

國立成功大學
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碩士論文

無光罩式數位微影暨灰階曝光應用於
製作三維微結構

Fabrication of Three-Dimensional
Microstructures Based on Maskless Digital
Lithography and Grayscale Exposure

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摘要

本研究以無光罩式數位微影技術為基礎，利用步進與灰階曝光的方式，在光阻表面製作出三維的立體微結構。研究方法是藉由控制數位微反射鏡裝置 (Digital Micro-mirror Device, DMD) 的脈衝寬度調變 (Pulse-Width Modulation, PWM)，精準地調控紫外 (UV) 光源投影在光阻表面的劑量，並且依據光阻的特性曲線，將目標結構的深度轉換成所需的 UV 劑量。結合本研究開發的數值模擬和最佳化，藉由光點的卷積疊加，精確地預估 UV 曝光劑量，以大幅降低實驗的次數。

此一步進式灰階曝光演算法，先針對正型光阻材料，以正面曝光的方式成功地在面積 $35 \times 30 \text{ mm}^2$ 範圍內，製作出週期性的擴散片和非球面微透鏡陣列。為了抑制結構表面的粗糙度，引入熱回流技術 (Thermal Reflow)，將表面粗糙度 Ra 值從 21.1 nm 降低到 10.6 nm，同時保持整體結構形貌的精確度。

最後，本研究也針對負型光阻材料，開發出背後曝光的技術，在石英基板上塗佈的光阻層上直接製作出二種不同型貌的非球面微透鏡陣列。為了驗證微透鏡陣列的光學聚焦品質，本研究建立一套光學聚焦檢測系統，得出兩種非球面微透鏡陣列聚焦光點的半峰全寬 (FWHM) 分別為 15 和 5 μm ，驗證本研究有能力製作光學元件等級的三維微結構。

關鍵詞：無光罩數位微影、步進式灰階曝光、數值模擬與最佳化、三維微結構、熱回流、背後曝光

Abstract

This study is based on maskless digital lithography technology and a stepwise grayscale exposure method to fabricate three-dimensional (3D) microstructures on a photoresist (PR) layer. It involves precise control of the spatial distribution of ultraviolet (UV) light dose projected onto the photoresist surface by using pulse-width modulation (PWM) of a digital micro-mirror device (DMD). Numerical simulation and optimization algorithm are developed to determine the UV dose distribution and the DMD's grayscale images based on deconvolution calculation and the PR's characteristic curve.

The proposed stepwise grayscale exposure method is applied for fabricating two kinds of periodic microstructures, namely, diffusers and aspherical microlens arrays. A positive PR is used with UV exposure on the PR surface directly. Accurate 3D profiles are successfully obtained over an area size of $35 \times 30 \text{ mm}^2$. Thermal reflow technology is used to reduce the average surface roughness (R_a) from originally 21.1 nm to 10.6 nm.

As for negative types of PR, a back-side exposure technique is developed in which the UV light is incident from the PR's coated substrate. Two kinds of aspherical microlens arrays are directly fabricated on a quartz substrate. To verify the optical focusing quality of these fabricated microlens arrays, an optical focusing inspection system is established. The full width at half maximum (FWHM) of the focused light spots for the two types of non-spherical microlens arrays are measured to be 15 μm and 5 μm , respectively. This validates the capability of the methods developed in this research to fabricate three-dimensional microstructures with the optical qualities that can

be used as optical components.

Keywords: Maskless digital lithography, Stepwise grayscale exposure, Numerical simulation and optimization, Three-dimensional microstructures, Thermal reflow, Back-side exposure.

