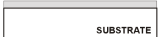


Direct Laser-writing of Complex Photopolymer Structures using Diffractive Optical Elements.

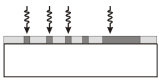
Polymer and Processing Techniques

1: SUBSTRATE PREPARATION & POLYMER APPLICATION



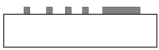
- Substrates types: FR4, glass, silicon, ...
- Clean / scrub the substrate appropriately
- Place in oven to dry
- Apply required thickness of liquid photo-polymer using appropriate technique

2: U V EXPOSURE



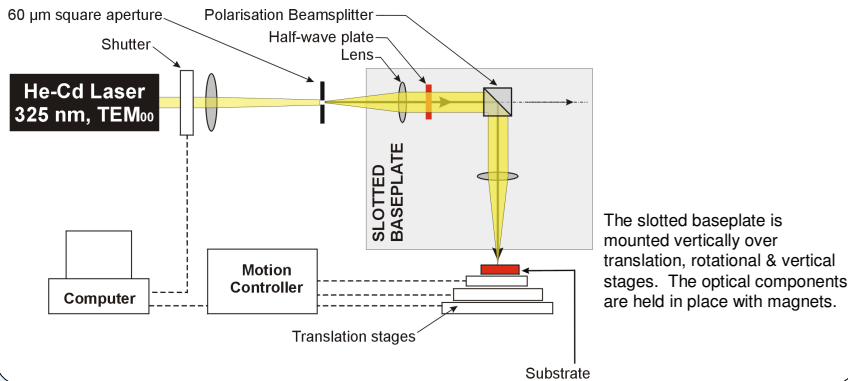
- Blanket curing** is used for large areas such as lower and upper claddings. The sample is placed in a nitrogen atmosphere and cured using a UV lamp
- Direct laser-writing** is used for the fabrication of the micro-structures such as waveguide cores, polymer bumps & 45° surfaces

3: DEVELOP POLYMER



- The polymer exposed to UV is cured and remains when the sample is developed (i.e. similar to negative photoresist).

Schematic of laser-writing setup



- Custom, multifunctional acrylate photo-polymer
- Tuning of refractive index and viscosity
- ~ 0.05 dB/cm at 850 nm
- High glass transition temperature Tg ~ 250°C
- Compatible with a wide range of substrates
- e.g. FR4, glass, silicon, polystyrene
- Polymer application techniques
- Spinning at ~300 to 1500 rpm for up to 60sec.
- Doctor blading for thicknesses greater than ~70 μm
- Casting: Used for thicknesses up to 30 μm over small areas e.g. 25 x 25 mm.

DOE Algorithm Development and Fabrication Steps

Closed form solution of Fraunhofer diffraction integral

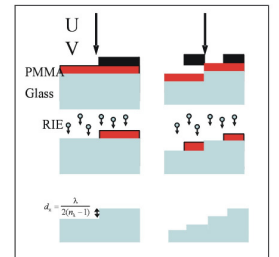
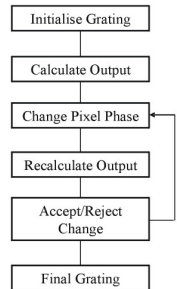
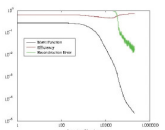
$$U(m, n) = \frac{e^{i\pi/4} f \sqrt{m^2 + n^2}}{i\lambda f} \mu \nu \text{sinc}(m\mu) \text{sinc}(n\nu) \sum_{a=1}^M \sum_{b=1}^N e^{i(\phi_{ab} - \pi [m(2x_a + \mu) + n(2y_b + \nu)])}$$

$$\Rightarrow P(m, n) = \frac{H\nu}{(\lambda f)^2} \text{sinc}^2(m\mu) \text{sinc}^2(n\nu) \left| \sum_{a=1}^M \sum_{b=1}^N e^{i(\phi_{ab} - \pi [m(2x_a + \mu) + n(2y_b + \nu)])} \right|^2$$

- Alteration of a single pixel does not require the calculation of the entire grating output.
- By defining a merit function and accepting only those changes which decrease the merit function (or satisfy a temperature condition), an optimised grating can be generated for any arbitrary diffraction pattern.

$$M_f = \sum_{i,j \in \text{grid}} \left(P_{ij} - \frac{n_{\text{target}}}{N(m)} \right)^2$$

Example: 5x7 array of spots.



Direct Laser-Writing of Waveguide Arrays Using Fan-out DOEs

Schematic diagram of optical arrangement of using a fan-out DOE with expanded Gaussian beam

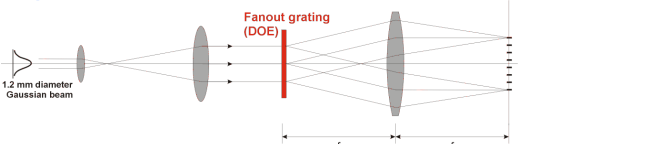
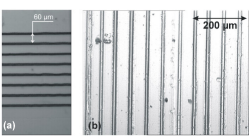
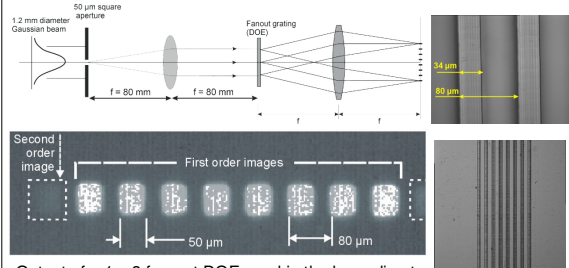


Figure (a) shows optical microscope photograph of an array of 8 polymer waveguides written on a glass substrate using a 1 x 8 fanout DOE. Waveguides were written at 250 μm/s scan speed, are ~8 μm wide and on a ~60 μm pitch. (b) shows an optical microscope image of a part of 1 x 74 array of waveguide fabricated using a 1 x 74 fan-out DOE. Waveguides are 10 μm wide and on a 50 μm pitch.



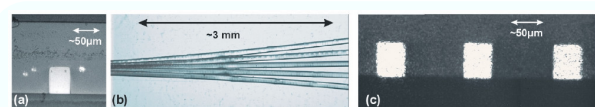
Schematic diagram of optical arrangement of using a fan-out DOE with imaged aperture approach



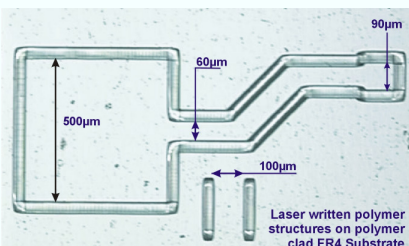
Output of a 1 x 8 fan-out DOE used in the laser direct writing system with imaged aperture. Second order is also evident in the picture.

Optical microscope image of laser direct-written array of eight multimode waveguides written simultaneously using an imaged aperture and 1 x 8 fan-out DOE. The picture on the left shows the complete array of the waveguide cores and the other picture is close up of the array. The waveguide cores are ~34 μm wide and on a ~80 μm pitch.

Direct Laser-Writing of Polymer Splitter, Micro-fluidic Channel and other Complex Structures



Direct laser-written polymer 1 x 5 splitter: Optical images showing (a) input facet, (b) plan view of splitter layout & (c) waveguide cores at the output facet.



Direct laser-written polymer micro-fluidic channel: Optical microscope image of a polymer micro-fluidic channel fabricated on a polymer-clad FR4 substrate. This can be used to dispense liquid samples to a localized area.

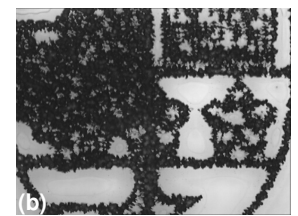
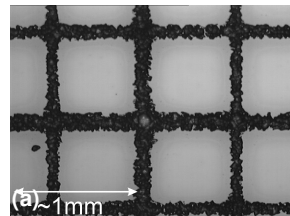


Figure (a) and (b) are optical microscope images of features written in polymer on a glass substrate using different DOEs in the laser writing system to generate the appropriate intensity profiles. The image shown in (a) is a part of grid which was fabricated using 1.0 s exposure. The image (b) shows part of the Heriot-Watt University logo, which is shown in (c), replicated in polymer using a 0.8 s exposure.



References

- F. Tooley, N. Suyal, F. Bresson, A. Fritze, J. Gourlay, A. Walker, "Optically written polymers used as optical interconnects and for hybridisation", *Optical Materials* 17, 235-241 (2001).
 A. McCarthy, H. Suyal and A. C. Walker. "45° Out-of-plane Turning Mirrors for Optoelectronic Chip Carriers based on Multimode Polymer Waveguides." *European Conference on Optical Communications (ECOC 2004)*, Stockholm, Sweden, paper Th1.4.3, (September 5-9, 2004).