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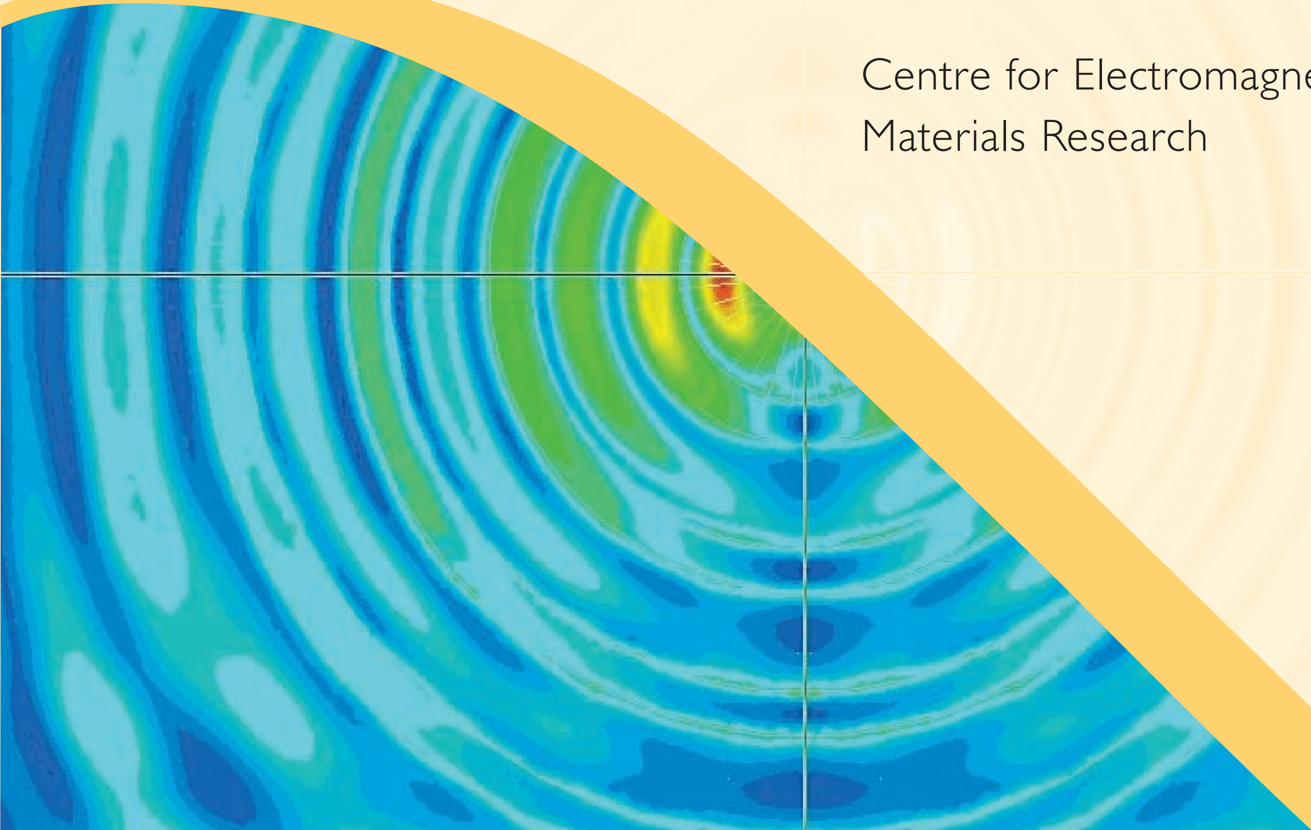
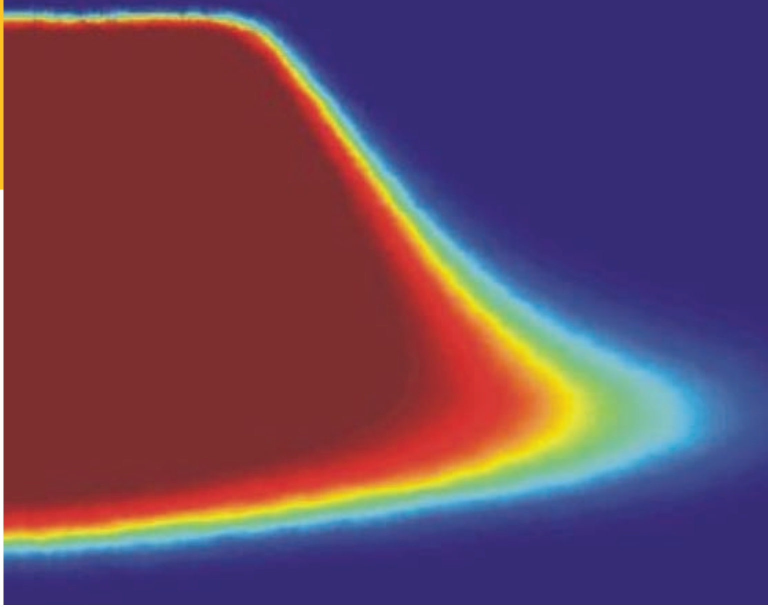


Centre for Electromagnetic Materials Research



Cross-section of a 15nm-radius data-bit (as modelled by theory) that has been thermally-written in chalcogenide glass using an AFM tip. The red and blue areas indicate crystalline and amorphous material, respectively.

INTRODUCTION

The Centre for Electromagnetic Materials Research (CEMR) at the University of Exeter is comprised of 9 academics and approximately 20 research fellows and postgraduate students. This brochure is designed to provide an overview of our expertise and the facilities that we have available. We are always looking to further our research endeavours and welcome enquiries both from industry and academia with a view to forming collaborative partnerships.

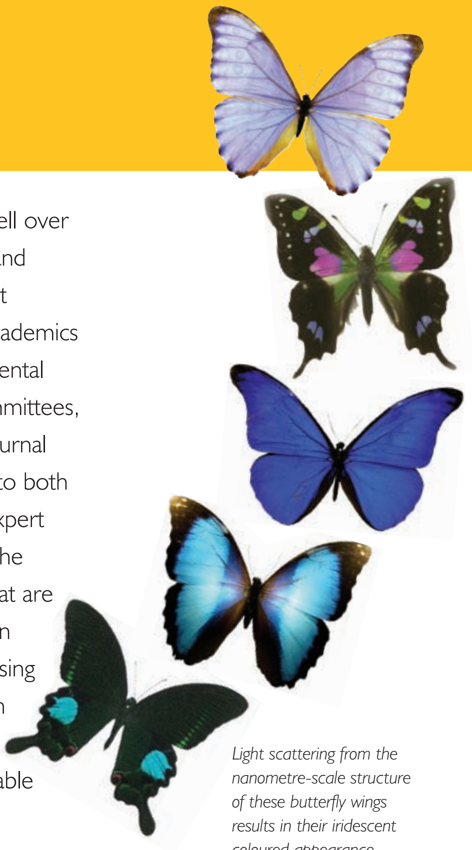
CONTENTS

CEMR is led by Professors Roy Sambles FRS, Bill Barnes and David Wright whose research interests include:

- Diffractive optics
- Photonic control of light-matter interactions
- Magnetic, optical and probe data storage
- Phase-change materials
- Thin-film magnetics
- Photonics in biology
- Liquid crystals

Colour enhanced image of the micro-structured scales that make up an iridescent butterfly wing (each scale is approximately 0.1mm by 0.2mm).

The **CEMR** team have published well over 1000 academic papers and patents and regularly give plenary / invited talks at international conferences. **CEMR** academics also sit on many important governmental review bodies, research council committees, international academic bodies and journal editorial boards and are consultants to both industry and government. We are expert and in many cases world-leading in the design and fabrication of materials that are structured on the nanometre, micron or centimetre scale and in characterising the electromagnetic response of such materials. A concise overview of the fabrication and analysis systems available is provided on the following pages.



Light scattering from the nanometre-scale structure of these butterfly wings results in their iridescent coloured appearance.

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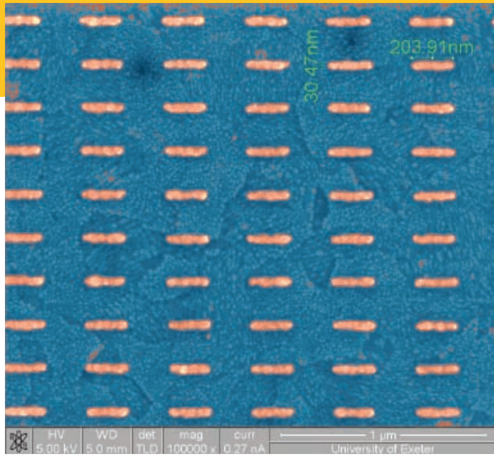
Images produced by the Focused Ion Beam (FIB)/SEM dual beam system:



An array of 200nm long, 30nm thick silver rods that have been fabricated on a silica substrate via e-beam lithography. The area shown is ~2µm x 2µm.

A silver zig-zag diffraction grating with a groove depth of 50nm. The area shown is ~4µm x 4µm.

FABRICATION FACILITIES

Ion Milling

A Focused Ion Beam (FIB) – Scanning Electron Microscope (SEM) Dual Beam System allows the manufacture of complex patterns on the nanometre scale along with selective sputtering.

Multi-Source Sputtering *Separate system to above*

Up to 4 materials can be sputtered at once allowing the deposition of multi-layers or compounds.

Deposition of thin-films by evaporation or spin-coating

Metal (e.g. gold, silver) and dielectric (e.g. silicon monoxide, PMMA, photoresist) can be deposited with film thickness being controlled with a precision of a few nanometres.

Manufacture of diffraction gratings

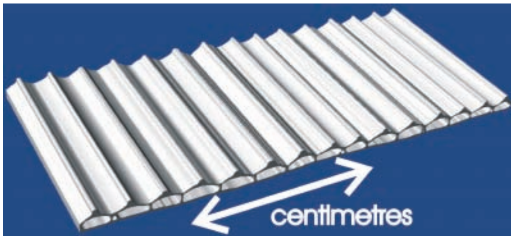
Both mono- and bi- diffraction gratings with groove pitches typically in the range 170nm to 2µm can be produced (longer pitch gratings can also be made).

Manufacture of photonic surfaces

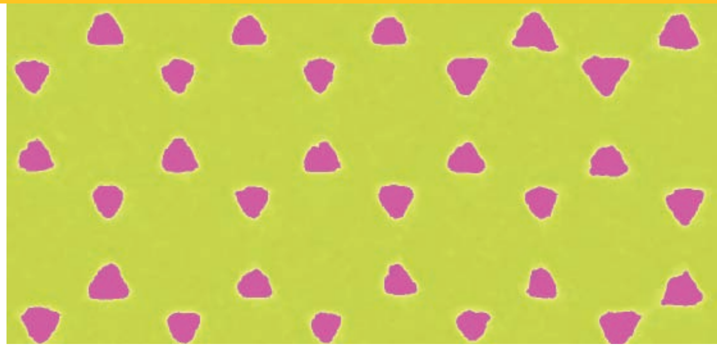
Arrays of spheroidal, triangular, rectangular or cylindrical particles and hole-arrays can be fabricated in metals or fused silica. The techniques used include: holography, nano-sphere lithography, electron beam lithography and etching.

Manufacture of microwave surfaces

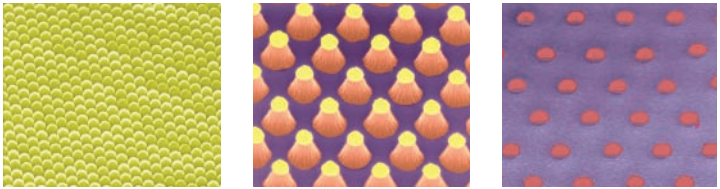
Extensive engineering facilities are available including a laser sinter system, CNC lathes and milling machines allowing the manufacture of surfaces and structures that diffract microwave radiation.



The nano-metre scale structure of a white butterfly wing is mimicked on the centimetre scale using a laser sinter system. This allows the reflective properties of the structure to be studied at microwave frequencies.



An hexagonal array of triangular metal particles fabricated using nano-sphere lithography. (The area shown is approximately ~2μm x 2μm.)



a) *b)* *c)*

Three stages in the fabrication of an hexagonal array of NiFe magnetic dots. (a) A close-packed monolayer of 390 nm diameter polystyrene spheres deposited on a polymer film and a 30 nm thick NiFe underlayer. (b) Reactive ion etching leaves a template of polymer posts capped by spheres. (c) NiFe dots of 120 nm diameter are formed after selective Ar ion milling through the sphere/polymer mask.

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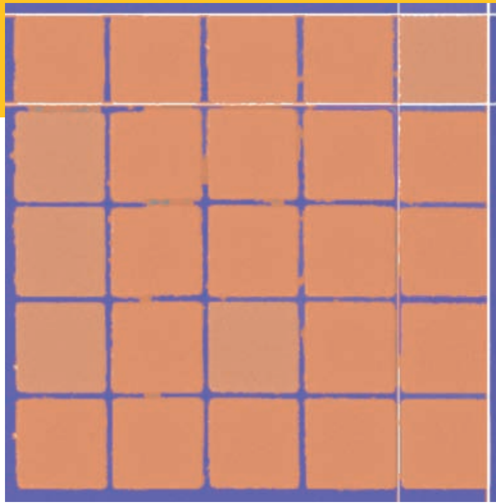
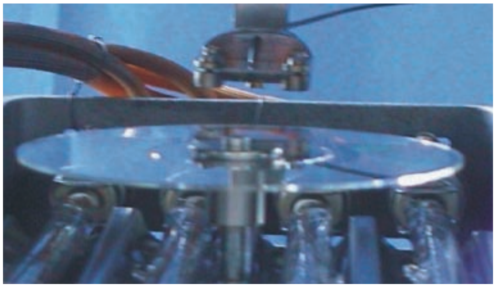


An array of multi-layered, square magnetic particles, the side of each square particle being 630nm in length, created using e-beam lithography and ion milling.



The halogen lamp-based rapid thermal processor that is used to anneal platinum / cobalt films. These high anisotropy films are used for high density magnetic data storage.

FABRICATION FACILITIES

Rapid Thermal Annealing

A halogen lamp-based system allows samples to be heated to 500°C in less than 1 minute. A 60W laser annealing system is also available.

Liquid crystal cell fabrication

Facilities include a vacuum-filling system and rubbing machine (the latter being for preparation of liquid crystal-aligning layers.)

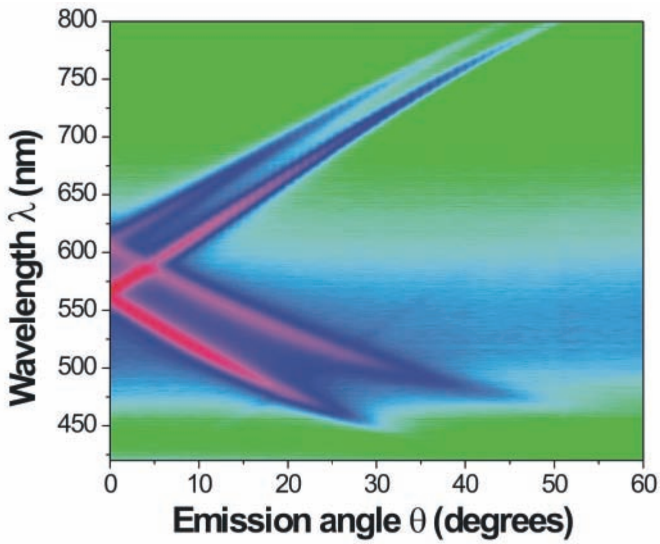
Langmuir-Blodgett (LB) film deposition

"Molecular staircases" with a step resolution of 5nm can be constructed.

The optical reflectivity and transmissivity of optically-thin, multi-layered, metal and dielectric films, liquid crystal cells and micro-structured samples can be measured as a function of wavelength (visible to infra-red), angle-of-incidence and/or polarisation.

The time-resolved (1μs resolution) dynamic optical response of liquid crystal cells can be measured as a function of temperature.

Characterisation and use of acousto-optic devices including acousto-optic modulators, deflectors and tuneable filters.



The photoluminescence from a diffractive, multi-layered organic light emitting diode structure. The red lines represent high intensity.

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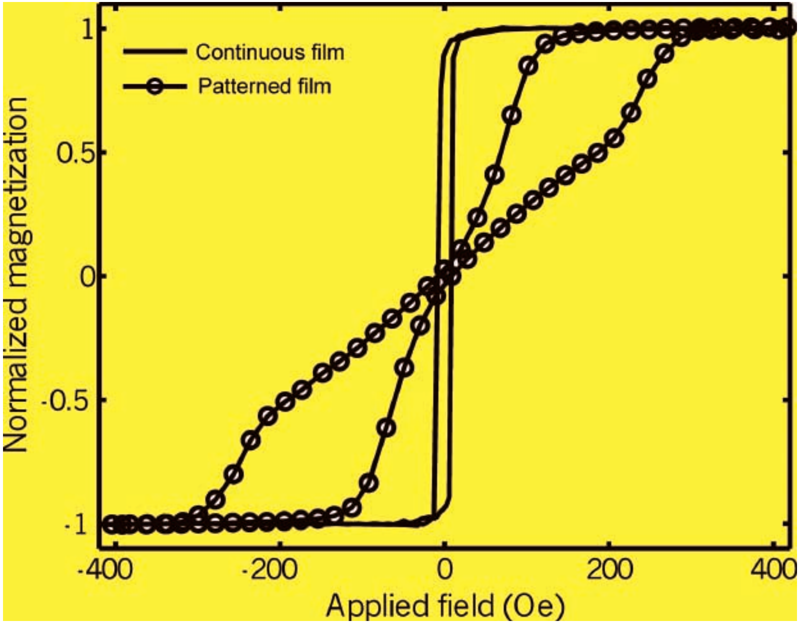


Magnetization reversal of a 30 nm thick NiFe film, before and after patterning. An obvious change in reversal behavior is observed after the original continuous film is patterned into an hexagonal array of 120 nm diameter dots.

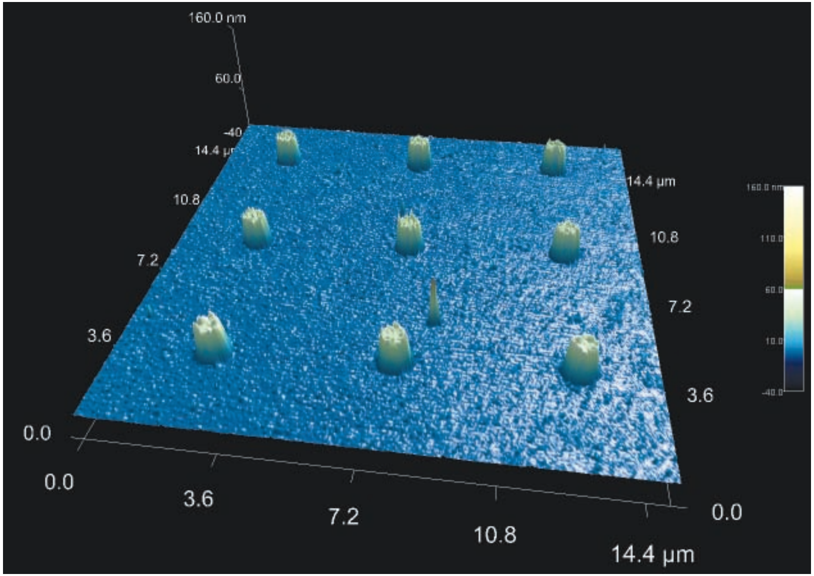
Magnetic materials including multi-layer and nano-particle structures can be characterized via: Vibrating Sample Magnetometry, Torque Magnetometry and Magneto-Optic Kerr Effect (MOKE) measurements. The magnetization dynamics of magnetic materials can also be measured to femtosecond resolution using a pulsed laser system.

We have expertise in understanding and characterizing (theoretically and experimentally) the complex write and read processes and noise characteristics involved in 'phase-change material'-based probe storage memories and magnetic, optical and solid-state data storage systems.

A TbFeCo disc used for thermo-magnetic recording.

Microscopes available include: Scanning Electron (SEM), Atomic Force (AFM), Magnetic Force (MFM), Scanning Tunneling (STM), Electrical Force (EFM), Scanning Electrostatic Potential (SEPM), Confocal Fluorescence and Dark Field Microscopes.

We have a range of in-house-designed sensors that lock to, and thereby track, the position of an optical mode as it changes with time having sensitivity to a change in refractive index of 10^{-7} (or better). Different systems are available that are wavelength-tuneable, can be fibre-coupled, have a pixilated sensing head, can be compact, lightweight, cheap and / or employ electrochemically-controlled binding at the sensor head. These are leading to new biosensing techniques. A non-invasive detector for malaria is currently under development.



An array of silver nano particles approximately 200 nm in diameter and 60nm high fabricated using e-beam lithography.

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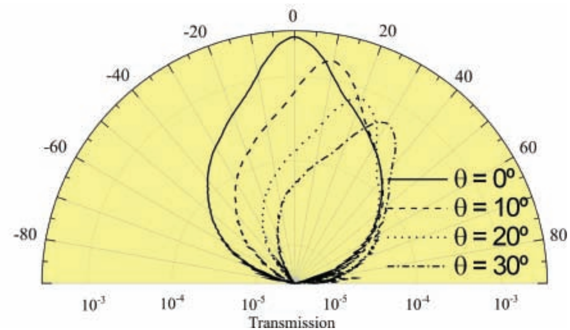
CHARACTERISATION OF MATERIALS AND STRUCTURE



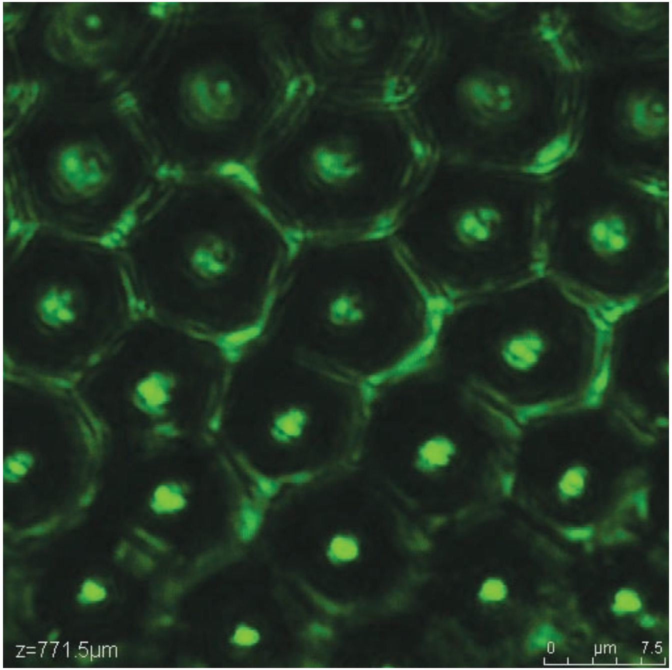
Angle dependent transmissivity, as measured by experiment, of a structure having concentric rings on both surfaces, at the resonant frequency of the sample for incident angles of 0, 10, 20 and 30°. The structure is shown in the photo above.

Natural optics: The transmissivity and reflectivity of (for example) iridescent insect wings that incorporate microstructure can be measured as a function of angle and wavelength. Microstructures that occur in nature can also be replicated on the centimetre scale (using a laser sinter system) so that the electromagnetic response of such systems can be characterized in the microwave regime.

Microwave studies: We are able to characterise the reflectivity and transmissivity response of diffraction grating, slit-array, hole-array, particle array and liquid crystal-filled structures over the frequency range: 5 to 100 GHz.

Fluorescence studies: The measurement of fluorescence lifetimes (~1ns-1ms) and photo-luminescence spectra allows the effects of microstructure on emissive materials to be studied.

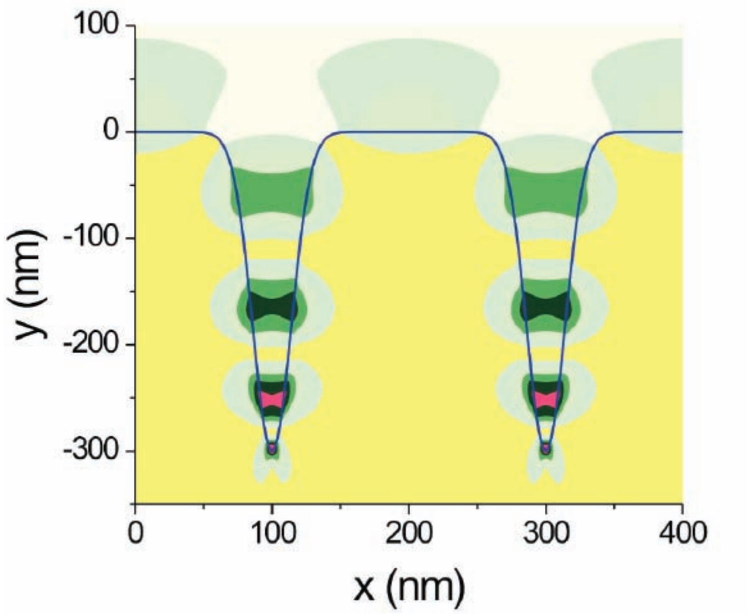
Laser sources available include HeCd (325nm), Argon ion (458nm) and a 100 femto-second pulsed Ti-doped Sapphire (700nm and 1μm).



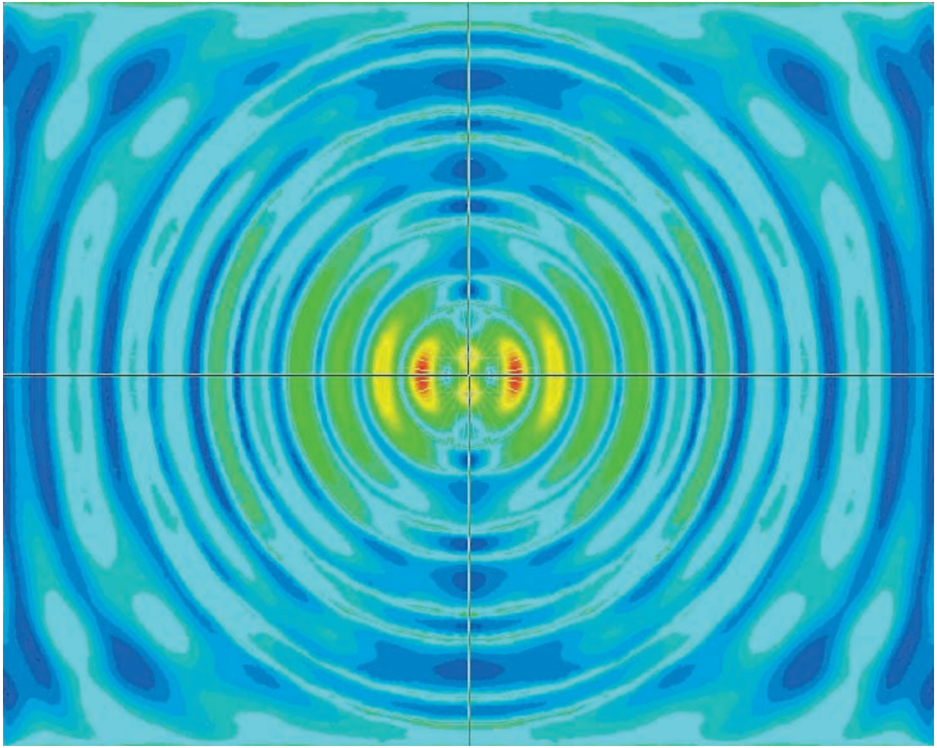
Images collected using a confocal microscope from a region of the outer shell of a Plusiotis boucardi beetle illuminated at normal incidence with light of 514nm wavelength.

Finite Difference Time Domain (FDTD) codes are used to model how electromagnetic fields affect both magnetic and non-magnetic materials. Alternatively, the electrothermal processes that occur in probe storage devices, based on phase-change materials, can be modelled.

Computer codes based on Fresnel and conformal mapping theory allow modelling of the optical response of planar and diffraction grating multi-layer systems. By comparison with data acquired via experiment, the director profile through a liquid crystal cell, the groove profile of a diffraction grating, electromagnetic field profiles through a multi-layered structure or the optical permittivities and thickness of a metal or dielectric film (for example) may be determined.



Magnetic field magnitude for a surface plasmon excited on a 200nm pitch, silver diffraction grating (the grating surface is indicated by the blue line). The red areas represent regions of highest intensity.



Transmitted microwave intensity, as modelled by finite element theory, for a sub-wavelength aperture surrounded by concentric grooves in a perfect insulator. Red indicates areas of high intensity.

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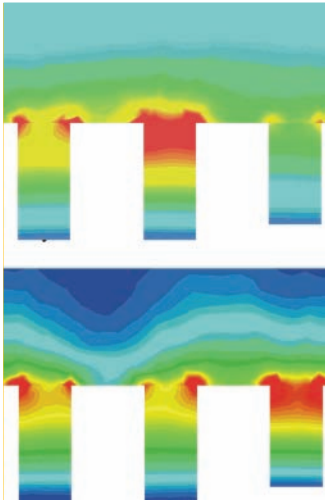
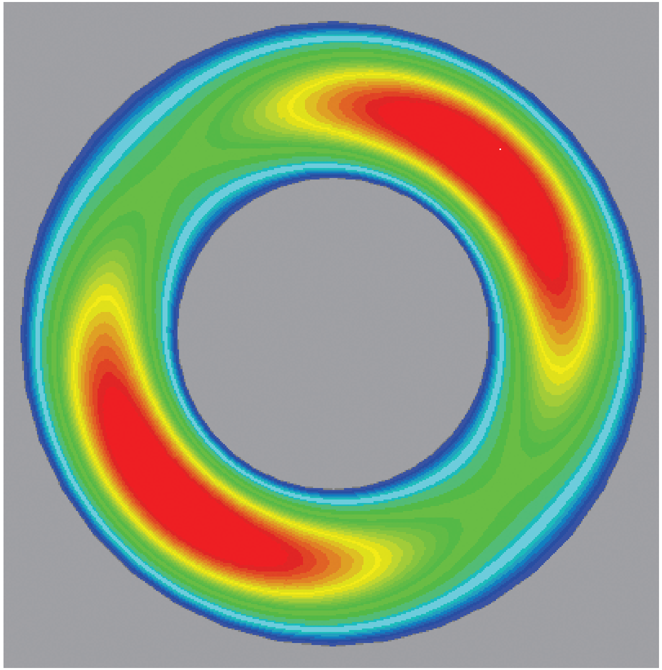
Finite element modelling codes allow the optical and microwave response of complex diffractive structures to be predicted.

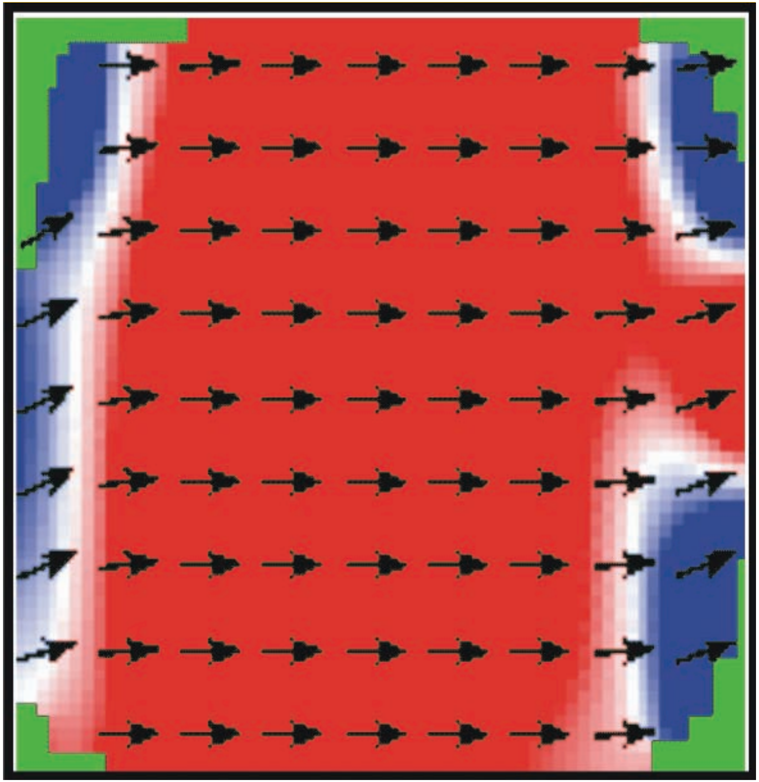


The microwave intensity, as modelled by theory, in the wax-filled grooves of an aluminium (shown as white) diffraction bi-grating. Red indicates areas of high intensity.



Electric field magnitude, as modelled by finite element theory, for a waveguide mode, in a perfectly conducting co-axial waveguide. The grey areas represent perfectly conducting material.

Modelling codes allow simulation of magnetization dynamics within both single isolated elements and arrays of particles with the predicted response of a system being displayed as the spatial distribution of the magnetic field magnitude.



Dynamic magnetization map as modelled by theory for the resonant modes in a nano-scale square element, having sides of length ~240mm.

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Centre for Electromagnetic Materials Research
Harrison Building
North Park Road
Exeter UK EX4 4QF

Tel: 01392 263628 (School of Engineering)
Tel: 01392 264151 (School of Physics)

Email: cemr@exeter.ac.uk

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