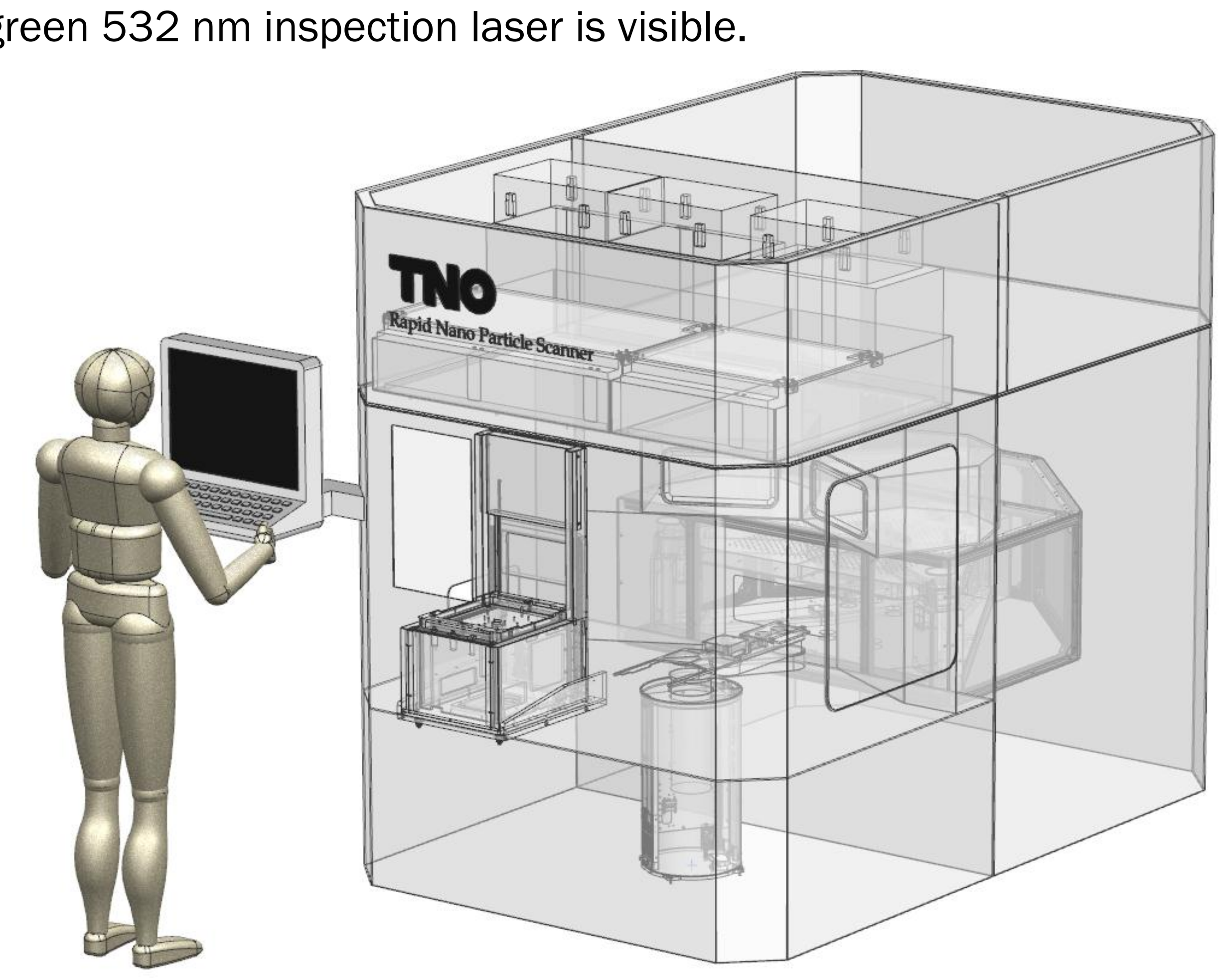

Figure 3: Version of the Rapid Nano particle scanner with automated reticle loading from EUV dual-pods (currently under development).

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