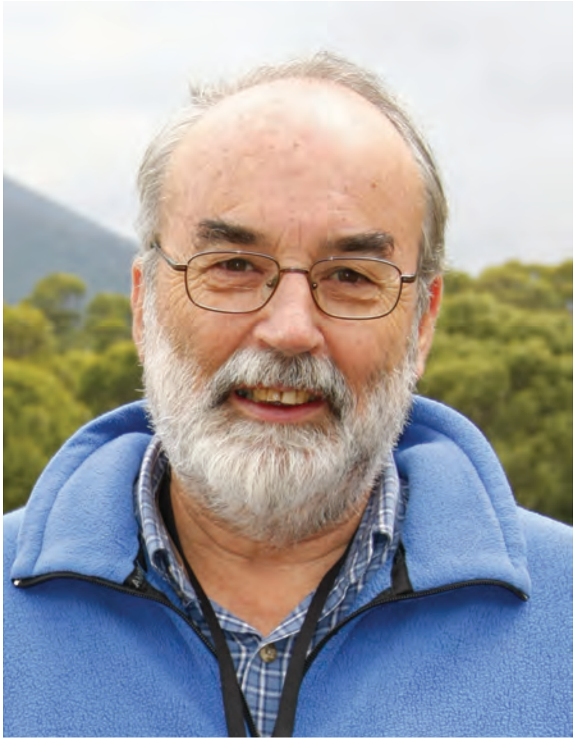

CI short biography

Ross McPhedran completed his undergraduate studies and PhD at the University of Tasmania, before moving to Sydney in 1975 as a Queen Elizabeth II Fellow. He was appointed a Senior Lecturer in the School of Physics in 1984, and was promoted to a Personal Chair in 1994. His interests range over many aspects of wave theory, photonics, microstructured fibres, elastodynamics, composite science, mathematical methods and numerical algorithms.

Awards, honours, major international visits

In 2010 Professor McPhedran was awarded a Doctorate Honoris Causa by the Universite Paul Cezanne, Aix en Provence and Marseille France, in recognition of his research and mentoring contributions over the period since his first postdoctoral studies in Marseille in 1973. He gave invited talks on *Metamaterials, Transformation Optics and Cloaking* at the Intercontinental Advanced Materials and Photonics (ICAMP) Summer School, Sydney, June 21-25, the Fourth International Workshop on Theoretical and Computational Nano-Photonics, Bad Honnef, Germany, November 3-5 and at the CNRS Summer School on Mesoscopic Physics in Complex Media, Cargese, Corsica, July 12-16. He also gave an invited talk on *Ideal Cloaking and Local Density of States* at the SIAM Conference on Mathematical Aspects of Material Science, Philadelphia, Pennsylvania, 23-26 May. He gave an invited talk on Band Structures for Platonic Crystals at the New Zealand Conference on Applied Mathematics, Dunedin, 7-9 December.

He made research visits to work on platonic crystal theory at the University of Liverpool in March and November. He visited the Institut Fresnel in September to work on a chapter for a book entitled *Introduction to Plasmonics*, to be published by Springer Verlag. He serves on the Editorial Advisory Board of the journal Waves in Random and Complex Media.

Key areas of research contribution within the Centre

Professor McPhedran is engaged in the theory underlying the electromagnetic properties of photonic crystals, and currently is particularly involved in the development of theories for the properties of defects and resonant cavities in PC's. He is also involved in the development of methods for density of states calculations in photonic crystals and their applications in radiation dynamics effects, and the modeling and applications of microstructured fibres. He works on the theory and applications of surface plasmons in structured materials, and is active in the study of the use of plasmonic resonances in optical cloaking.

Researchers and students

Sahand Mahmoodian is working with Professors McPhedran, de Sterke and Botten, together with Drs. Kokou Dossou and Chris Poulton, on analytic methods for accurate evaluation of the properties of defects and resonators in photonic crystals. Parry Chen is working with Professors McPhedran, de Sterke and Botten, and Drs. Michael Steel, Chris Poulton and Ara Asatryan on the theory of photonic crystals incorporating both negative index materials and normal materials. Felix Lawrence is supervised by Professors de Sterke, McPhedran and Botten on the development of impedance concepts for photonic crystals. Casey Handmer worked under the supervision of Profs. McPhedran, de Sterke and Botten on a highly successful project on the achievement of super-resolution using stacked diffraction gratings. Bjorn Sturmberg worked under the supervision of Profs. McPhedran, de Sterke and Botten, and Drs. Dossou, Poulton and Steele on a project involving the analysis of a new type of architecture for photovoltaic cells, which enables the combination of efficient extraction of energy with minimisation of the amount of silicon required. Professors McPhedran and de Sterke are collaborating in the supervision of Najmeh Nozhat, a PhD student from the Faculty of Electrical and Computer Engineering, K. N. Toosi University of Technology, Tehran, Iran, who is working for a period of nine months in CUDOS on the theory of the non-linear plasmonic folded directional coupler.

Research achievements during 2009

This report will concentrate on topics involving metamaterials, density of state functions and super-resolution, in order to avoid duplication of research described elsewhere in this Annual Report.

An article with Sebastien Guenneau and Andre Diatta [1] discusses the controversial issue of the resolution available due to imaging by graded index structures such as the Maxwell fish-eye and Eaton lenses, in comparison with the Veselago-Pendry slab lens. Resolutions in the range of a half to a quarter wavelength are calculated numerically, but it should be noted that the wavelength itself is a spatially-varying quantity. The difference between conjugate and perfect images is discussed (the former not necessarily containing evanescent field components from the source).

A series of five articles [2-6] builds the methodology for calculating density of state functions in lossy materials. The motivation for this investigation is in the question as to whether and how cloaked objects and cloaking systems may be detected by electromagnetic probes. There is much current activity in investigation of various designs for electromagnetic cloaking systems, but virtually all attention is being paid to defeating active detection of objects. Passive detection schemes would rely on the altered radiation from objects in the immediate neighbourhood of the cloaking apparatus, much as passive burglar detection systems rely on infrared radiation emission from moving bodies in a target region. In order to characterise such altered radiation patterns, it is necessary to calculate the local density of states function (LDOS) in the vicinity of the structured regions which cloak objects from active probes.

The calculation of LDOS in lossy structured systems has proved difficult, particularly for that polarization for which the LDOS is related to a Green's tensor rather than a scalar Green's function. In this case, the transverse or radiative part of the tensor must be constructed, and its trace used to give the LDOS. A result

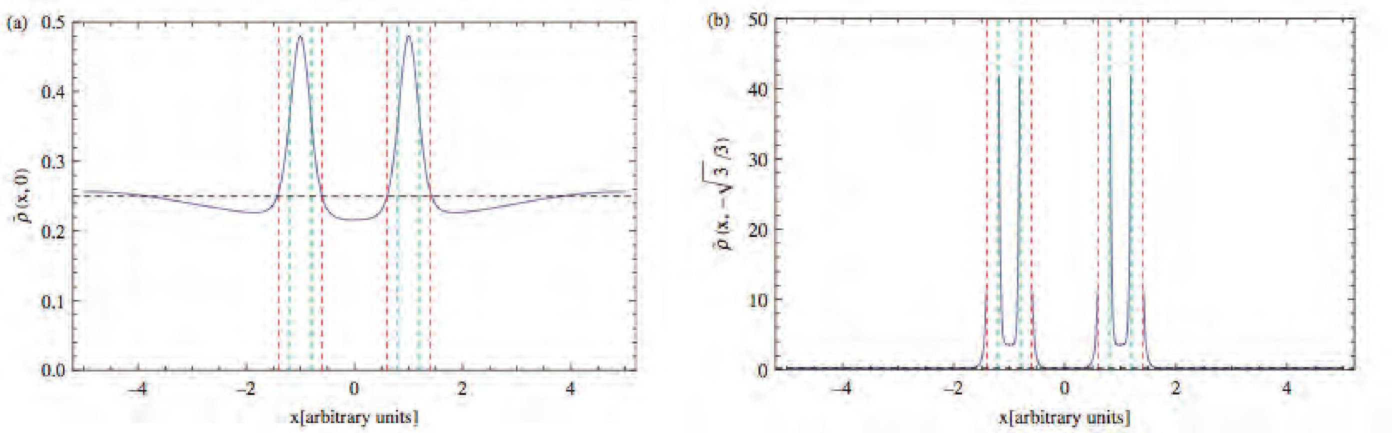

Fig 1: Relative local density of states in a triangular cluster of three coated particles, above on a line passing through the centre of the cluster, but not through a particle, and below on a line passing through two particles. The cylinders have a coating with permittivity and permeability equal to -1+0.001 i and -1 respectively.

of this procedure is given in Fig. 1 below, from Ref. [6]. This shows that the LDOS peaks strongly in the neighbourhood of resonant metallic particles, reaching around 160 times its free space value. Thus the particles could have a "halo" of strongly radiating molecules surrounding them, rendering them vulnerable to passive detection methods.

It is appropriate to mention here that this work was principally carried out by Dr. Nicolae Nicorovici, who has been a Research Associate both in the School of Physics, University of Sydney and Department of Mathematical Sciences, the University of Technology Sydney since 1991. He died in late December 2010, and leaves a considerable scientific legacy, which will continue to benefit work being carried out in CUDOS on photonic crystals, plasmonics and metamaterials.

Parry Chen's PhD is concerned with fundamental issues connected with wave propagation in dispersive and lossy structured materials, such as those often encountered in metamaterials. He has recently carried out important studies into the relationship between group velocity, energy velocity and photonic band diagrams in composite systems incorporating loss [7]. He has been able to define a generalised quantity called the *adjoint field* velocity (Fig 1). This is constructed from the electric field of a Bloch mode, and the magnetic field of the counter-propagating Bloch mode. It agrees with the gradient of the band diagram in lossy photonic crystals, and reduces to the energy velocity for Bloch modes not suffering attenuation. It thus provides a link between the slope of the dispersion relation and the modal fields, even when substantial energy loss is encountered.

The final research topic we will discuss is that of super-resolution, and of designs based on stacked dielectric diffraction gratings which can better the Rayleigh resolution limit [8,9]. This work was carried out by Casey Handmer in his honours year, and further developed for publication in 2009. It is based around the concept of *blazing evanescent orders*, i.e., controlling the strength of non-propagating orders generated by a diffraction grating. Highly evanescent orders are in fact good approximations to solutions of Laplace's equation rather than the Helmholtz equation- i.e., they are effectively independent of the wavelength, and thus of criteria like the Rayleigh resolution limit, which is proportional to the wavelength. The super-resolving designs use chains of dielectric gratings, which have sharp surface features.

Through proper design, these grating chains can shunt energy out to the highly evanescent orders which can resolve features much smaller than the wavelength, and then couple the result back again into propagating orders. Such designs have been shown to be capable of providing steerable spots as small as a twentieth of the free space wavelength.

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