MICROFABRICATED BARCODES FOR PARTICLE IDENTIFICATION

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Abstract *— Microfabricated barcodes formed in SU8 photopolymer are presented as a method for identifying individual particles based on their diffraction patterns. Two designs of barcoded particles are considered; a single layer SU8 process and a two layer SU8 process. Theoretical data shows that for ideal barcoded particles it should be possible to obtain several million uniquely identifiable codes for particles as small as 50 microns in length.*

Key Words: *SU8, barcodes, diffraction pattern*

I INTRODUCTION

The ability to identify and track microparticles is important for a wide variety of scientific and industrial applications. Examples of such applications are found in the field of combinatorial chemistry; where multiple chemical reactions are carried out on the surfaces of micron-sized beads in one tube [1]. To this end we have fabricated micron-sized SU8 bars encoded with diffraction gratings allowing the identification of individual barcoded particles. Laser illumination of the particles as they pass through a detection zone in a microfluidic channel results in a particle specific diffraction pattern readable using a CCD array.

In this paper we describe the fabrication of the SU8 particles with diffraction gratings patterned on their surfaces. Details of two fabrication processes are discussed; the first a single SU8 layer with the diffraction pattern on the side walls of the particle, second a two layer process with the diffraction grating being formed on the surface of the SU8 particle in a second layer of SU8. Details of the diffraction patterns produced by such barcoded particles are also presented showing that several million individually distinguishable codes are possible using such a technology.

II FABRICATION

II.1 FABRICATION OF SU8 BARCODES

The SU8 barcodes were fabricated using either a single layer of SU8 and one photolithography step, or a two layer SU8 process requiring two photolithography steps. Lift-off was then used to release the bars from the silicon wafer substrate. A schematic of the process is shown in figure 1 illustrating the various steps.

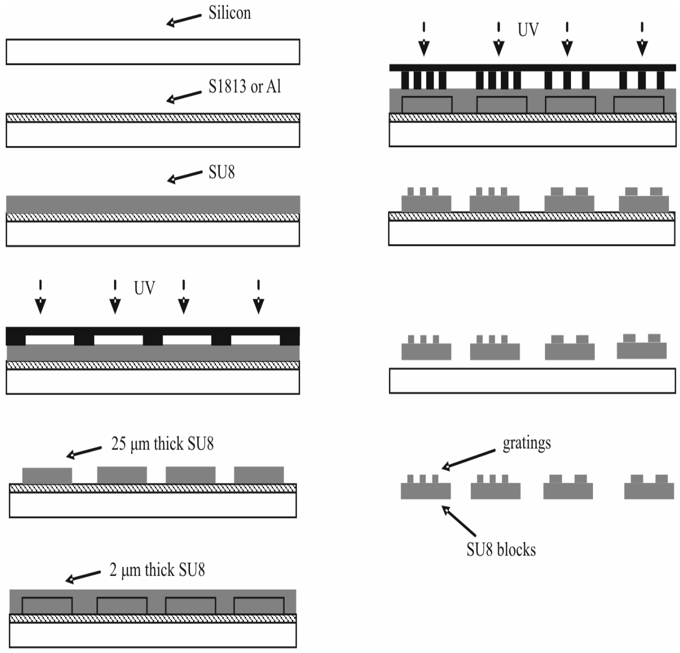

Figure 1. Schematic of the barcode fabrication process.

SU8-25 epoxy photoresist, and polypropylene-glycol-methyl-ether-acetate developer (PGMEA) were purchased from Microchem Co., UK. Rohm and Haas S1813, Microposit MF-319 (Al etchant) and Microposit EC solvent were purchased from Chestech Ltd, UK. Microposit primer was purchased from Shipley Europe Ltd, UK. Single sided polished 4 inch silicon wafers with thickness 525 ± 25 µm were purchased from Si-Mat Silicon Materials, Germany. Darkfield glass-chromium photomask plates were designed using L-Edit (version 11.0) software and manufactured via electron beam lithography by Compugraphics International, UK. Spin coating was done using a Headway Research Inc. spin coater.

II.1.1 SACRIFICIAL LAYER

Two sacrificial layers were tested to allow lift-off of the SU8 bars following processing, S1813 photoresist or a 50nm layer of aluminium. Silicon substrates were used in both cases, these were prepared by cleaning in fuming nitric acid for 20 minutes and rinsed in distilled water and dried. S1813 was then spin coated onto the substrates at 2000 rpm for 30 minutes. In the first instance the S1813 was soft baked at 95°C for 30 minutes. However, it was found that this layer was damaged by the PGMEA solvent involved in the subsequent SU8 processing steps. S1813 was therefore baked at 115°C for 30 minutes [2] prior to SU8 coating. Alternatively, a 50nm layer of Al was evaporated onto the cleaned silicon wafers using an electron beam evaporator. The Al coated silicon wafers were baked at 200° C for 1 hour just prior to coating with SU8, this increased the adhesion of the SU8 to the Al.

II.1.2 DOUBLE LAYER SU8 BARCODES

For the double layer barcodes processing was carried out as follows. Microposit primer was spin coated on top of the sacrificial layer at 2000 rpm for 30 seconds. The substrate was then left for 20 seconds prior to SU8 coating. SU8-25 was spin coated onto the silicon substrates using the following spin cycle; an initial spread cycle of 500 rpm for 5 seconds at an acceleration of 100 rpm per second from 0 rpm, this was followed by a 300 rpm per second acceleration to 3000 rpm for 30 seconds giving an SU8 layer thickness of 15 – 20 µm [3-4]. Soft bake of the SU8 was carried out at 65°C for 5 minutes and 95°C for 30 minutes. Photolithography was carried out using an MA6 SUSS Microtech mask aligner. The optimal exposure time for the SU8 was 18 seconds (13.6 mw cm^{-2}). A post exposure bake of 65°C for 1 minute and 95°C for 5 minutes was performed to fully cross-link the SU8. Developed was carried out in polypropylene-glycol-methyl-ether-acetate (PGMEA) for 2 minutes under constant agitation.

A second layer of lower viscosity SU8, SU8-2, was then spin coated over the entire substrate. A spread cycle of 500 rpm for 5 seconds at acceleration of 100 rpm per second was followed by an acceleration of 300 rpm per second to a final spin speed of 2000 rpm for 30 second to achieve a 2 µm thick layer of SU8 on top of the previous SU8 layer. Soft bake was carried out at 65°C for 5 minutes and at 95°C for 15 minutes. A second photolithography step was carried out to define the diffraction gratings in this thin layer of SU8. The optimal exposure time was found to be 3 seconds (13.6 mw cm^{-2}). Finally, the second SU8 layer was developed in PGMEA for 20 - 30 seconds.

II.1.3 SINGLE LAYER SU8 BARCODES

For the single layered barcodes all prepossessing of the sacrificial layers was identical to that described above. SU8-2 was spin coated onto the substrate. The spin cycle was started from the spread cycle of 500 rpm for 5 seconds at acceleration of 100 rpm per second followed by an acceleration of 300rpm per second to 1000 rpm for 30 seconds giving an SU8 thickness of 3 - 4 µm. Soft bake of 65°C for 5 minutes and at 95°C for 15 minutes was performed. The optimal exposure was found to be 12 seconds (12.5 mw cm^{-2}). Post exposure bake at 65°C for 1 minute and 95°C for 5 minutes was performed to cross-link the SU8.

Microscope images of the single layer and double layer SU8 barcodes attached to the Si wafers are shown in figures 2a and 2b respectively.

II.1.4 RELEASE OF SU8 BARS

For the case of the S1813 sacrificial layer acetone was used to dissolve the S1813 and release the barcoded particles. This was found to be problematic with the S1813 having been baked at 115°C and being partially resistant to the acetone. Release of particles was approximately 50%.

For the aluminium layer Rom and Hass MF 319 developer was used to dissolve the Al to release the bars from the substrates. After immersing the wafers into the solution and leaving for few seconds the bars were released. These were then subsequently filtered and washed with water followed by acetone.

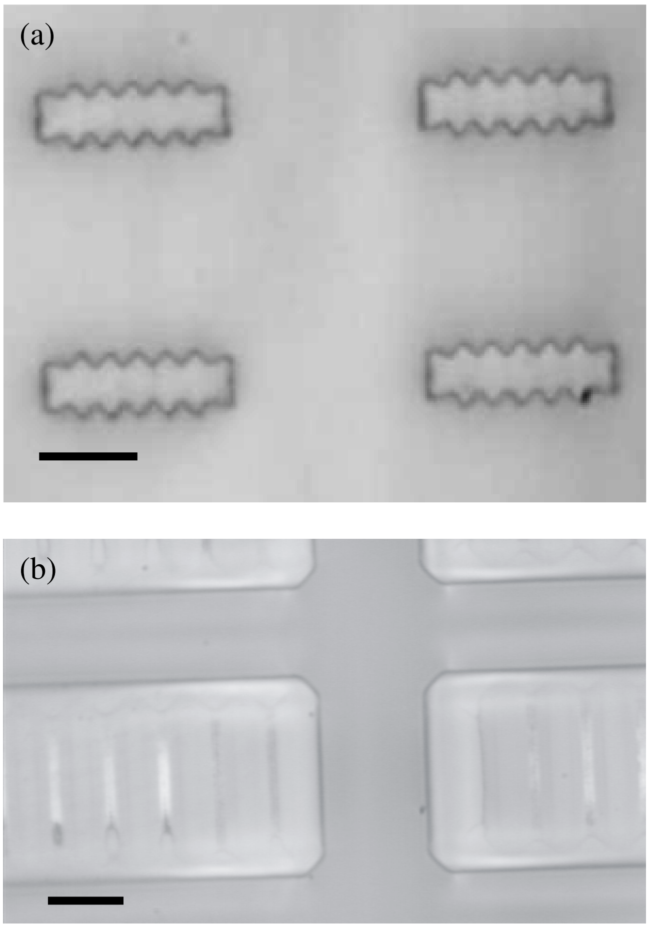

Figure 2. Optical micrographs of the barcodes showing (a) the single layer and (b) the double layer structures. Scalebar 10µm.

III THEORY

III.1 DIFFRACTION PATTERNS

A periodic pattern written on a micro-tag can be used to carry information, we can call this a 'barcode'. In order to obtain that information encoded in such a barcode, one can read the far-field optical diffraction pattern. The position of the first order diffracted spot in this pattern can be used to recover the period on the tag; this can be used as a unique identifier. A simple reading system for the SU8 barcodes presented in this work consists of a laser for illumination and a CCD (or linear diode array) to detect the diffraction pattern from a particle. The ideal encoding capacity is dependant on the length of the bar and wavelength of the reading laser. In order to increase the number of possible different barcodes, gratings with more than one period can be superimposed onto a SU8 particle. As we can see from figure 3 it is possible to make of the order of millions of different codes on a particle just 50 µm in length, using such superimposition technique.

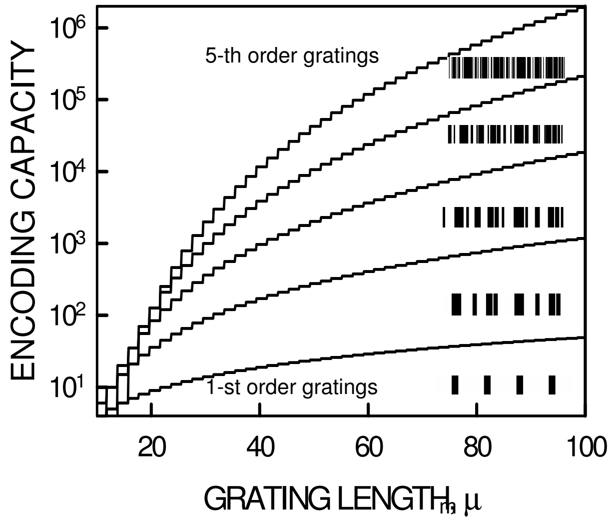

Figure 3. Theoretical number of different codes on a 50µm bar.

IV DISCUSSION AND CONCLUSION

We have produced micron-sized particles in SU8 tagged using a diffraction grating in the surface of the particles. Due to restrictions in photolithographic resolution, the period of barcode patterns obtained from this technique cannot be smaller than 3 - 4 μm, corresponding to a small diffracted angle of 10 - 12°, for a reading wavelength of 635 nm.

Due to the semi-transparent nature of SU8 and the small difference between its refractive index and that of the flowing solution, the signal to noise ratio of the diffraction signal from these tags is very low.

Theoretical predictions suggest that several million distinct patterns can be encoded using such a technology on particles as small as 50 µm in length we do not currently see such large numbers of distinct codes due to the reasons stated above. To improve on the current barcoded particles we propose doping of the SU8 used for the barcode defining layer in order to increase its optical density and refractive index. Patterning of the barcodes using nano-embossing techniques will allow the production of large numbers of such particles cheaply and with nanometer resolution allowing the number of experimentally achievable codes to increase towards the theoretical limit.

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