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Ross C McPhedran

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.

Key Areas of Research Contribution and 2011 Achievements

Ross McPhedran is active in the CUDOS Programs on Functional Metamaterials and Plasmonics.

The research achievements selected for discussion involve band structure of metamaterial composites, and super-resolution using metamaterials, with other topics being covered elsewhere in the Annual Report. Parry Chen is doing his PhD in CUDOS under the supervision of Professors McPhedran and de Sterke and with the participation of Professor Botten, A/Prof Steel and Drs Poulton, Asatryan and Dossou. His research is centred on the properties of electromagnetic waves in metamaterials, where inclusions have negative and strongly dispersive dielectric permittivities and magnetic permeabilities, and are placed in a background material with positive permittivity and permeability. Band diagrams were constructed for such metamaterial composites, and these showed anomalous features, such as band surfaces cut up into disconnected regions and points on bands where the group velocity was infinite (see Fig. 1).

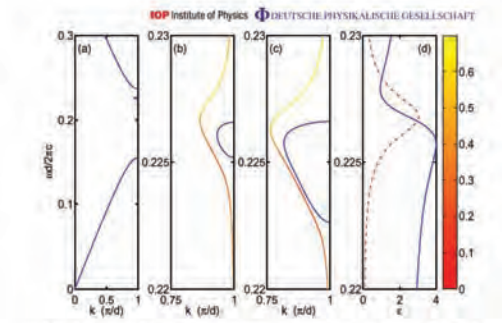

Figure 3. The Γ–X band diagram of a 1D photonic crystal, consisting of Si and a polymer with a suspension of quantum dots with $\epsilon_{Si} = 12$ and $\epsilon_{poly} = 2.56$, and layer lengths $l_{Si} = l_{poly} = 0.5$. Shown are $\omega(k)$ calculated with loss (red–yellow line) and without loss (blue line). Where applicable, $\mathrm{Im}(k)$ is represented by the red–yellow color gradient. The quantum dots are modeled by the Lorentz oscillator parameters $\omega_0 = 0.22d/\lambda$, $\omega_p = 0.8\omega_0$, and $\gamma = 0.01\omega_0$. The volume fractions of quantum dots are (a, b) $\eta = 0.05$ and (c) $\eta = 0.02$. (d) $\mathrm{Re}(\epsilon_{poly})$ (blue solid) and $\mathrm{Im}(\epsilon_{poly})$ (red dash dot) for $\eta = 0.05$, calculated using the Maxwell–Garnett model.

The question then arises as to which condition must be satisfied for such strange band diagrams to occur, and whether this condition can be met by physically-possible structures. Professor McPhedran and his team answered this question by deriving a simple physical constraint that balances the product of negative group index and positive electric energy in the metamaterial inclusions with the product of positive group index and positive electric field energy in the background material. This constraint can be satisfied in physical systems, and will then guarantee the existence of infinite group velocity points.

A second research highlight was work done by Ross McPhedran in connection with Professor Johan Helsing of Lund University, Sweden, and Professor Graeme Milton of the University of Utah, U.S.A. This concerned the properties of arrays of square particles or cylinders of square cross section, illuminated by light of wavelength long enough so that their properties could be modeled in the electrostatic approximation.

Rigorous results are known for the electrostatic properties of isolated square particles. These indicate that the resonances do not occur in isolation, but rather are spread continuously along what is known as a branch-cut. The branch-cut of an isolated particle with sharp corners is determined by the angle subtended by the sharp corner, but it was not known whether interaction effects would smooth out details of the branch-cut, and weaken its effects. In fact, highly accurate calculations using a specially developed method have shown that in fact arrays of such particles always have branch-cuts with ends determined precisely by the shape of the particles. Thus, knowledge of the particle shape is always possible, even if the optical properties of the array are interrogated with light whose wavelength far exceeds the particle size. Furthermore, branch-cut resonances could be employed in metamaterials designed to operate over a wide wavelength range, given the way they fill a continuous interval, rather than occurring in isolation.

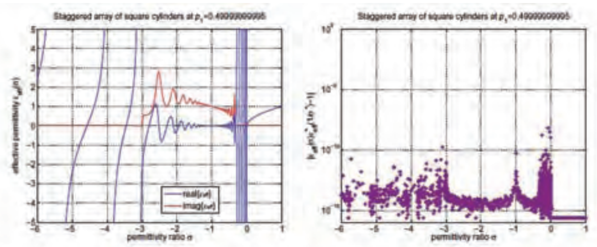

Figure 4. Left: the effective relative permittivity of a staggered array of square cylinders at $p_1 = 0.499\,999\,999\,95$. The curves are supported by 2006 adaptively spaced data points. Right: the absolute difference between the left- and the right-hand side of (16).

Recognition

In 2011, Ross McPhedran was elected as a Fellow of the Australian Academy of Science. He made research visits to the University of Liverpool in April and December to work on the theory of elastic waves in structured thin plates, and in particular on the development of structures showing high quality filtering action. He gave an invited talk at the international conference Metamaterials 2011, October 10-15 in Barcelona, Spain. He also organised with Dr Dragomir Neshev a focus meeting at the conference IQEC/CLEO Pacific Rim at Darling Harbour in August/September 2011, which featured a panel of international experts debating the practical applications of metamaterial technology. The meeting attracted a capacity audience.

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