DEVELOPMENT OF 3D MICROSTRUCTURES BY USING GRAYSCALE PHOTOLITHOGRAPHIC TECHNIQUE

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DEVELOPMENT OF 3D MICROSTRUCTURES BY USING GRAYSCALE PHOTOLITHOGRAPHIC TECHNIQUE

by

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LIST OF ABBREVIATIONS

2D	2-dimensional
3D	3-dimensional
Bi	Bismuth
CAs	Contact angles
CoG	Chrome-on-glass
DI	Deionised
dpi	Dot per inch
EBL	Electron beam lithography
EUVL	Extreme ultraviolet lithography
FIB	Focused ion beam lithography
H_2O_2	Hydrogen peroxide
HCl	Hydrochloric acid
HEBS	High Energy Beam Sensitive
HF	Hydrofluoric
IC	Integrated circuit
In	Indium
IPA	Isopropyl alcohol
LDW	Laser Direct Write
MEMS	Micro-electromechanical-systems
Mo	Molybdenum
NFM	Nanofabrication and Functional Materials
NGL	Next Generation Lithography
NH_3	Ammonia

PDM	Pulse-density modulation
PDMS	Poly-dimethyl-siloxane
PET	Polyethylene terephthalate
PMMA	Polymethyl methacrylate
PWM	Pulse-width modulation
rpm	Revolution per minute
SEM	Scanning electron microscope
Si	Silicon
Si-OH	Silanol groups
Sn	Tin
UV	Ultraviolet light

LIST OF SYMBOLS

CD	Minimum feature size
λ	Wavelength of light source
NA	Numerical aperture
θ	Contact angle
UV_{dosage}	UV exposure dosage
$UV_{intensity}$	UV illumination intensity
$t_{exposure}$	UV exposure time

PEMBANGUNAN MIKROSTRUKTUR 3D MENGUNAKAN TEKNIK FOTOLITOGRAFI SKALA KELABU

ABSTRAK

Perkembangan pesat teknologi seperti bio-chip, peranti pendalir mikro, peranti mikro-optik dan sistem mikro elektro-mekanikal (MEMS) memerlukan keupayaan membina struktur tiga dimensi (3D) yang kompleks di skala mikro. Bagi membina struktur 3D di skala mikro, kebiasaannya beberapa topeng cahaya digunakan bagi menghasilkan corak 3D diatas beberapa lapisan photoresist yang ditindan. Namun begitu teknik ini memakan masa, tidak efisien dan rumit untuk diadaptasi dalam industri pembuatan. Teknik lithografi terbaru seperti litografi mengunakan pancaran elektron (EBL), pancaran ion terfokus (FIB) dan sinar ultraviolet ekstrem (EUV) memerlukan kos terlalu tinggi dan kepakaran yang mahir dalam bidang tersebut. Tujuan utama kajian ini adalah untuk menghasilkan teknik mudah bagi menghasilkan struktur 3D pada skala mikro mengunakan topeng emulsi dengan teknik litografi skala kelabu. Kajian dimulakan dengan mencari prosedur dan parameter yang sesuai bagi menghasilkan hasilan microfabrikasi yang optimum. Dalam eksperimen ini, kepekatan skala kelabu ditentukan dengan mengawal peratusan titik hitam di sesuatu kawasan. Peratusan skala kelabu yang tinggi akan menghasilkan struktur mikro yang lebih tebal. Corak yang telah direka akan dicetak di atas kertas plastik lutsinar. Corak ini yang akan dipindahkan ke atas topeng kaca emulsi (Plat Cahaya Berprestasi Tinggi). Plat ini dihasilkan oleh Konica Minolta Inc. Selepas itu, corak dari topeng kaca emulsi akan dipindahkan ke atas photoresist MicroChem SU-8 2010 yang telah didepositkan di atas substrak kaca. Dengan mengunakan teknik mikrofabrikasi ini, struktur mikro antara 17 μm sehingga 750

µm dapat dihasilkan dengan hanya mengunakan sekali pendedahan cahaya sahaja. Kajian seterusnya adalah untuk menghasilkan saluran mikrofluidik mengunakan teknik litografi skala kelabu. Saluran mikrofludik ini dinilai mengunakan sistem mengukur Infinite Fokus daripada ALICONA dan mikroskop imbasan elektron (SEM). Dengan mengunakan teknik mikcofabrikasi ini, liang yang berdiameter 35 µm telah berjaya dihasilkan dalam saluran mikrofluidik. Kesimpulannya, ketebalan struktur mikro adalah ditentukan oleh peratusan skala kelabu di peringkat mereka bentuk.

DEVELOPMENT OF 3D MICROSTRUCTURES BY USING GRAYSCALE PHOTOLITHOGRAPIC TECHNIQUE

ABSTRACT

Recently, the rapid development of technology, such as biochips, microfluidic device, micro-optical devices, and micro-electromechanical-systems (MEMS), demands the capability to create complex designs of three-dimensional (3D) microstructures. Nevertheless, in order to create 3D microstructures, the traditional photolithography process often requires multiple photomasks to generate a 3D pattern from several stacked photoresist layers. This fabrication method is extremely time consuming, has low throughput, and is complicated for high volume manufacturing scale. On the other hand, the next generation lithography, such as electron beam lithography (EBL), focused ion beam lithography (FIB), and extreme ultraviolet lithography (EUV) is however too costly and requires experts to setup the machines. Therefore, the purpose of this study had been to develop a microfabrication method in producing 3D curvature microstructures by employing the single-step grayscale emulsion mask photolithography technique. In the first part of this study, suitable procedure and parameters were determined to produce optimum microfabrication results. In the experiment, the concentration of grayscale was determined by the percentages of halftone dots filling in a particular area. Therefore, the lower the concentration of halftone dots on the emulsion mask, the thicker the developed microstructure will be. First, the designed patterns were printed out on a transparent sheet. Then, the patterns were transferred onto an emulsion glass mask (High Precision Photo Plate) from Konica Minolta, Inc. After that, SU-8 2010 negative photoresist (MicroChem) was deposited on a glass substrate, while the

patterns from the emulsion glass were transferred onto a photoresist coated glass substrate. From this microfabrication method, a microstructure with maximum and minimum thickness of 750 µm and 17 µm respectively had been obtained in a single-step lithography exposure. On the other hand, as for the second part of this study, this grayscale fabrication method was demonstrated on the fabrication of microfluidic channel. The microfluidic channel was then evaluated under InfiniteFocus measurement systems from ALICONA and also under scanning electron microscope (SEM). By using this microfabrication method, microfluidic channel with 35 µm pores was successfully fabricated. Therefore, it is concluded that different thickness of developed photoresist can be obtained by manipulating the percentage of grayscale concentration during the mask designing stage.

CHAPTER 1

INTRODUCTION

1.1 3D MICROFABRICATION

The rapid growth of technology has increased the efficiency and the quality of our lives. Therefore, in order to cope with the pace of technology development, micro and nanofabrication skills have been increasing in demand over each year. These days, technologies such as biochips, microfluidic device, micro-optical devices, and micro-electromechanical-systems (MEMS), are designed in more complex three-dimensional (3D) micro-profiles. In fact, some of the benefits of designing 3D microstructures are to maximize the functional efficiency, as well as to minimize the space and material consumption.

For example, in a microfluidic device, the geometry of microchannel in a micromixer plays an important role during the fluidic mixing process. However, a straight microchannel could only produce laminar flow, which is less favourable for the mixing process. Hence, 3D microfabrication is important to improve the properties of fluidic handling by creating well-defined 3D microstructures in the microchannel. Figure 1.1 illustrates an image taken by using scanning electron microscope (SEM) where the 3D microstructures were fabricated inside the microchannel in order to increase the surface roughness in the microchannel, as well as to generate a turbulent flow that could ease the mixing process [1].

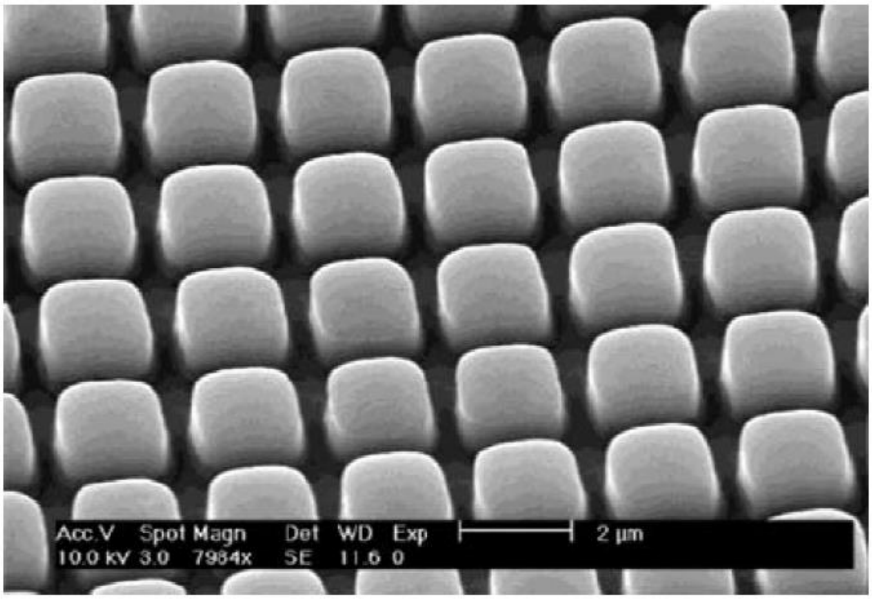

Figure 1.1 SEM image of a microchannel surface with 3D micro-square elements [1].

1.2 LITHOGRAPHY

The key for microfabrication process is the patterning process where it determines the feature size of the microstructures. Among all patterning techniques, lithography is the most commonly used method especially in the fabrication of integrated circuit (IC) [2]. The word ‘lithography’ comes from Greek; ‘lithos’ means stones, while ‘graphia’ means write [3]. As suggested by the name, lithography literally means writing on stones. In most cases of microfabrication, stones are referred as substrates and the patterns are written on substrates by using a light sensitive polymer called photoresist.

Recently, many different forms of lithography technique have been employed by the industry. The most common form of lithography used is the photolithography technique. In the IC industry, patterns are transferred from photomask onto substrate via photolithography [4]. However, due to the endless demand of critical feature size