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SCREEN PRINTING OF SU-8 LAYERS FOR MICROSTRUCTURE FABRICATION

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We report on a screen printing fabrication process for large-area SU-8 layers utilised for the preparation of microstructures in display devices such as microelectronic, electrowetting or bistable devices. The screen printing method has been selected for its effectiveness and simplicity over traditionally used spin-coating ones. Layers and microstructures produced thereof have shown proper homogeneity. Relationships between screen parameters to coating thickness have been established. Coating on an ITO (indium tin oxide) hydrophobic surface is possible when surface has been treated by UV/Ozone to increase its aqueous ability. To this end, the hydrophilic microstructure grids have been successfully built on a hydrophobic layer by screen printing and traditional lithography processes. Compared to conventional spin-coating methods, the screen printing method offers the advantages of simple, cheap and fast fabrication, and is especially suitable for large-area display fabrication.

Keywords: *pixel walls, screen printing, SU-8.*

1. INTRODUCTION

SU-8 is an epoxy based, photo sensitive polymer developed by IBM in the late 1980s [1]. SU-8 is widely used in preparation of microstructures in electrowetting displays [2] and microelectromechanical (MEMS) devices [3]. The standard and most common SU-8 application method is spin-coating. However, this method is hardly suitable for large square areas due to edge bead effects [4] and geometric defects due to solvent evaporation [5]. High material consumption [4] renders this method unsuitable for higher volume production.

Screen printing is an inexpensive and versatile manufacturing method for material deposition on almost any surface. It allows minimising waste during deposition by directing it to specified locations, unlike spin-coating and physical vapour deposition (PVD). The robustness, simplicity, precision, high-throughput and low-cost of this method are reasons why it is well suited for mass production. Screen printing is widely used in the microelectronic industry for fabrication of printed circuit boards, in solar cell industry, display and electronic industries [6], [7].

The basic principle of coating deposition using screen printing is to move a squeegee over a polyester or stainless steel mesh, forcing coating through the screen onto a substrate. Applying pressure to the squeegee causes the screen to come in contact with the substrate and forces the coating material to pass through the screen. When the screen is released from tension, it snaps back leaving the material adhered to the substrate. Mesh is covered with blocking stencil forming open areas where printable material is pressed through onto a substrate (see Fig. 1) [6].

SU-8 resin can be spin-coated on silicon wafers [8], [9], [10] and metals like Ti, Au, Cu, Cr and Ni [11], [12]. There is less information on results of SU-8 spin-coated on glass [13], [14] and ITO [15], [16], but no information has been found where SU-8 has been successfully screen printed on ITO, glass or any other substrate.

There are only general guidelines for choosing the right screen to obtain a correct layer thickness [17] and for every material screen and printing parameters need to be found empirically. The resulting film thickness depends not only on printing properties, but also on the amount of solid content in the SU-8 solution before coating. High-viscosity materials cannot be printed with a screen printer, because material forms a mesh pattern instead of a uniform coating.

Good wetting properties of the substrate by SU-8 are crucial for obtaining homogenous coatings. They are determined by substrate surface energy. SU-8 as an organic material is hydrophobic – contact angle of cured SU-8 is 73° [18].

In the present research, we demonstrate large-area screen printing of SU-8 resin on ITO glass substrate with thickness from 4 to 21 µm. We show that 200–300 cSt viscosity SU-8 can be successfully printed and the best way to control the thickness of SU-8 layer is with meshes with different theoretical ink volume. For screen printed SU-8 photoresist, relaxation time allowing material to reflow is necessary in order to get a homogenous layer. Also substrate cleaning plays an important role to achieve good adhesion of photo-resist to ITO glass.

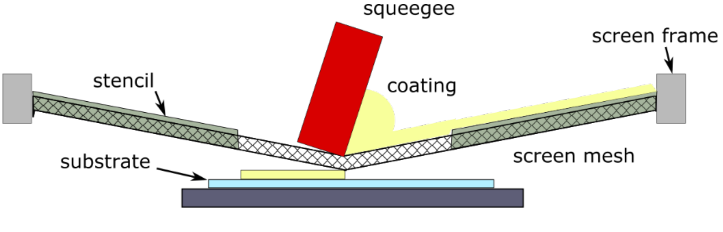

Fig. 1. Screen printing process.

2. EXPERIMENTAL PART

Two 95x396 mm large SU-8 areas were printed on ITO etched glass, where both ITO and glass were covered with SU-8. Then a pixelated pattern was made out of SU-8 coating using conventional SU-8 photolitography. Pixels were in size of 85x85 µm with 15 µm wide pixel walls. Coating thickness was determined by measuring height of a pixel wall.

2.1. Materials

SU-8 is a commonly used epoxy based photo-resist manufactured by Microchem or Gersteltec. Microchem manufactures SU-8 2000 and SU-8 100 series material. SU-8 2000 series resists use cyclopentanone for the primary solvent while the SU-8 100 series uses gammabutyrolactone (GBL). GM1075 is manufactured by Gersteltec, uses GBL as its primary solvent. ITO coated glass (300x400 mm, thickness 0.5 mm) with the resistance of 10 ohms/sq [250 nm thick ITO layer] was provided by Yeebo Display Limited from the People's Republic of China and used as the SU-8 coating substrate. Additionally, Isopropanol (puriss grade), Developer MR-DEV 600, and DI water were used.

2.2. Equipment

In the experiment, Newlong LZ-9906 screen printer was used. Materials were manufactured by various companies: the stainless steel screens were designed by Coated Screens Scandinavia (CSS); meshes were purchased from CSS and manufactured by BOPP; emulsion came from Foteco Topaz Capillary film; hot plate oven by Yamamoto Works NRY-101V10LCD was used as a pre-bake and post-bake oven; and UVOCS T16X16/OES was used for substrate preparation and cleaning. Thickness of coating was measured by Veeco Dektak 150 profilometer or white light interferometer by Zygo NewView 7100 at the Institute of Solid State Physics (ISSP) at the University of Latvia. Viscosity was measured with Brookfield DV-II+ Pro viscometer. The surface contact angle was measured according to the Bikerman [19] method by in-house developed measurement equipment.

3. RESULTS AND DISCUSSION

To obtain the desired SU-8 structures using a screen printer, multiple experiments were completed. First, the screen printer settings were established to achieve a proper coating quality of printed SU-8 material. Different coating thicknesses were achieved and finally the coating thickness homogeneity was improved overall.

3.1. Printability

To achieve positive results, it is important that the material flows together after the printing step and makes a uniform layer on the substrate.

Screen printing of SU-8 onto ITO substrate has some challenges that have to be overcome. Firstly, the SU-8 2100 viscosity is 45000 cSt [20], which is too high for printing with a screen printer. When such a viscous fluid material is used, the mesh sticks to the substrate and does not peel off, which may result in mesh damage. The coating in this case is non-uniform, bubbly and cannot be used as a coating for microstructures.

To reduce the viscosity of SU-8, cyclopentanone was added to SU-8 2100 in proportions SU-8: cyclopentanone 2:1, 10:3 and 5:2. A 5:2 solution with viscosity down to 200 cSt was possible to print, because mesh did not stick to the substrate.

Before each sample print the screen gets flooded with a thin layer of SU-8, then material is pressed through the mesh forming coating. Cyclopentanone boiling point is 130.3 °C [21] and it evaporated quickly during printing, which increased viscosity from one print to another and resulted in a material that was printed on a substrate but did not flow together and formed dots on the substrate. These dots correspond exactly to mesh opening size and position (see Fig. 2).

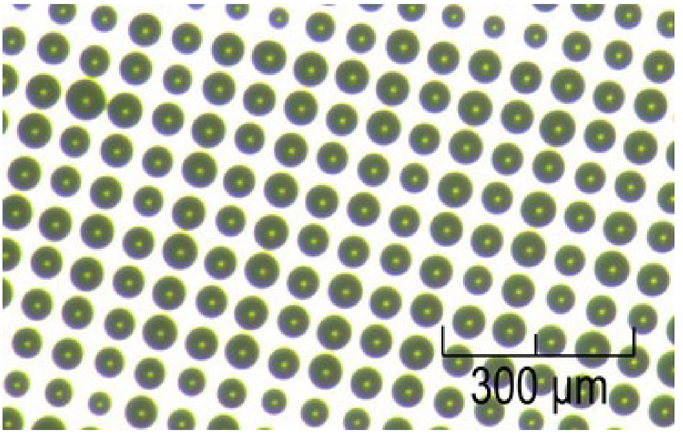

Fig. 2. Viscous SU-8 material forms separate dots instead of a uniform coating. Dots are in size up to 50 µm matching the size and positioning of mesh openings.

SU-8 formulation GM1075 viscosity is approximately 66 000 cSt and was diluted with GBL in proportions 2:1, 10:3 and 5:2. As for SU-8 2100 proportion 5:2 yielded viscosity 250 cSt. As GBL boiling point is 203 °C [21], solvent evaporation was not observed and the viscosity of the material did not change; the material flew together and did not form separate dots on the substrate.

Secondly, additional focus on surface preparation is equally as important as screen printing with SU-8. Substrate had a pixel pattern on ITO glass. After wet cleaning with brush and detergent water droplet contact angle was 35 degrees on etched glass and 70 degrees on ITO pixelated pattern. This caused an uneven coating on the substrate – SU-8 had a uniform coating on the etched glass surface, while coating on the ITO surface was not uniform (see Fig. 3).

To overcome this problem, the surface was prepared using UVOCS. First, multiple UV treatment times were tested and contact angle measured on 5 positions throughout the whole substrate (including completely etched glass surface and pixelated ITO surface areas). This preparation step gave the necessary result. Contact angle was measured on minimum 5 positions throughout the whole substrate surface. Table 1 shows that the contact angle after 5 minutes of UV treatment was uniform throughout the whole substrate surface on both the etched glass and pixelated ITO area and increasing the UV treatment time improved the average contact angle insignificantly. This allowed successfully printing SU-8 on the used glass substrate.

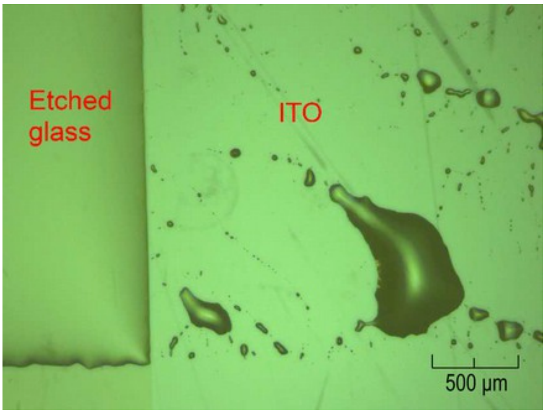

Fig. 3. Image of SU-8 on the glass and ITO surface. The glass surface has a uniform coating of SU-8 while ITO surface has separate parts coated.

Table 1

Surface Contact Angle after UV Treatment of ITO Pixelated Substrate

UV treatment time [minutes]	Average contact angle [degrees]	Standard deviation
1	39.4	13.7
2	22.9	7.1
5	14.0	0.9
10	14.6	0.6
20	14.3	1.3

Table 2

Most Suitable Screen Printer Settings for Printing SU-8 Material Using a Stainless Steel Mesh

Setting	Value
Snap-off (frame height)	4 mm
Coating speed	40 mm/s
Printing speed	300 mm/s
Squeegee	G-profile 60 degrees, Durometer: 75
SU-8 dilution (GM1075:GBL)	5:2
Surface UV treatment	5 minutes

3.2. Coating Thickness

When the printing parameters were established, different meshes were tested to manage the coating thickness. The wet coating thickness for large printed areas mostly depended on the mesh type [22]. While the wet printed thickness of fine lines depended mostly on the emulsion thickness [22], other variables such as printing speed, squeegee durometer, snap-off distance also influenced the wet thickness but within the guidelines of our tested case studies, this did not provide a significant effect on coating thickness. See Table 2 for used printing settings. The snap-off setting was 4 mm high and high printing speed was used to reduce the mesh sticking to the substrate surface; coating speed was slow to coat the mesh with SU-8 uniformly. Table 3 shows the used meshes, their parameters and measured dry SU-8 coating thickness.

Table 3

Meshes Tested to Change the Final SU-8 Coating Thickness

(Mesh number characterises mesh properties – 265/50; 265 – size of mesh opening, 50 – size of thread diameter. Open area – shows the total open area of mesh, theoretical ink volume is a value provided by a manufacturer that shows the amount of printed material on a substrate).

Mesh	Open Area [%]	Mesh thickness [µm]	Theoretical ink volume [cm^3/m^2]	Coating thickness [µm]
265/50	71	110	78	9.9
140/65	47	140	65	24
125/65	43	140	61	201
118/56	46	120	55	14.7
100/65	37	140	51	11.5
100/50	44	110	49	11.6
90/40	48	90	43	9.3
56/32	40	68	28	6.8
50/30	39	62	24	3.9

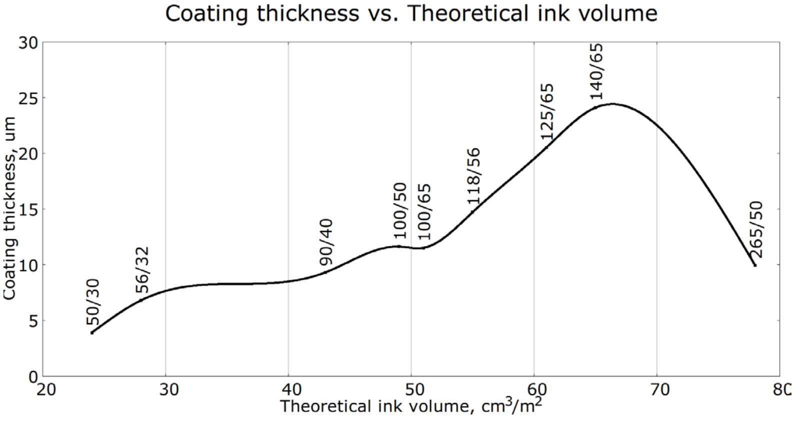

Fig. 4. Achieved coating thickness for tested meshes vs. theoretical ink volume of mesh.

The thickness of final structure was measured using DekTak profilometer. Average height of pixel walls was calculated out of 500 pixel wall measurements for each sample. Distance between two pixel walls was 85 µm. The results show that the coating thickness depends mostly on the theoretical ink volume of the mesh and its thickness. If the mesh thickness was not changed, the relationship between coating thickness and theoretical ink volume was linear (see Fig. 5). If the mesh thickness was changed then changes in coating thickness were not linear (see Fig. 4).

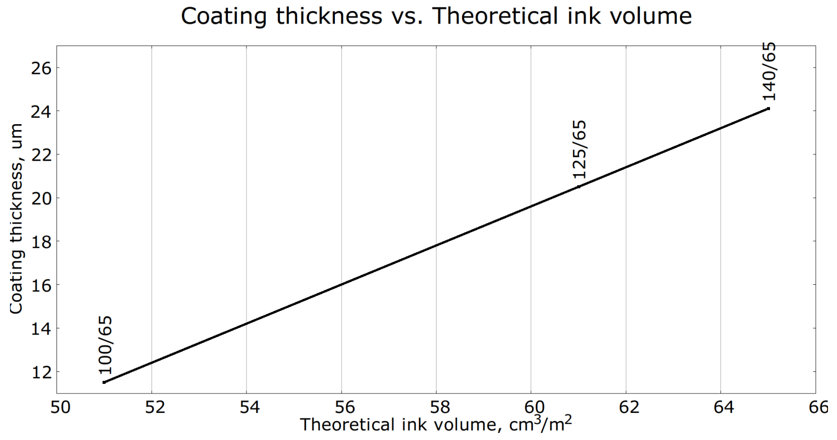

Fig. 5. Achieved coating thickness for tested meshes vs. theoretical ink volume of mesh.

3.3. Homogeneity

To improve the homogeneity of SU-8 layer, research suggests one should let the SU-8 level out (relax) before the per-bake step [3], [23]. This would also allow the solvent to evaporate. Samples were left on a flat surface for the SU-8 to level out and reflow over the course of various time periods: 1 h, 3 h and 24 h. To evaluate the homogeneity of coating thickness, the height of five hundred pixel walls was measured and the standard deviation calculated. Figure 6 shows a plot of 500 pixel wall height measurements. The empty spaces represent the places on the sample, where a scratch in the pixel walls was made to determine the height correctly. As indicated in Table 4, the standard deviation in height measurements reduced from 0.63 µm to 0.23 µm if the levelling time was increased from 1 hour to 24 hours.

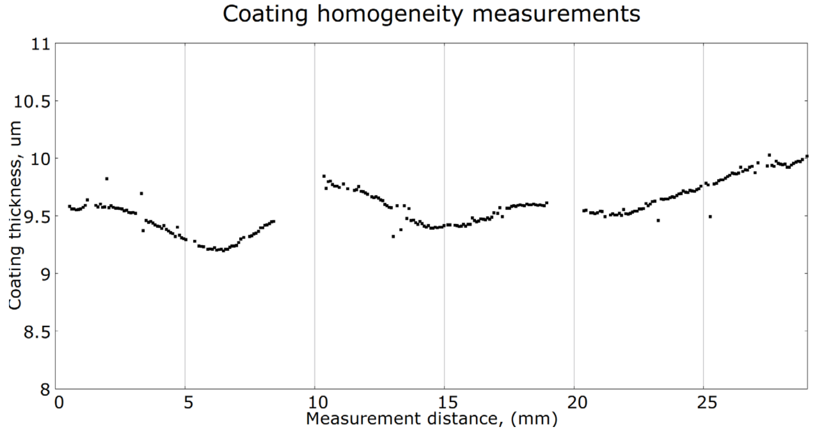

Fig. 6. Coating homogeneity measurements. The coating thickness varies within 1 µm from 9 µm to 10 µm.

Table 4

Standard Deviation for Coatings with Different Relaxation Time

Relaxation time	**Thickness standard deviation [µm]**
1 hour	0.63
3 hours	0.36
24 hours	0.23

4. CONCLUSIONS

We propose a method for coating SU-8 material on an ITO glass substrate using a screen printing technology. In comparison with a standard spin-coating, screen printing is a fast and cheap method to coat a variety of large and different shaped areas and reduces the quantity of wasted material. Coatings of different thicknesses were successfully created when working with meshes of different thickness. It is possible to print SU-8 if its viscosity is below 300 cSt. The overall coating homogeneity was improved by changing the relaxation time and increasing the process time. As a final result, we have created a pixel-wall grid on ITO coated glass substrate (see Fig. 7). Pixel walls were 7.4 µm wide and up to 25 µm high. These devices were successfully used in elector-osmosis type displays.

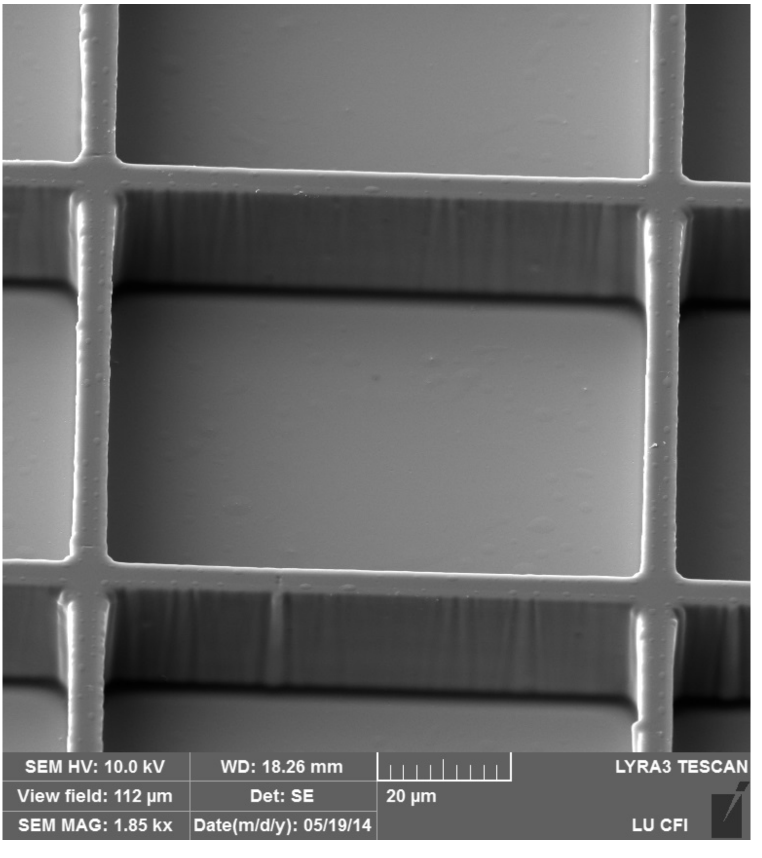

Fig. 7. Final SU-8 pixel wall structure. It is 7.4 µm wide and up to 25 µm high.

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AR SIETSPIEDI UZKLĀTU SU-8 PĀRKLĀJUMI MIKRO-STRUKTŪRU IZGATAVOŠANAI

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K o p s a v i l k u m s

Rakstā aprakstīta sietspiedes metode liela izmēra SU-8 pārklājumu iegūšanai, lai izgatavotu mikrostruktūras mikroelektronikai, elektroslapināšanas un bistabilajiem ekrāniem. Sietspiede ir efektīvāka un vienkāršāka metode nekā tradicionāli izmantotā *spin-coating* metode. Šādiem pārklājumuiem un mikrostruktūrām ir pietiekoša homogenitāte. Tika atrasta sakarība starp sietu parametriem un pārklājumu biezumu. Pārklājumus var uzklāt uz hidrofobiskās ITO (indija alvas oksīds) virsmas, ja tā tiek apstrādāta ar UV/Ozonu, jo tas palielina ūdens slapināšanas īpašības. Tika izgatavoti hidrofīliskas mikrostruktūras režģi uz hidrofobiskas pamatnes ar sietspiedi un tradicionālo SU-8 litogrāfijas metodi. Salīdzinājumā ar tradicionālo *spin-coating* metodi, sietspiede ir vienkārša, lēta un ātra un ir labi piemērota liela izmēra ekrānu izgatavošanai.

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