PhD Project 1

Supervisor Name:	F. Aníbal Fernández
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Project Title	Accurate modelling of defects and small features in liquid crystal devices – Exploitation in advanced LC displays
Abstract	**This project is sponsored (half-funded) by Sharp Laboratories Europe** Defects in the orientation of the liquid crystal material naturally occur in devices and their presence can have important detrimental effects in the device performance. The project will investigate, develop and implement novel methods for the accurate modelling of the occurrence of defects, their evolution and their effects on the overall performance of display devices, including optical effects, and apply these methods to the modelling and design of liquid crystal structures, and in particular, LC microlenses. Sharp is interested in the development of methods for the design of optimised microlens arrays for use in auto-stereoscopic 3D displays, dual view displays and displays with switchable privacy among other applications. Accurate modelling not only will be able to show the occurrence of defects but can also be used to devise mechanisms to control their occurrence and evolution by the use of surface relief features, dielectric layers and electrode shapes. Current device-scale modelling techniques need to consider the relatively large volume of an LC cell or a pixel and at the same time, should be able to model accurately the behaviour of the LC in the vicinity of small objects, surface features and LC defects where large changes of the order parameter are expected in small spaces. This mixed scale problem is difficult to tackle with standard methods based on volume discretisation. The approach to follow in this project will consist of a hybrid method that will combine finite elements with a special treatment of the regions containing defects. The project will also include the development of a method for the accurate modelling of the optical performance of these devices, including in particular, the diffraction effects. The research will also be applied The student will be expected to visit Sharp's laboratories at least a few times a year to discuss the research and present results. Some experimental/measurement work can also be expected in the course of the project.

PhD Project 2

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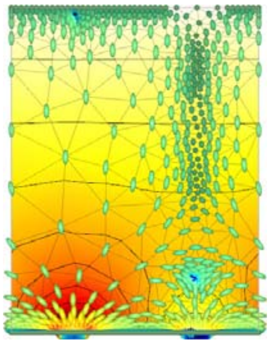
Project Title	Reconfigurable LC photonic crystal type devices controlled by microelectrode arrays.
Abstract	Periodic arrays of structures with different refractive index are very useful as wavelength selective devices and can be incorporated in a wide range of photonic devices and systems. Using 1D or 2D arrays of microelectrodes in a Liquid Crystal on Silicon (LCoS) device to control the LC orientation, such patterns of refractive index can be created, with the added advantage of reconfigurability (or tuneability). Defects in the ordering in LC structures are normally unwanted in LC devices, however, their presence and evolution can be very useful by providing the abrupt transitions required. Using arrays of small and closely spaced electrodes, large scale bulk switching effects can be observed, while the electric fields generated by the electrodes remain bounded to their proximity. This is due to the generation of defects in the vicinity of the electrodes and their evolution. Other interesting cases are also possible, for example, with a combination of small, closely spaced electrodes defects can be created to evolve into the formation of a twist wall. Using long interdigitated electrodes, these twist walls will occur periodically and the complete structure can be regarded as a sequence of alternate values of the effective refractive index to a wave propagating along the LC structure, behaving as a photonic crystal waveguide. Similarly, it is possible that with 2D arrays of electrodes a 2D photonic crystal like structure can be formed with frequency selective properties. As the twist walls depend on the application of voltages to the electrodes, and the refractive indices depend on these voltages, the complete structure can be easily reconfigured and tuned.  *Defect evolution to form a defect wall* This project will use modelling techniques and experimental observation with LC on silicon (LCoS) interdigitated structures to be fabricated at Cambridge Univ., to study the creation of index discontinuities in waveguide structures filled with LC. Using the existing LC modelling tools new modelling methods need to be developed to study wave propagation through such type of anisotropic structures. These can be largely based also on existing methods developed in our group. The work in the project will also include the possible application of these index discontinuities to practical photonic devices.

PhD Project 3

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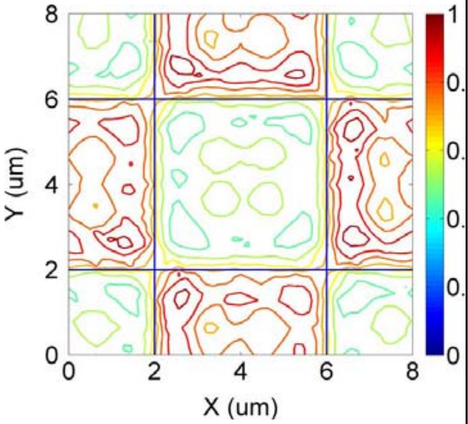
Project Title	Advanced design techniques for Liquid Crystal on Silicon (LCoS) devices.

Abstract

Liquid Crystal on Silicon (LCoS) devices are now at the core of many photonic devices and systems, from displays, microdisplays, projectors and picoprojectors to spatial light modulators and holographic devices for applications in photonic and communication systems. There is an inexorable trend to increase resolution in these devices that take advantage of the very large electro-optic response of liquid crystals and the massive processing power of the electronics in the silicon backplane.



Near electric field amplitude on a pixel array of 4μm pixel size with a chequerboard pattern.

As the resolution increases, the pixel size decreases bringing new challenges to the design of new devices. The effect of neighbouring pixels on the liquid crystal orientation of each pixel (fringing fields), the elasticity of the liquid crystal itself and the unavoidable presence of defects are some of these issues. Switching speed is another important aspect of considerable relevance to device design and this has an incidence on the choice of alignment methods and switching modes of the liquid crystal layer.

This project will consist of using advanced modelling methods developed in our group to investigate new methods of switching liquid crystal cells for this type of applications, new methods for the alignment of the liquid crystal based on surface patterning, the effect of surface profile and liquid crystal defects on the overall performance of the device and the effect of the size reduction on the diffractive properties of the pixel cells.

This work will be carried out in collaboration with researchers at Cambridge University and their experimental evidence will be used to validate the modelling results.

PhD Project 4

Supervisor Name:	F. Aníbal Fernández
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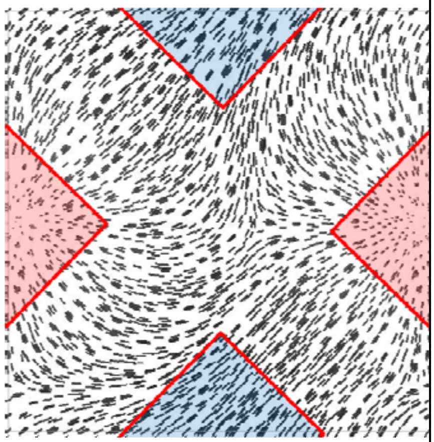
Project Title	Modelling novel pixel configuration and development of design methods for phase-only LCOS devices
Abstract	Liquid crystal on silicon (LCOS) is a technology that takes advantage of the very large electro-optic response of liquid crystals and the massive processing power of the electronics in the silicon backplane. LCOS devices have been traditionally designed for display applications and are used extensively in projectors and micro and pico-projectors. They have also been used in phase-only devices like spatial light modulators (SLMs) holographic devices and diffraction displays. However, extreme increase of resolution brings problems due to the fringing fields and the elastic behaviour of the liquid crystal, combined with trend towards high fill ratio (or increasingly small inter-pixel gaps). The traditional design approach is no longer adequate for diffractive devices and a new design strategy is needed. The objective should be to obtain a desired phase distribution over the pixel surface and consequently, in the far-field. The phase output depends on the liquid crystal orientation throughout the cell and this, on the electric field distribution produced by the electrodes. This project will investigate using and extending advanced computer modelling programs developed in our group and experimental evidence from researchers at Cambridge Univ. to model the effect of different electrode configurations and surface relief structures included in the cell, on the phase output of LCOS cells and to design electrode shapes and surface relief features to approximate desired phase outputs. The project will also be concerned with the integration of the individual pixel behaviour into the response of group of pixels and their effect in the far-field. For this, our current methods for the calculation of diffraction from LCOS cells will be used and extended.



Distribution of liquid crystal orientation on a section through an LCOS cell with square electrodes in a chequerboard pattern.

PhD Project 5

Supervisor Name:	F. Aníbal Fernández
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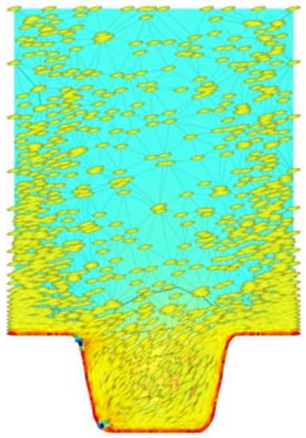
Project Title	Bistable LC displays based on surface patterns
Abstract	Bistable displays have the advantage of needing very little or no power to operate. They are environmentally-friendly devices suitable for a wide variety of uses, in e-books, advertising, signage and public information. Bistable states in liquid crystals can be induced by defects that occur in the vicinity of surface features. Defect patterns and their evolution play an important role in the switching of some LC structures into different stable states, and these have been exploited in commercial bistable displays, as for example in the PABN and the ZBD displays. These devices rely on the distortion of the LC alignment in the proximity of arrays of micron-size posts and gratings on a surface for the transition between a continuous state and a defect state. Combination of gratings or surface relief objects and voltage patterns on electrodes can be used to create defects in the LC orientation and to cause their movement and evolution through the cell leaving behind the desired type of bulk alignment. However, these devices only operate as on-off and gray levels and limited colour will be desirable.  *Defect structure inside a pit inducing bulk alignment* The purpose of this project is to study, using the computer modelling techniques available in our group and some specifically developed extensions, the characteristics of the behaviour of LC materials in confined spaces and around small surface features and apply this to investigate the use of dyes and combinations of gratings to produce some gray levels and colour in in multistable liquid crystal display based on the ZBD structure.

PhD Project 6

Supervisor Name:	F. Aníbal Fernández
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Project Title	Characterisation of Liquid Crystal Materials at Terahertz Frequencies
Abstract	Liquid crystals are very attractive dielectric materials for a large range of applications in addition to displays, from low frequency, microwaves to optical devices. Liquid crystals are highly anisotropic materials and their permittivity can be controlled by the application of an external low frequency field, opening the possibilities for a variety of applications in tuneable or reconfigurable devices. These properties have been exploited extensively in the visible and infrared spectrum but only rudimentary studies have been conducted in the terahertz range. One of the difficulties in the design of liquid crystal devices in these frequencies is that the material properties of the liquid crystal materials, in particular its permittivity tensor, is unknown. Neither the methods and devices used to obtain the dielectric characteristics in low frequencies nor those used in the visible range are suitable for the material characterisation in the terahertz range, where special devices and techniques need to be designed for this purpose. This project will focus first on the characterisation of the liquid crystal materials in the terahertz range of frequencies, designing and building appropriate devices for this purpose. By using existing advanced liquid crystal and electromagnetic modelling, the results of experimental observation on these devices can be contrasted with those of modelling to extract the relevant material parameters. A second stage of the project will consist of using the modelling and the knowledge of the material properties for the accurate design of practical devices: filters, switches or couplers.

PhD Project 7

Supervisor Name:	F. Aníbal Fernández
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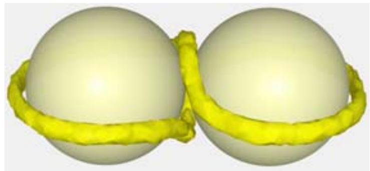
Project Title	Modelling the behaviour of nano-particles immersed in liquid crystals
Abstract	Colloidal suspensions of nano-particles in liquid crystals have been found to be of great interest in the development of materials with enhanced properties for use in photonic devices. It has been found that remarkably small concentrations of nano-particles in a liquid crystal can bring about large changes in the bulk properties of these composite materials *e.g*. very high optical non-linearity and dielectric anisotropy. It has also been found that it is rather difficult to form stable colloidal suspensions, what indicates the need to understand more about the interaction between nano-particles and liquid crystals.  *Two spherical particles entangled by a liquid crystal defect ring.* Further to the possibilities to develop new optical materials with enhanced and engineered properties by using these mixtures, modelling and experiments also show that nano-particles interact with liquid crystal defects and it has been suggested that nano-scale biological entities such as proteins, cells strands of DNA, can be immersed in an LC medium and manipulated by controlling the movement of LC defects, effects that can be used to design optical sensors. The purpose of this project is to extend the current liquid crystal modelling capabilities developed in our group to include the study of the dynamic behaviour of micro- and nano-particles immersed in liquid crystals. The effect of the liquid crystal anchoring on the surface of the particles and walls induce elastic deformations in the bulk of the liquid crystal and this generates forces acting on the particles that control their dynamic behaviour. These forces are further modified by the flow of the liquid crystal. The work in the project will derive expressions for these forces and incorporate them in the current models of LC reorientation and flow to model the particle dynamics.

PhD Project 8

Supervisor Name:	F. Aníbal Fernández
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Project Title	Modelling the transmission characteristics of finite metal gratings filled with liquid crystals at terahertz frequencies.
Abstract	Metal grids placed in the path of electromagnetic waves at terahertz frequencies exhibit a resonance behaviour that can affect the transmission characteristics of the grid. These resonances, which depend on the period of the grid or grating and the permittivity of the medium, can be modified by placing liquid crystal material between the bars that form the grid. If further, the liquid crystal is switched by applying a voltage across the bars, the effective permittivity of the medium can be gradually changed and the structure behaves like a tuneable filter. This project will use computer modelling and experimental work to study the behaviour of terahertz electromagnetic waves in 1D and 2D gratings and in similar types of structures and will require the development of modelling tools for electromagnetic waves in the presence of non-uniform, anisotropic dielectric materials. Experimental evidence suggests that transverse plasmon waves are generated along the plane of the grid and that their resonance depends on the finite size of the grid. The project will include investigation of the effect of changing the width and spacing of the end bars of the grid to alter the matching conditions that affect the resonance of the transverse waves. The work will require the use of existing liquid crystal modelling to determine the orientation of the liquid crystal everywhere between the bars of the grid and consequently, the permittivity of the material. This will then be used in the modelling of the propagation of the waves through the structure, including the transverse resonant waves. Experimental findings will be used to validate the modelling results.

PhD Project 9

Supervisor Name:	F. Aníbal Fernández
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Project Title	Accurate modelling of defects and small features in LCoS structures
Abstract	Liquid Crystal on silicon (LCOS) is a promising technology for photonic LC devices for communications, spatial light modulators and holographic devices as well as for the next generation of LC displays, diffraction displays and micro- and pico-displays. Current device-scale modelling techniques need to consider the relatively large volume of an LC cell or a pixel and at the same time, should be able to model accurately the behaviour of the LC in the vicinity of small objects, surface features and LC defects where large changes of the order parameter are expected in small spaces. This mixed scale problem is difficult to tackle with standard methods based on volume discretisation. Current methods rely on successive and adaptive refinement of the calculation meshes but this brings other associated numerical problems where extreme refinement is undesirable. A better approach can be achieved using some hybrid method that uses the standard discretisation procedures in general but regions containing defects have a special treatment. The form of this special representation of these regions can be designed to match the behaviour of the problem variables in those regions obtained by different methods, like for example analytic approximations or molecular modelling, which is appropriate for problems of very small scale, but not for the scale of the entire LC cell. This project will investigate this alternative special treatment and incorporate it to the methods already in use. It will also consider combining the current method based on a variable order parameter with a simpler constant order version, appropriate for regions that are approximated well with it, and is much faster and less onerous to implement. The methods will be validated using experimental work carried out in the laboratories in Cambridge. LCOS backplanes from a selection of possible resolutions will be assembled into cells with a choice of LC and alignment layer. An appropriate structure needs to be identified and modelled, which will then be fabricated in Cambridge and on which far-field measurements will be made with a laser.

PhD Project 10

Supervisor Name:	F. Aníbal Fernández
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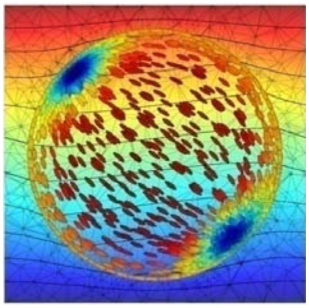
Project Title	Behaviour of liquid crystal materials in confined spaces and around small surface features
Abstract	The operation of liquid crystal cells, for displays or other photonic applications rely on the correct alignment of the LC material to the cell walls. Liquid crystal cells with at least one of the surfaces exhibiting arrays of protrusions or pits of different shapes have been investigated for possible applications in low cost biological or chemical sensors. Additionally, arrays of microns-size posts and gratings are also used in bistable structures for displays, where the defect patterns induced by the elastic distortion of the liquid crystal in the vicinity of these surface features are central to the transition between different stable states. Alignment of the liquid crystal material to the surfaces of the cell is a very important issue in all classes of liquid crystal devices, from displays to liquid crystal on silicon devices for diffractive optics (for beam steering, holographic devices or for communication applications) and techniques that can reliable produce a desired alignment pattern are extremely important. It has been found recently that arrays of nano-scale dimension pits on a surface have specific forms of surface alignment of the liquid crystal and by changing the size, shape and depth of the objects, the characteristics of this alignment can be changed within a wide margin.  *LC orientation inside a PDLC bubble under applied E field* The purpose of this project is to explore, using the computer modelling techniques available in our group and some specifically developed extensions, the characteristics of the liquid crystal behaviour in the different cases listed above. In the case of the alignment technique, it will investigate the effect of size, shape of pits and protrusions on the degree of surface pre-tilt and the anchoring strength. The project will also include the study of the behaviour of the LC around very small surface features using molecular modelling and extract the relevant macroscopic parameters for use in the continuum LC models. It could also include some experimental work on devices fabricated from designs made in this project, for example, for a bistable display, and the corresponding measurements.

PhD Project 11

Supervisor Name:	F. Aníbal Fernández
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Project Title	Tuneable and reconfigurable liquid crystal based microwave devices
Abstract	As the mm-wave band is finding new applications especially in the 30-60 GHz window for short-range high-speed data communications, the need for cheaply mass produced components and subsystems in this band is increasing rapidly. To conform to various communication standards, to minimise power and human exposure to radio waves, and to guarantee stability and continuity in data transmission, future transceivers will need to be adaptive and reconfigurable. Liquid crystals are a very attractive option for this purpose as a device substrate because they are cheap and are responsive to low voltages. They are liquid anisotropic materials that exhibit a large variation of relative permittivity when subjected to an external electric or magnetic field. In a current research project we have developed methods and devices for the accurate characterisation of LCs in these frequencies. This allows the accurate analysis and design of devices using liquid crystals, combining our advanced LC modelling capabilities with EM device modelling. Work in this project will include the development and adapting of appropriate EM modelling tools which will be used in conjunction with liquid crystal modelling for the analysis and design of waveguide devices and for radiating structures containing liquid crystal materials. Reconfigurable and tuneable microwave filters, couplers and steerable planar antennas will be designed. The work will also include the appropriate processing and characterisation of microwave substrates for adequate liquid crystal alignment, the assembly of the devices filled with liquid crystal and their measurement and testing.

PhD Project 12

Supervisor Name:	F. Aníbal Fernández
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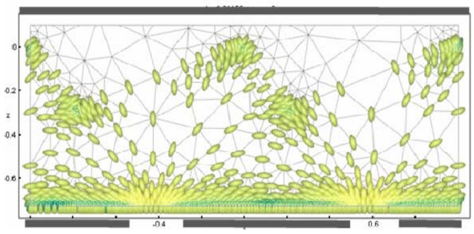
Project Title	Control of the generation and evolution of defects in liquid crystal structures and its applications to bistable displays.
Abstract	Defect patterns and their evolution play an important role in the switching of some LC structures into different stable states, and these have been exploited for bistable displays as for example in the PABN and the ZBD displays. These devices rely on the distortion of the LC material in the proximity of a fixed grating or electrodes on a surface for the transition between a continuous and a defect state. Combination of gratings or surface relief objects and voltage patterns on electrodes can be used to create defects in the LC orientation and to cause their movement and evolution through the cell leaving behind the desired type of bulk alignment. Similarly, the generation of defects and their manipulation using appropriate voltage patterns on electrodes can be used to generate defect walls or twist walls that can be used to produce an abrupt phase change to the light passing through the LC cell. This can be used to write blazed phase gratings along an LC cell for beam steering, spatial light modulators and holograms. The patterns are dependent on the voltage patterns applied at the electrodes, so the devices can be reconfigured easily. This project will use computer modelling to explore this technique. The purpose is to design structures containing surface relief features of different shapes and sizes and appropriately selected voltage patterns over a number of electrodes to generate and to control the evolution of defects in order to design a new series of bistable or multistable structures with possible applications in bistable displays. The creation of defect walls will also be explored for applications in reconfigurable phase gratings. The possibility to produce abrupt changes of orientation between neighbouring regions caused by these defects is of great interest for the design of phase modulation devices, phase gratings, SLMs and holograms. The project can also involve the fabrication and testing of some of the structures designed.  *Defects are moving in this intermediate stage in the transition between stable states.*