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利用可膨脹之彈性材料及微混流器製造高數值孔徑且可調式微透鏡陣列

Manufacturing High Numerical Aperture and Adjustable Microlens Array by Using Expandable Elastomer And Microfluidic Mixer

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摘要

微透鏡陣列為近年重點開發的微型光學元件之一，可以廣泛的運用在光電及通訊領域。本研究利用多種精密製程加工技術，搭配改變矽油黏度可收縮膨脹之彈性體材料，成功製造高均勻度及高數值孔徑的球面形貌微透鏡陣列，本研究後半段也將微型混流器和微透鏡陣列整合，成為一可藉由改變矽油黏度而調整焦距的微透鏡陣列。

研究中利用微銑削在聚甲基丙烯酸甲酯(Poly(methyl methacrylate, PMMA)基材上加工，製造出流道和圓形微孔洞陣列，同一時間也利用旋轉塗佈製造厚度均勻的聚二甲基矽氧烷(Polydimethylsiloxane, PDMS)薄膜，兩者完成後利用氧電漿結合技術將 PDMS 薄膜固定於 PMMA 微孔洞陣列上，再將矽油注入流道中與 PDMS 薄膜接觸，油中的高分子鏈會擴散進入 PDMS 薄膜並使之膨脹，成為球面形貌 7x7 微透鏡陣列，單顆直徑為 500 μm。

本研究中設計並執行多種實驗，可分為兩大階段。第一階段實驗用來了解此微透鏡陣列的製程控制因素、微透鏡陣列的形貌均勻度、以及成像表現；在第二階段實驗中，將此微透鏡陣列的入口端和微混合器整合成一裝置，操作中藉由調整注入微混合器的矽油流率，於出口端產生不同黏度的矽油，進而調整微透鏡陣列的形貌和焦距。第一階段的實驗結果顯示：(1)本製程可以開發形貌均勻、高數值孔徑、焦點亮度均勻且成像清晰的微透鏡陣列，數值孔徑最大可達 0.504，透鏡陣列高度的變異係數為 0.01；(2)低黏度矽油（短分子鏈）可以製造短焦的透鏡陣列，而高黏度矽油（長分子鏈）可以製造長焦的透鏡陣列；(3)了解各參數（薄膜厚度、矽油溫度、浸泡矽油時間等）對於微透鏡陣列的影響，例如同樣黏度的矽油在可以在較薄的 PDMS 薄膜上造成較高的透鏡陣列。第二階段的實驗結果顯示：(1)不同的矽油注入流率可以在混流器出口端產生不同黏度的矽油；(2)使用混流器可以有效控制微透鏡陣列的高度，例如 5 cst 的矽油可以製造高度 190 μm 的微透鏡陣列，而 100 cst 的矽油可以製造高度 86 μm 的微透鏡陣列；(3)藉由控制混流器入口端的矽油流率，可以調整微透鏡陣列的高度，進而調整焦距長短。

關鍵字：微透鏡陣列、可調式微透鏡晶片、精密加工、微流體晶片、彈性體材料

Abstract

Microlens arrays, a micro-optical element developed in recent years, is widely applied in optoelectronics and communications. Using multiple precision manufacturing technologies and expandable elastomer material with variable silicone oil viscosity, we successfully developed a spherical microlens array with high uniformity and a high numerical aperture. We also combined the microlens array with a micromixer to create a microlens array in which the focus can be adjusted by altering the viscosity of the silicone oil.

Polymethyl methacrylate (PMMA) was processed using micro-milling to create microchannels and an array of round micropores. At the same time, a polydimethylsiloxane (PDMS) thin film with uniform thickness was fabricated using spin coating. Using oxygen plasma bonding technology, the PDMS film was fixed to the PMMA micropore array. Then, silicone oil was injected into the microchannels to come into contact with the PDMS film. The polymer chains in the oil diffused into the PDMS, caused it to expand and formed a 7×7 spherical microlens array in which the diameter of each microlens was 500 μm.

We designed and conducted multiple experiments that were divided into two major phases. The purpose of the first phase of experiments was to understand the process control factors, morphological uniformity, and imaging performance of the microlens array. In the second phase of experiments, the inlet of the microlens array was combined with a micromixer. By adjusting the flow rate of the silicone oil being injected into the micromixer and creating silicone oil with viscosities at the outlet, we adjusted the morphology and focus of the microlens array. The results of the first phase of experiments indicated the following: (1) Our fabrication process can produce microlens arrays with a uniform morphology, high numerical aperture, high uniformity, and clear images; the maximum numerical aperture could reach 0.504, and the coefficient of variance of microlens height uniformity was 0.01; (2) Low-viscosity silicone oil (short molecular chains) can be used to create microlens arrays with short focal length, whereas high-viscosity silicone oil (long molecular chains) can be used to create microlens arrays with long focal length; (3) Understanding the influence of various parameters (thin film thickness, silicone oil temperature, soak time in silicone oil, etc.) to the microlens array; for instance, silicone oil with the same viscosity can create a higher microlens array on a thinner PDMS thin film. The results of the second phase of experiments indicated: (1) The silicone oil injection flow rates influences the viscosity of the silicone oil at the outlet of the micromixer; (2) The micromixer can effectively control the height of the microlens array; for instance, silicone oil with 5 cst viscosity can create a microlens array with height 190 µm, whereas silicone oil with 100 cst viscosity can create a microlens array with height 86 µm; (3) Altering the flow rate of the silicone oil at the inlet of the micromixer changes the height of the microlens array and thereby adjusts the focal length.

Keywords: microlens array、tunable microlens chip、microfluidic chip、swelling、micromixer