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High numerical aperture singular beam scanning microscopy: preliminary experimental results

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ABSTRACT

High sensitivity and a high speed nanoscale measurement becomes an important subject in modern industry, when analysis of high speed moving nanoscale objects on a surface is required. Recently we have shown a possible approach to this problem using singular beam microscopy. Singular beam microscopy performs scanning by utilization of the relative movement between the focused singular beam and the investigated object. This allows collection of sufficient information for evaluation of various features of the investigated object. Our theoretical results were in good agreement with the experimental results, which showed 20nm experimentally proven sensitivity under a moderate numerical aperture of 0.4. One of the possibilities for sensitivity improvement is increasing the numerical aperture. In this publication we report our progress with a numerical aperture of 0.55. This transition requires rigorous numerical analysis and a more accurate experimental setup. In order to approach the problem of modeling tight singular beam focusing, we developed an extension of the existing Richards-Wolf method which allows evaluation of a 3D tightly focused optical field. The modeling of scattering of tightly focused singular beams can be done by existing electro-magnetic methods. In this work we will present experimental results of detection and evaluation of a phase step in different experimental conditions. The investigated equivalent phase step heights were down to 10nm.

Keywords: Singular beam, nano-scale, focusing, high-NA

1. INTRODUCTION

Methods for characterizing geometrical and optical properties of nanoscale objects and features receive much attention in the present decade. This interest is justified by the importance of these methods in nanotechnology and related industries. Recently we suggested a promising method, capable of nano-metric sensitivity at sufficiently long working distance[1]. The suggested method allows both, high speed and a high sensitivity, by trading off some aspects, which are less important for industrial applications. This method demonstrated experimental sensitivity of 20nm for a moderate numerical aperture (NA) of 0.4 while paraxial numerical analysis predicted capability of an order of 1nm sensitivity for a reasonable optical system signal to noise ratio of 30dB. A good correlation between the experimental results and corresponding numerical simulations was observed.

The performance and capabilities of the suggested scanning microscopy method can be extended further in a number of ways. Increasing the NA of the optical system can produce higher localization of the scanning beam and thus improve the sensitivity. Unfortunately, increasing the NA places more stringent experimental and practical requirements on the optical system and the measurement procedure and requires a much more complex analysis than the one needed for lower numerical apertures. Extension of the analysis to 3D presents an additional analytical and numerical challenge.. The suggested method was initially demonstrated on a phase step[1,2,3] but in practice, other types of nanoscale objects should be investigated as well. An interesting option for an extension of the original method is utilizing other types of structured illumination. The aim of this publication is a summary of recent advances in the field of scanning singular beam microscopy both analytical and experimental. This paper is organized as follows. The next section is dedicated to a short description of high NA scanning singular beam microscopy and related rigorous analysis. Section 3 reports on our progress with NA=0.55. Finally, conclusions are drawn.

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