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Experimental validation of 20nm sensitivity of Singular Beam Microscopy

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ABSTRACT

Quickly developing nanotechnology drives the industrial need for fast but sensitive nano-scale feature detection and evaluation. In this work we bypass the diffraction limit for achieving nanoscale sensitivity by introducing optical singularities into the illuminating beam for a modified laser scanning microscopic architecture. A good correspondence was obtained between laboratory experiments and corresponding simulations that indicated a theoretical potential of 1nm sensitivity under a practical signal to noise ratio of 30dB. For analysis of the experimental and simulation results, two simple but effective algorithms were developed. A significant improvement of signal to noise ratio in the optical system with coherent light illumination can be achieved by utilization a highly redundant data collected during experiments. Our experimental results validate achievable sensitivity down to 20nm. The unique combination of nano-scale sensitivity together with implementation simplicity and on-line, real-time analysis capability make Singular Beam Microscopy a valuable industrial analytic method.

Keywords: Singular beam, nano-scale, microscopy, sensitivity

1. INTRODUCTION

Progress in high-tech production and scientific research relies heavily on high sensitivity instrumentation for measurements and quality control. Parameters to be evaluated include the dimensions and position of nano-scale surface features, surface roughness, surface defects and particle size distributions. High volume and high cost of production processes impose the need for high-sensitivity and high-speed inspection systems operating on the production lines.

Traditional approaches for high sensitivity surface inspection, such as confocal microscopy, scanning probe microscopy and interferometry cannot combine high speed with high sensitivity and spatial resolution, as required by cutting edge technologies. Singular Beam (SB) microscopy is being developed with an attempt to fill this technology gap.

As opposed to other techniques, that use Gaussian beam, plane wave or evanescent wave illumination, this method uses a singular beam. Based on the intensity pattern of a singular beam, scattered by the investigated surface, surface feature parameters can be deduced. While most of the other methods intend to generate images of investigated surface features, SB microscopy aims to collect more refined information. Generally, a singular beam contains one or more optical singularities, where the amplitude vanishes and the phase is indeterminate. At the early stages it became apparent that SB microscopy has nano-scale sensitivity[1-3]. In this paper we continue to investigate the capabilities of SB microscopy using a line phase singularity imbedded in a Gaussian laser beam. The principles of SB microscopy are provided in the next section and the experimental results are described in Sect. 3. This is followed by a discussion and conclusions.

2. SINGULAR BEAM MICROSCOPY

The main idea of the SB microscopy can be outlined as follows. A SB scans the investigated sample and interacts with objects, frequently of dimensions in the nanometer region. The light scattered from this interaction is propagated in free space and/or through optical systems and is recorded by a detection system and its intensity distribution is analyzed in time and space. The classical diffraction limit is evaded by collecting information as the object is scanned by the singular beam and the analysis of the scattered light is constrained by the overall system Signal-to-Noise Ratio (SNR), as opposed to the fundamental diffraction limit of conventional imaging systems.