Phase Retrieval Algorithms for Direct Laser Writing of Holograms in Liquid Crystals

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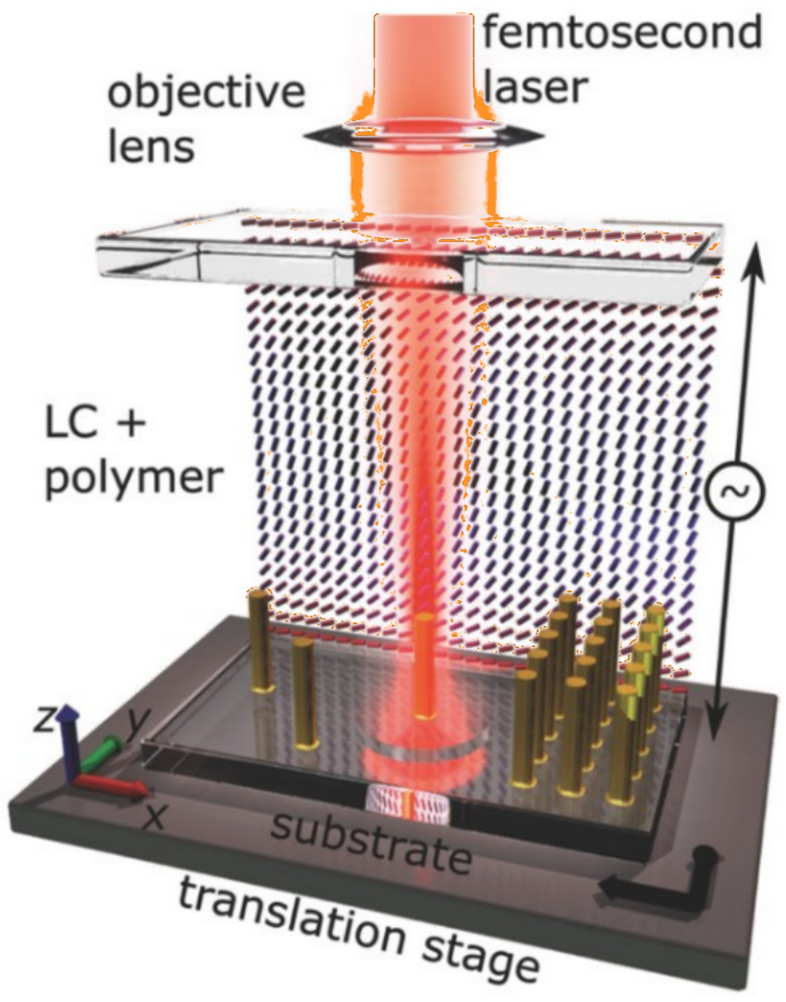
What is holography?

- A hologram is a structure which produces a desired diffraction pattern when illuminated by a coherent light source e.g. a laser.
- The holograms used in this project cause a phase change in each of their pixels. These have a **theoretical efficiency of 100%**, since the hologram only changes the phase of the light and not the amplitude.
- **Interference** between light passing through neighbouring pixels causes an image to form in the far-field with magnitude equal to the hologram's Fourier transform squared.
- To calculate a hologram that will give us a specific image we can use phase retrieval algorithms.

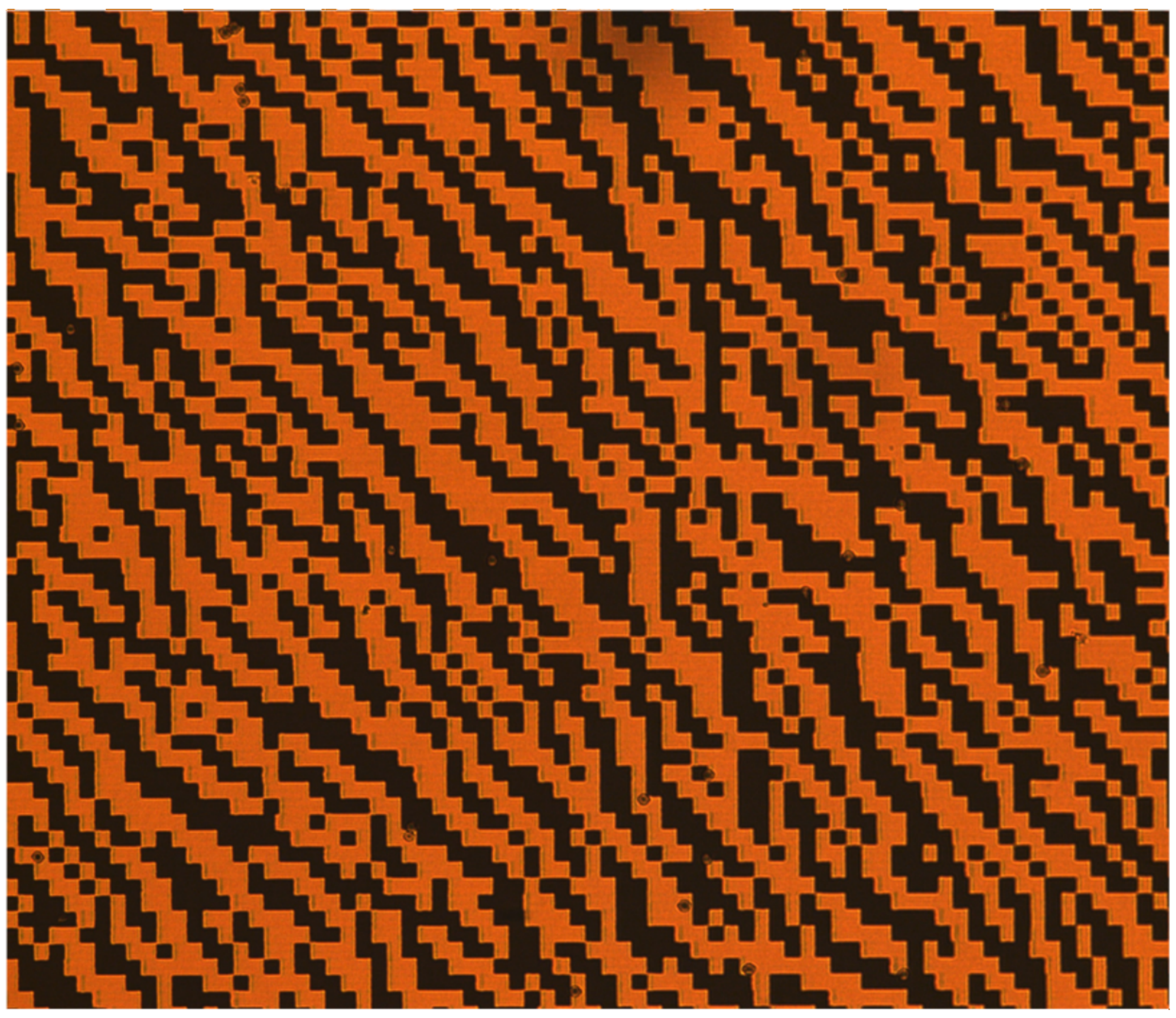
Direct Laser Writing

- The LC devices are made up of a **5μm thick layer of liquid crystal** sandwiched between two electrodes.
- The liquid crystal mixture contains molecules known as **reactive mesogens**, and a high-power **femtosecond laser** causes these to polymerise.
- The resulting **polymer network** locks in certain liquid crystal molecules so that their **orientation remains fixed**.



Schematic of the laser writing system creating a polymer pillar within a liquid crystal device [1].

- Polymerisation is controlled by **modulating the speed of the stage** - for unpolymerised pixels, the stage moves too fast for the reaction to occur



A portion of a laser written hologram viewed using a polarised optical microscope. Bright areas are fixed in place by the polymer network while dark areas have been reoriented by applying a voltage to the cell.

Project Goals

1. Develop phase retrieval algorithms which would generate holograms with **higher quality replay field images** than those produced by existing algorithms.
2. Write holograms into **single-electrode liquid crystal devices** and characterise them using polarised optical microscopy.
3. Test the holograms with a **free-space optics experiment**.

Liquid Crystals

- Changing the **orientation** of a LC molecules will cause its **refractive index** to change, and therefore the **phase delay.**
- In addition, the molecules **align with an electric field**, allowing us to finely tune their orientations.
- The hologram can also be **switched on and off** by applying or removing a voltage. When the voltage is removed, the molecules will realign and the hologram, and therefore the projection, will disappear.

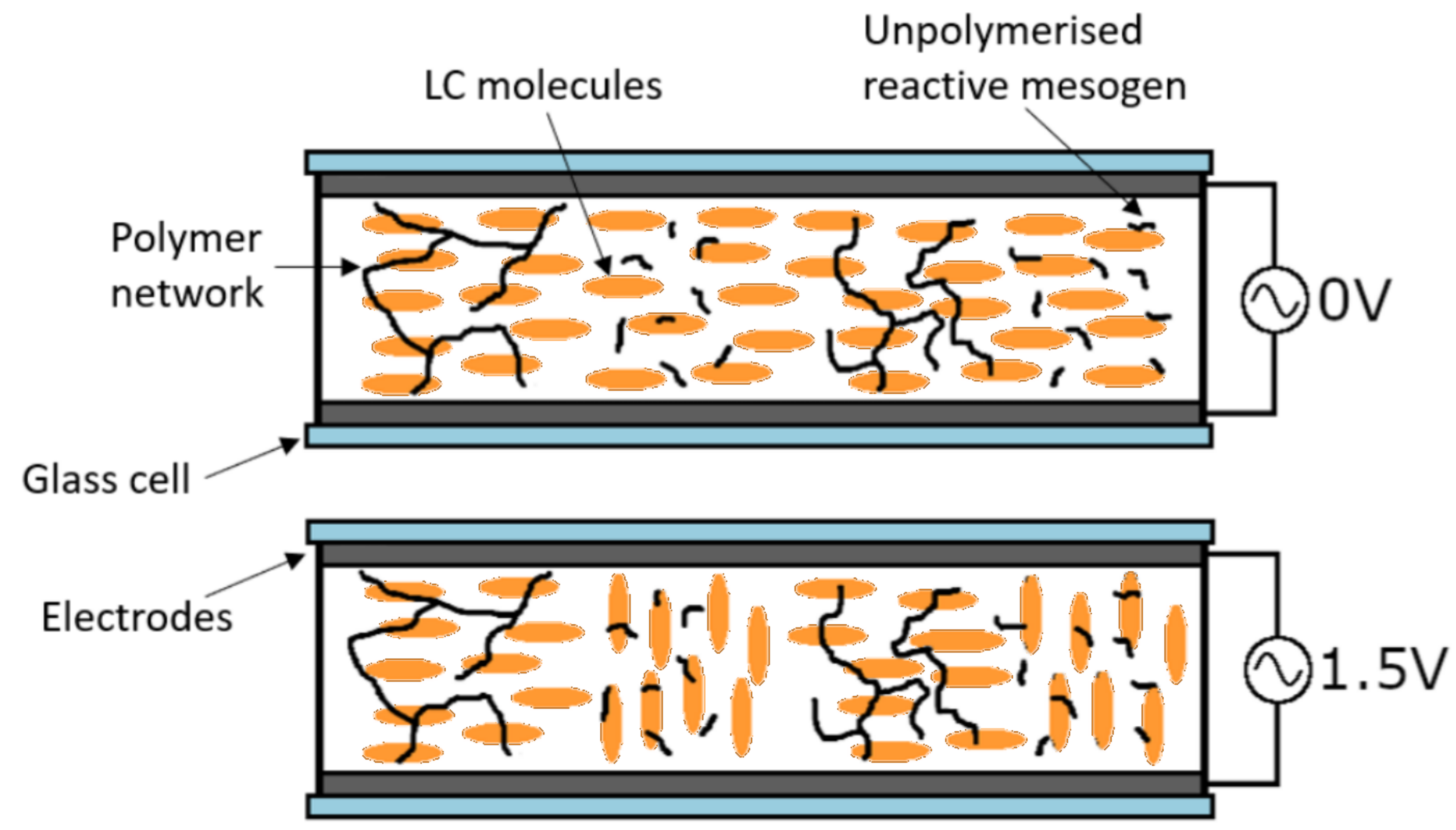


Diagram showing the structure of the LC cells and the locking-in of certain pixels by the polymerised reactive mesogen.

Projection

- The written holograms were tested by **illuminating them with laser light**, with the image captured directly onto a CCD.
- There were a few issues that cause the errors which are visible. However, even this fairly complex image is recognisable.
- Future work will look at resolving these issues to improve the reconstruction quality.

A projection of the Oxford crest using a hologram written into a liquid crystal device.

Acknowledgements

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[1] Tartan, C. C., Sandford O'Neill, J. J., Salter, et al., *Advanced Optical Materials,* **6**, 1800515 (2018).