EPJ Web of Conferences **266**, 10008 (2022)
EOSAM 2022
https://doi.org/10.1051/epjconf/202226610008

Particle detection enhancement by combining coherent Fourier scatterometry with synthetic optical holography

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Abstract. By combining coherent Fourier scatterometry (CFS) with synthetic optical holography (SOH) we show that the sensitivity of detection of isolated nanoparticles on surfaces can be substantially increased. This improvement is a result of the boost in the signal at the detector due to the added reference beam, and the reduction of background noise caused by the electronics. We demonstrate an improvement of sensitivity of about 4 dB for the case of detection of a 60 nm polystyrene latex (PSL) particle on a silicon wafer at the wavelength of 633 nm ($\sim \lambda/10$).

1 Introduction

The detection of contamination due to isolated nanoparticles on surfaces that are used as substrates in nanofabrication has become one of the major challenges in the past decades, given the continuous decrease of the size of the features. Scatterometry is one of the most used techniques for this purpose since it is not limited by diffraction and it is based on far field detection. Recently, coherent Fourier scatterometry has been introduced to tackle this problem. The technique is similar to a confocal microscope operating in reflection where the surface to be inspected is scanned while being illuminated by a focused light beam. The difference with the latter is that instead of imaging the focal plane at the detector, in CFS the back focal plane is imaged into a split detector, where both halves of the detector are aligned perpendicular to the sample scan direction. The differential signal from both halves is recorded for each scan position. The sensitivity of the technique lies in the fact that although it operates in bright field mode (in the sense that both scattered and non-scattered fields are collected in reflection at the detector), the background is eliminated because when no particles are being illuminated by the focused beam, the far field is symmetric and the differential signal is zero. When a particle passes through the focused beam, the far field becomes asymmetric and position dependent, generating a differential signal that can be either positive or negative, depending on the relative position of the focused laser beam with respect to the particle. In CFS, the position of the particle can be determined with high accuracy and its size can be inferred by calibration [1].

In this work, we implement the synthetic optical holography (SOH) phase imaging technique [2] to enhance the sensitivity of CFS.

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2 Experimental setup

In order to combine SOH with CFS we simply add a piezo-actuated mirror at the open port of the beamsplitter of the existing CFS setup as in [1]. A collimated and linearly polarized He-Ne laser (λ = 633 nm) passes through a 50-50 non-polarizing beamsplitter which splits the beam into two halves: one beam goes to a microscope objective (NA = 0.9) and is focused on the sample of interest, and the other beam goes to a piezo actuated reference mirror. The sample is placed on a piezo stage that can be laterally scanned in a raster fashion. The reflected and scattered light from the sample arm is collected by the same objective and goes back into the beamsplitter, where it is combined with the reflected reference beam, similar to a Michelson interferometer. The Fourier plane of the objective is de-magnified by a telescopic setup consisting of two lenses and imaged on the split detector. The split detector has two halves, and here the intensity voltage from the left half is subtracted from the right half, resulting in a position dependent differential signal. While the sample is raster scanned, the reference mirror moves one step per scanned line creating a virtually tilted reference field. The reconstruction of the hologram is done as in the conventional off-axis digital holography [3, 4], which consists of Fourier transforming the scanned map containing the 0th and the ± first orders, isolating one of the first orders followed by shifting to zero and inverse Fourier transforming. The result of this operation is the retrieval of the complex field of the measured differential signal.

3 Results

We demonstrate the new combined technique by detecting a polystyrene latex (PSL) nanosphere with a diameter of 60 nm ($\sim \lambda/10$) on a silicon wafer. The laser power was set so low that the SNR of the detected signal from the nanoparticle in the conventional CFS setup was ≈ 3 dB. For the Fourier reconstruction procedure we used a band pass filter consisting of a 2D cosine window superimposed with a high pass filter. We also included the (noise filtered) map of the conventional CFS as reference.

After reconstruction, we observe that with the imaginary part of the first order signal one achieves a SNR of approximately 10 dB, despite the size of the particle and the wavelength of our laser. Compared to the reference measurement, our new technique has a higher signal amplitude and a SNR gain of 7 dB is achieved over the unfiltered signal or a gain of 4 dB over the filtered signal.

Beyond the detection of particles on wafers, our technique could also be implemented in other applications where the contrast between the nanoparticles and substrate is low due to the phase sensitive nature, such as PSL particles on glass or plastic substrates and pellicles. Furthermore, due to the modulation property, our technique is also suitable for low power applications, as in the case of biological samples.

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