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Characterization of surface generation of optical microstructures using a pattern and feature parametric analysis method

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ABSTRACT

Optical microstructures have a small scale topography classified as micro-grooves, microlens arrays, pyramids, lenticulations, etc. They are widely applied in optical components such as light guide panels for electronic displays. Most previous research work focuses on either the characterization of individual scale topography, or the optical performance of optical microstructures. There is a lack of surface characterization methods which are capable of characterizing the surface generation in terms of the form errors and the lattice relationships in the small scale topography of optical microstructures with sub-micrometer accuracy.

This paper presents a pattern and feature parametric analysis method (PFPAM) for the characterization of the surface generation of optical microstructures. The method includes data acquisition, data processing and pattern analysis, exploration of and analysis of feature parameters, etc. Digital image processing technology has been employed and a series of lattice dislocation parameters have been developed to characterize the features of the distribution and the dislocation of optical microstructures. To verify the PFPAM, a prototype surface characterization system has been built. A series of cutting and measurement experiments have been conducted on microlens arrays and titled flats using a two-axis ultra-precision machining system equipped with Fast Tool Servo (FTS) and examined by a non-contact micro-surface profiler system. The results demonstrate that the PFPAM provides an adequate basis for good form characterization of optical microstructures, with form accuracy down to below sub-micrometer range. The proposed lattice dislocation parameters are shown to be useful for the characterization of the distribution and dislocation features in the small scale topography of the optical microstructures. This is not possible using traditional methods. Potential applications of the PFPAM for quality control and evaluation of optical microstructures are discussed.

1. Introduction

Nowadays, optic parts are being used in more and more products, especially optical microstructures which can produce a unique or particular optical performance. Optical microstructures have small scale topography classified as micro-grooves, microlens arrays, pyramids, lenticulations, etc. They are critical components, widely used for photoelectrical parts such as light guides for display devices, microlens scanners [1,2], or microlens arrays for flat-panel devices, and are applicable for optical communications, optical data storage, digital displays, and laser beam shaping [3].

Although ultra-precision machining based on Fast Tool Servo (FTS) machining provides a solution for machining optical microstructures with sub-micrometer form accuracy and nanometric surface finish, without the need for any subsequent post processing, the methodologies for the characterization of surface generation for optical microstructures have received relatively little attention. Optical microstructures are usually characterized by their surface quality, such as surface roughness, as well as by their optical properties, such as their modulation transfer function. Most previous research work on micro-optics testing is based on interferometric methods [4–8] and wavefront measurement, such as Mach-Zehnder interferometry (MZI) [9–11]. Some research work has been found in the application of the 2D discrete Fourier transform (DFT) of the interference microscope image to evaluate the fabricated grid surface [12,13]. However, interferometric testing of micro-optics incurs certain difficulties due to the small dimensions, such as Fresnel diffraction artifacts, coherent noise, distributed interferences, etc. [14]. On the other hand, most previous research work fails to articulate the surface quality of the optical microstructures to the functional specifications of the micro-optics systems.

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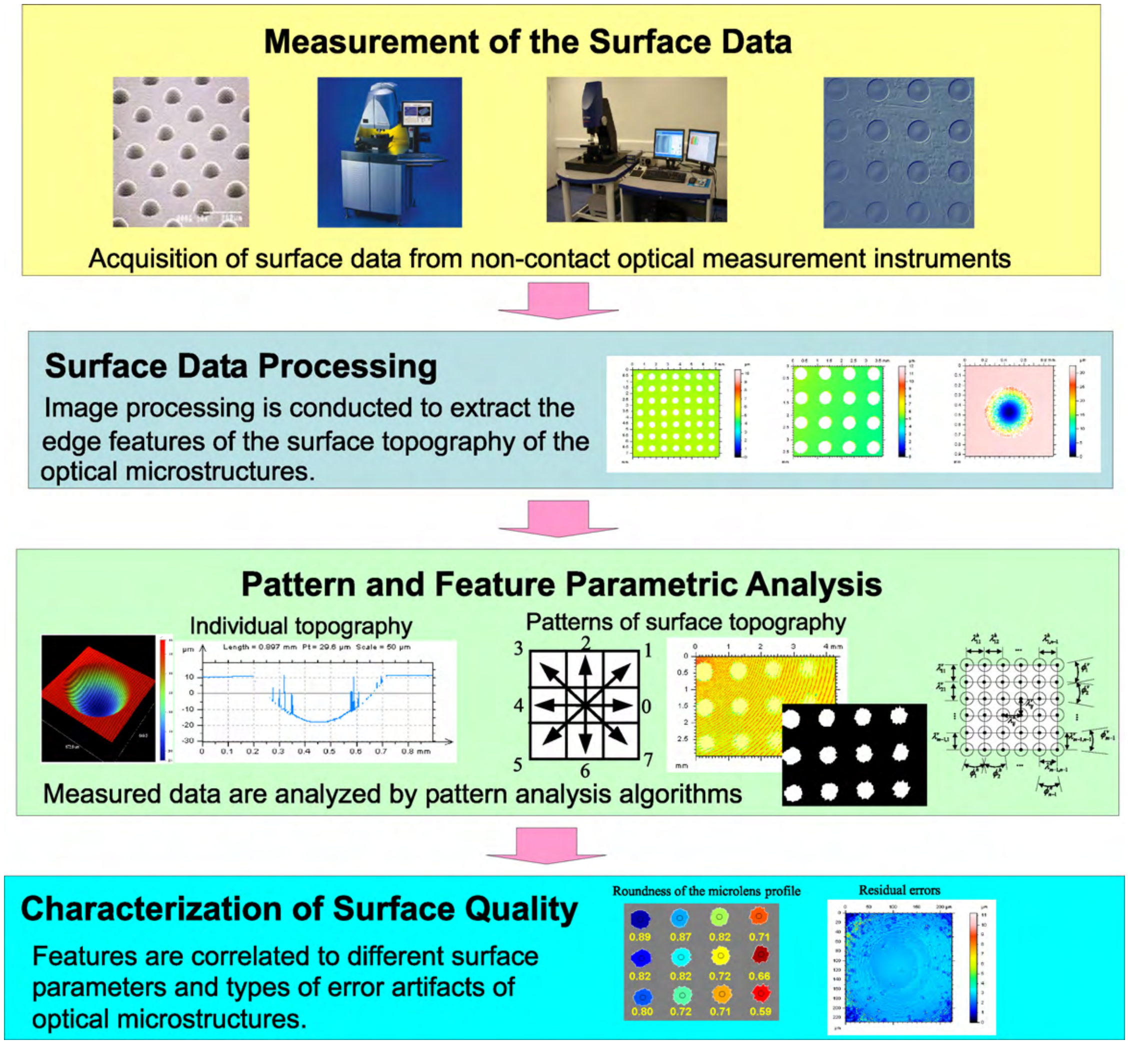

Fig. 1. A schematic diagram of pattern and feature parametric analysis method (PFPAM).

Among different types of optical microstructures, the microlens array is most widely used. It is composed of many microlenses which are arranged in a certain pattern, and there is a difference in the radii of the microlenses in the rows. There has been an upsurge of interest in microlenses, as the benefits of photonics over electronics have been realized since the late 1980s [15]. With the use of microlens arrays, fewer light sources (one or several LEDs) may be used to achieve a uniform distribution of light. Microlens arrays are mainly used in Liquid Crystal Displays (LCDs), and the applications include mobile phones, hand-held palm pilots and TVs, etc. During the past decade, research on microlens characterization can be found in the available literature. Nussbaum et al. [16] characterized the surface profile and the wave aberrations, besides the surface roughness. The research emphasized geometrical features and functional performance of microlens array products. In the research by Liu et al. [17], the optical performance of microlens arrays was tested, such as the spot uniformity, the spot sizes, and the positions of the focused spots at various accessible locations, which is an indirect method for the characterization of the quality of microlens arrays. Some parameters, such as microlens pitch, fill factor, surface quality and wave front quality, have been examined for lens-let arrays for astronomical spectroscopy by Lee and Haynes [18]. Ottevaere et al. [19] measured the geometrical dimensions, the sag and the surface roughness of the microlenses, as well as the optical characteristics such as wavefront aberrations and the focal lengths. Gu et al. [20] measured microlens profiles and some optical parameters, such as focal length and spot size, using laser scanning reflection/transmission confocal microscopy. 2D and 3D profiles of microlens arrays were measured in the research [21]. However, a quantitative pattern analysis for the lens array was not provided. Lee and Baek [22] studied the effect of machining factors on surface quality of microlenses with respect to the surface roughness and profile accuracy of a single lens surface. Pahk and Ahn [23] proposed a non-contact measurement method and attempted to measure 3D micro patterns. However, their work was still focused on the use of conventional parameters such as flatness and roughness.

Most previous research work focuses either on the characterization of an individual lens, or the optical performance of the lens. This is inadequate for the analysis of the patterns and lattice dislocation errors of the optical microstructure array. This paper presents a pattern and feature parametric analysis method (PFPAM) together with a series of feature parameters for the characterization of optical structures. The capability of the method is evaluated through a series of cutting and measurement experiments. Some potential applications of the PFPAM are also explored.

2. Pattern and feature parametric analysis method (PFPAM)

Fig. 1 shows a schematic diagram for the pattern and feature parametric analysis method (PFPAM). The method starts with the acquisition of surface data from a measurement instrument. Surface data are processed by various digital image processing tech-