Advanced theoretical and numerical methods for waves in structured media

Mardi 13 mars 2018

Institut Langevin, Institut de Physique du Globe de Paris

1 rue de Jussieu, 75005 Paris

Mercredi 14 mars 2018

Campus Jussieu, LPNHE, amphithéâtre Charpak, tour 22 niveau – 1

4 place Jussieu, 75005 Paris

Programme

The development of novel structures with exotic wave phenomena (like metamaterials and photonic or phononic devices) requires the renewal of theoretical and numerical approaches. These days are intended to discuss recent issues and research advances in these areas, with all the different communities involved : electromagnetics, acoustics, mechanics, applied mathematics and computing sciences.

Des journées organisées par le GT1 du GDR Ondes du CNRS
http://gdr-ondes.cnrs.fr/groupes-thematiques/gt1-modelisation-et-simulation/
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Mardi 13 mars 2018

Institut Langevin, Institut de Physique du Globe de Paris

1 rue de Jussieu, 75005 Paris

10h00 – 10h45 Accueil café et installation des posters

10h45 – 11h00 Introduction

11h00 – 12h30 Metamaterials I – Chairperson S. Guenneau

11h00 – M. Wegener (KIT, Karlsruhe) : *3D chiral mechanical metamaterials*

11h30 – R. Craster (Imperial College London) : *Metamaterials for vibration control*

12h00 – M. Cassier (Institut Fresnel) and G. Milton : *Bounds on Herglotz functions and fundamental limits to broadband passive cloaking in the quasi-static regime*

12h30 – 14h00 Déjeuner et café-posters-discussions

14h00 – 15h30 Homogenization of composites and asymptotic models – Chairperson B. Delourme

14h00 – S. Fliss (POEMS) : *Modèle homogénéisé enrichi pour la propagation à la surface des métamatériaux*

14h30 – P. Millien (Institut Langevin) : *Volume integral approach for the computation of plasmonic resonance beyond the quasistatic approximation in the scalar case*

15h00 – A. Maurel (Institut Langevin) : *Homogénéisation d'interfaces localement résonantes*

15h30 – 16h10 Numerical modelling : benchmarks I – Chairperson G. Demésy

15h30 – C. Eyraud and A. Litman (Institut Fresnel) : *Modeling and imaging of an aggregate of spheres*

15h40 – M. Vanwolleghem (IEMN) : *Rigorous Coupled-Wave Modeling of Plasmonic Gyrotropic One-Way Reflection Gratings*

15h50 – A. Shcherbakov and Y. Jourlin (LHC) : *2D hexagonally arranged dielectric microsphere arrays diffraction*

16h00 – G. Renversez (Institut Fresnel) : *Stationary solutions propagating in axis-invariant nonlinear waveguides: results from semi-analytical and finite element methods*

16h10 – 17h00 Café-posters-discussions

17h00 – 18h40 Numerical modelling : softwares – Chairperson A. Nicolet

17h00 – C. Geuzaine (University of Liège) : *GetDP, Gmsh and ONELAB*

17h20 – J. Roman (Universitat Politècnica de València) : *An overview of SLEPc*

17h40 – J. Viquerat and S. Lanteri (NACHOS, INRIA) : *DIOGENeS : une suite logicielle dédiée à la Nanophotonique computationnelle basée sur des méthodes Galerkin discontinues*

18h00 – E. Lunéville (POEMS) : *XLiFE++ : une librairie éléments finis FEM-BEM polyvalente*

18h20 – A. Sentenac and P. Chaumet (Institut Fresnel) : *IF-DDA : un logiciel pour l'électromagnétisme basé sur la méthode des dipôles couplés*

Mercredi 14 mars 2018

Campus Jussieu, LPNHE, amphithéâtre Charpak, tour 22 niveau – 1

4 place Jussieu, 75005 Paris

08h30 – 09h00 Accueil et installation des posters

09h00 – 10h00 Spectral analysis of non-conventional systems – Chairperson P. Joly

09h00 – L. Chesnel (CMAP) : *A new complex spectrum related to invisibiliy in waveguides*

09h30 – C. Hazard (POEMS) : *Curiosities about the spectrum of a cavity containing a negative material*

10h00 – 10h40 Numerical modelling : benchmarks II – Chairperson G. Demésy

10h00 – A.-L. Fehrembach (Institut Fresnel) : *Modélisation numérique de réseaux résonnants sub-longueur d'onde en cavité étendue*

10h10 – A. Moreau (Institut Pascal) : *Beyond the Drude model : simulating plasmonic structures with spatial dispersion*

10h20 – A. Modave (POEMS) : *An efficient DDM with cross-points for the parallel finite Element solution of scattering problems*

10h30 – C. Sauvan (LCF) : *Calculation of quasinormal modes in dispersive resonant structures*

10h40 – 11h30 Café-posters-discussions

11h30 – 12h30 Numerical modelling of complex media I – Chairperson J. De Rosny

11h30 – Philippe Lalanne and Wei Yan (LP2N) : Rigorous modal analysis of plasmonic nanoresonators

12h00 – P. Ciarlet (POEMS) : *A brief review of methods for computing singular electromagnetic fields*

12h30 – 14h00 Déjeuner et café-posters-discussions

14h00 – 15h00 Numerical modelling of complex media II – Chairperson F. Triki

14h00 – M. Campos Pinto (LJLL) : *Formulations stables pour des ondes résonantes dans un plasma magnétisé*

14h30 – M. Kachanovska (POEMS) : *Stable perfectly matched layers for anisotropic metamaterials*

15h00 – 16h00 Metamaterials II – Chairperson M. Kadic

15h00 – V. Laude (FEMTO-ST) : *Modeling phononic crystals*

15h30 – V. Pagneux (LAUM) : *PT symmetric scattering and acoustics*

16h00 – 16h15 Conclusion

Résumés

Mardi 13 mars 2018

11h00 – 12h30 : Metamaterials I

11h00 – 11h30 : 3D chiral mechanical metamaterials
Martin Wegener
Karlsruhe Institute of Technology, Institute of Applied Physics, Karlsruhe, Germany

Optical activity is a well-established phenomenon. It means that the eigenstates are chiral, leading to a polarization rotation for incident linearly polarized light. Here we investigate the counterpart of optical activity in mechanics, namely "mechanical activity" in tailored 3D microstructured metamaterials. In the static regime, the simple-cubic chiral metamaterials exhibit a twist upon pushing onto them – a degree of freedom that is forbidden in ordinary (Cauchy) continuum mechanics. We discuss results from microstructure theory, experiment, and generalized continuum mechanics. In the dynamic regime, we find a splitting of the lowest two bands in the phonon band structure, which is most pronounced near the middle of the first Brillouin zone, and chiral eigenstates.

11h30 – 12h00 : Metamaterials for vibration control
Richard Craster
Imperial College London, Department of Mathematics, London, United Kingdom

This talk will provide an overview of techniques being used in elastic wave systems to control, redirect or manipulate waves. Systems of graded sub-wavelength resonators allow for mode conversion between wave types and wave systems, graded index lenses create opportunities to focus or redirect waves and phononic crystals can be used to create zero-frequency bandgaps. Each of these mechanisms will be illustrated.

11h30 – 12h00 : Bounds on Herglotz functions and fundamental limits to broadband passive cloaking in the quasi-static regime
Maxence Cassier, common work with Graeme Milton
CNRS, Institut Fresnel, Marseille

In this talk, we are interesting in the following challenging question : is it possible to construct a passive electromagnetic cloaking device that cloaks an object over a whole frequency band? We provide here an answer in the quasi-static regime of Maxwell's equations. Our approach is based on the fact that in passive linear materials, the frequency dispersion can be modeled by Herglotz functions. Thus, our strategy is first to derive new bounds on this class of functions that both generalize the ones existing in the literature and apply to a wide class of linear passive systems such as electromagnetic passive materials. Among these bounds, we describe the optimal ones and also discuss their meaning in various physical situations like in the case of a transparency window, where we exhibit sharp bounds. In a second time, we apply these bounds in the context of broadband passive cloaking in the quasistatic regime to refute the mentioned question. Our rigorous approach, although limited to quasistatics, gives quantitative limitations on the cloaking effect over a finite frequency range by providing inequalities on the polarizabilty tensor associated with the cloaking device. We emphasize that our results hold for a cloak or object of any geometrical shape.

14h00 – 15h30 Homogenization of composites and asymptotic models

14h00 – 14h30 : Modèle homogénéisé enrichi pour la propagation à la surface des métamatériaux

Sonia Fliss, collaboration avec Clément Beneteau, Xavier Claeys et Valentin Vinoles
ENSTA ParisTech, POEMS, Palaiseau

Quand on s'intéresse à la propagation des ondes dans un milieu périodique à basse fréquence (i.e. la longueur d'onde est grande devant la période), il est possible de modéliser le milieu périodique par un milieu homogène équivalent ou effectif qui a les mêmes propriétés macroscopiques. C'est la théorie de l'homogénéisation qui justifie d'un point de vue mathématique ce procédé. Cette approche est très séduisant car les calculs numériques sont beaucoup moins couteux (la petite structure périodique a disparu) et des calculs analytiques sont de nouveau possibles dans certaines configurations. Les ondes dans le milieu périodique et dans le milieu effectif sont très proches d'un point de vue macroscopique... sauf en présence de bords ou d'interfaces.
En effet, il est bien connu que le modèle homogénéisé est obtenu en négligeant les effets de bords et par conséquent il est beaucoup moins précis aux bords du milieu périodique. Quand les phénomènes intéressants apparaissent aux bords du milieu (comme la propagation des ondes plasmoniques à la surface des métamatériaux par exemple), il semble donc difficile de faire confiance au modèle effectif.
En revenant sur le processus d'homogénéisation, nous proposons un modèle homogénéisé qui est plus riche aux niveaux des bords. Le modèle homogénéisé enrichi est aussi simple que le modèle homogénéisé classique loin des interfaces, seule les conditions aux bords changent et prennent mieux en compte les phénomènes. D'un point de vue numérique, se rajoutent aux problèmes de cellule classiques qui apparaissent en homogénéisation, des problèmes de bandes périodiques qui prennent en compte la façon dont le bord coupe le milieu périodique.

14h30 – 15h00 : Volume integral approach for the computation of plasmonic resonance beyond the quasistatic approximation in the scalar case

Pierre Millien
CNRS, Institut Langevin, Paris

We present a new way to compute the resonant frequencies of a metallic nanoparticle using the volume integral equation. We show that an approximate value for the resonant parameter of a metallic particle can be computed easily (without computing the full resolvant for the Neuman Poincaré operator K*), and we apply some perturbative theory to compute the correction of these resonant values due to the finite ratio : size of the particule / wavelenght of the incoming light.

15h00 – 15h30 : Homogénéisation d'interfaces localement résonantes

Agnès Maurel, collaboration avec Jean-Jacques Marigo, Daniel Fuster, Sébastien Guenneau, Jean-François Mercier, K. Pham et C. Pideri
CNRS, Institut Langevin, Paris

Nous présenterons quelques études de systèmes structurés à l'échelle sublongueur d'onde et présentant des propriétés raisonnablement exotiques pour la propagation des ondes. Il s'agit de structures formées d'une ligne de résonateurs, pour lesquelles on cherche des conditions de sauts (ou de transmissions) effectives ; ces structures font intervenir des résonances locales, typiquement les résonances de Mie en électromagnétisme ou en élastodynamique, les résonateurs de Helmholtz ou de Minnaert en acoustique. Nous présenterons également des études sur des milieux massifs (associés à une équation de propagation effective) pour lesquels les effets de bord sont importants. C'est le cas du couplage d'une onde guidée avec un réseau de tiges. C'est également le cas de la réponse d'un milieu stratifié au voisinage de l'angle critique de réflexion. Notre approche s'appuie sur l'homogénéisation (analyse asymptotique à plusieurs échelles). Développée au-delà de l'ordre 0, qui coincide avec l'approximation de milieu effectifs (EMA), elle interroge la propagation dans le coeur de la structure et les effets de couches limites aux bords de la structure.

15h30 – 16h10 Numerical modelling : benchmarks I

15h30 – 15h40 : Modeling and imaging of an aggregate of spheres

Christelle Eyraud, common work with Amélie Litman and Jean-Michel Geffrin
Université d'Aix-Marseille, Institut Fresnel, Marseille

We present reconstructions of an aggregate of small spheres from experimental scattered fields using a working frequency of 18 GHz. The scattered field of this target has been measured in far field for different polarization cases (Fresnel database). Several modeling codes have already been compared to these measurements. The studied target is an aggregate composed by 74 dielectric spheres of 2.5 mm radius. It has a fractal dimension of 1.7. The spheres are made of polyacetal with relative permittivity experimentally estimated to be 2.85 ± 0.01. This aggregate presents several peculiar characteristics: Its geometry is entirely non-symmetrical (no symmetry axis or plane); It is a depolarizing target (hence measurements of the full scattering matrix are of interest); The target has very low density (filling ratio below 3%); The overall dimensions of the target are rather large with respect to the wavelength (approximately 5 wavelengths height).
Fresnel Database :
http://www.fresnel.fr/3Ddirect/database.php
http://www.fresnel.fr/3Ddatabase/database.php

15h40 – 15h50 : Rigorous Coupled-Wave Modeling of Plasmonic Gyrotropic One-Way Reflection Gratings

Mathias Vanwolleghem, collaboration with Oleksandr Stepanenko, Tomas Horak, Kamil Postava and Jean-François Lampin
CNRS, Institut d'électronique de microélectronique et de nanotechnologie, Lille

Gyrotropy (i.e. material tensors violating the fundamental Lorentz reciprocity of Maxwell's equations) appeals to the scientific imagination due for instance to the peculiar time reversal breaking that it creates. Precise modelling of gyrotropy in general requires solving besides the original structure also the adjoint electromagnetic problem. The involved asymmetric tensors cannot be diagonalised by an orthogonal transformation and proper orthonormalization of the complete basis is only possible by projection on the adjoint eigenmodes.
We will present benchmark modelling examples of a plasmonic grating on a gyrotropic substrate. The combination of a surface resonance with nonreciprocity can lead to an extreme time reversal behaviour where such a "gyro-plasmonic" surface behaves as a perfect mirror but becomes a perfect absorber upon beam reversal (see spectrum in figure as an illustration). Examples will be shown where the nonrecprocity comes from either gyroelectricity or from gyromagnetism. The latter case poses a nice challenge as due to duality in Maxwell's equations this requires the counterintuitive excitation of an E-polarised surface plasmon polariton. Moreover gyromagnetism is in general a low frequency phenomenon, creating the additional challenge of designing plasmon excitation on near perfect metals. An efficient fully gyrotropic RCWA approach based on a fast fourier factorization of the structure is used in these examples. It automatically treats the adjoint problem as it considers inherently the eigenproblem in the entire Brillouin zone instead of just the reduced part.

15h50 – 16h00 : 2D hexagonally arranged dielectric microsphere arrays diffraction

Alexey Shcherbakov, common work with Thomas Kämpfe and Yves Jourlin
Université de Lyon, Laboratoire Hubert Curien, Saint-Etienne

For applications in colloidal lithography we want to analyze a 2D monolayer array of silica microspheres with a diameter comparable to the incident light's wavelength, arranged in a hexagonal pattern. The interest lies in calculating the diffraction efficiency in transmission, as well as the field distribution behind the microspheres. To take into account real world fabrication variations, the sphere sizes as well as the distance to their ideal lattice positions are varied statistically. For comparison and the numerical benchmark, one variant of this statistical variation for a subset of about 10 x 10 microspheres will be fixed. This problem is difficult to analyze numerically since the considered structure has a small critical dimension (one microsphere's surface) and a large overall extent (simulation of at least 10 x 10 spheres to take fabrication variations into account). The Laboratoire Hubert Curien in collaboration with the Moscow Institute of Physics and Technology proposes to analyze such structures by a rigorous ultra-fast Generalized Source Method.

16h00 – 16h10 : Stationary solutions propagating in axis-invariant nonlinear waveguides: results from semi-analytical and finite element methods

Gilles Renversez
Université d'Aix-Marseille, Institut Fresnel, Marseille

We compute the stationary solutions propagating in axis-invariant nonlinear waveguides. The nonlinearity is of focusing Kerr-type and the single frequency harmonic regime is assumed. The studied one dimensional cross-section waveguides are made of a Kerr-type nonlinear core sandwiched in a metal slot. Results for both isotropic and anisotropic nonlinear core are provided so as to provide state of the art results for the proposed benchmark. Our test examples use either a semi-analytical method taking into account only one component of the electric field in the nonlinear term, or more versatile ones, based on the finite element method with the Galerkin approach and the fixed power algorithm. For the results using the fixed power algorithm, the convergence criterium is defined and the convergence properties are described.
More details on the different methods used and their validations will be provided on posters, together with the generalization to the 2D full vector case.

17h00 – 18h40 Numerical modelling : softwares

17h00 – 17h20 : GetDP, Gmsh and ONELAB

Christophe Geuzaine
University of Liège, Dept. Of Electrical Engineering and Computer Science, Liège, Belgique

In this talk I will present an overview of the open source mesh generator Gmsh, the finite element solver GetDP and the user interface ONELAB. After an overview of the main philosophy of the software I will focus on how it can be used to solve waves problems in structured media, from small scale problems on laptop computers to petascale problems on HPC clusters. The presentation will end with an overview of the features planned for the next releases.
http://gmsh.info/
http://getdp.info/
http://onelab.info/

17h20 – 17h40 : An overview of SLEPc

Jose Roman
Universitat Politècnica de València, València, Spain

SLEPc, the Scalable Library for Eigenvalue Problem Computations, is a software library for the solution of large sparse eigenproblems on parallel computers. It can be used for the solution of linear eigenvalue problems formulated in either standard or generalized form, as well as other related problems such as the singular value decomposition. It can also be used to solve nonlinear eigenvalue problems, either polynomial, rational or more general ones. Finally, SLEPc provides solvers for the computation of the action of a matrix function on a vector. The talk will focus on solvers that are more relevant in the context of numerical methods for waves.
http://slepc.upv.es/

17h40 – 18h00 : DIOGENeS : une suite logicielle dédiée à la Nanophotonique computationnelle basée sur des méthodes Galerkin discontinues

Jonathan Viquerat and S. Lanteri
INRIA, NACHOS, Sophia-Antipolis

Les méthodes Galerkin discontinues ont fait l'objet de nombreux travaux ces 10 dernières années pour la résolution numérique des équations de Maxwell modélisant la propagation d'ondes électromagnétiques en interaction avec des milieux complexes. Elles sont particulièrement attractives en régime temporel et se présentent aujourd'hui comme une alternative intéressante aux méthodes FDTD (Finite Difference Time-Domain). Elles sont relativement flexibles vis-à-vis du maillage utilisé (qui peut être complètement non-structuré, voire non-conforme) et ne nécessitent pas l'inversion d'une matrice de masse globale lorsqu'elles s'appuient sur un schéma d'intégration en temps explicite. De plus, elles permettent de construire une approximation d'ordre élevé à support compact, possiblement adaptée localement en exploitant un critère approprié. Dans cet exposé, nous présenterons nos travaux visant au développement d'une suite logicielle dédiée à la simulation de problèmes d'interaction lumière/matière nanostructurée, basée sur différentes formulations de type Galerkin discontinu, pour la résolution numérique des équations de Maxwell 3d en régime temporel et en régime harmonique, couplées à des lois comportementales de matériaux d'intérêt pour des applications en nanophotonique / nanoplasmonique. Cette suite logicielle, nommée DIOGENeS est l'objet d'une Action de Développement Technologique d'Inria qui a démarré en décember 2015 et durera 3 ans.
https://diogenes.inria.fr/

18h00 – 18h20 : XLiFE++ : une librairie éléments finis FEM-BEM polyvalente

Eric Lunéville
ENSTA ParisTech, POEMS, Palaiseau

XLiFE++, whose name is the acronym for eXtended Library of Finite Elements in C++, is a multi-platform library dedicated to solve any PDE problem on any 1D, 2D or 3D mesh using FEM, BEM, or FEM / BEM coupling. XLiFE++ can solve stationary, harmonic or transient problems, bounded or unbounded problems using DtN operators or PMLs, essential conditions like Dirichlet, periodic, quasi-periodic or transmission conditions (actually, any set of linear essential conditions). In particular, it adresses scattering problems related to any kind of wave, in homogeneous or heterogeneous media (acoustic, electromagnetism, elasticity, …). Computation libraries proposing FEM, BEM both and such a various set of coupling tools are quite rare. XLiFE++ users have to write simple C++ programs, mainly describing approximation spaces and variational formulations, so that you can easily get started with it, without having a relative advanced background in scientific programming. Because its large capacities, some more complex applications or methods can be attacked: building large invisible obstacles in waveguides; implementing the Half-Space Matching Method for the diffraction by polygonal scatterers; coupling High-Frequency methods and Boundary Element techniques for scattering problems with several obstacles; studying Maxwell problems with sign-changing coefficients; …

XLiFE++ is developed since 2010, by a collaboration between POEMS team (ENSTA-ParisTech) and IRMAR team (Université de Rennes).

For more information: http://uma.ensta-paristech.fr/soft/XLiFE++/

18h20 – 18h40 : IF-DDA : un logiciel pour l'électromagnétisme basé sur la méthode des dipôles couplés

Anne Sentenac and Patrick Chaumet

CNRS, Institut Fresnel, Marseille

IF-DDA is a three-dimensional Maxwell Equation solver in a monochromatic experiment. IF-DDA is based on the DDA (discrete dipole approximation) which is a volume-integral equation method. The target is discretized into a set of small subunits and the field at each subunit position is computed through a self consistent equation. Once the field inside the target is known, the scattered Field is evaluated easily and rigorously via a Fourier Transform.

This method can be used to simulate the scattering by arbitrarily shaped, inhomogeneous, anisotropic particles. The radiation condition is automatically satisfied. The meshing is restricted to the volume of the scatterer, hence this method does not need any PML (perfect matching layer). As a result, it can simulate the scattering by very large targets (500 000 cubic wavelength).

IF-DDA has a friendly guide user interface where many particles (cuboid, sphere, ellipsoid, many spheres, ...), beams (plane wave, Gaussian wave, multiple plane waves, ...) are accessible with a drop-down menu. With a click one can choose to calculate the scattering cross section, the Poynting vector, the image in an optical microscope, the optical force and torque and of course the field inside the target. We hope you will enjoy (and use) this numerical tool !!!!

http://fresnel.fr/perso/chaumet/ifdda.html

https://github.com/pchaumet/IF-DDA

Mercredi 14 mars 2018

09h00 – 10h00 Spectral analysis of non-conventional systems

09h00 – 09h30 : A new complex spectrum related to invisibiliy in waveguides

Lucas Chesnel
INRIA, Centre de Mathématiques Appliquées, Palaiseau

We consider the propagation of waves in an acoustic waveguide with a defect (local perturbation of the wall, penetrable obstacle, ...). For this problem, it is well-known that they may exist non-trivial solutions of finite energy called trapped modes. A classical method to compute them consists in using Perfectly Matched Layers (PMLs) which boils down to make a complex change of variables. In this talk, we show that it is possible, by modifying the parameters defining the PMLs to compute a new complex spectrum, which includes, in addition to trapped modes, frequencies for which the obstacle is in some sense invisible to one incident wave.

09h30 – 10h00 : Curiosities about the spectrum of a cavity containing a negative material

Christophe Hazard
CNRS, POEMS, Palaiseau

We are interested in the spectrum of a bounded cavity partially filled with a negative material, that is, a dispersive material whose electric permittivity and/or magnetic permeability become negative in some frequency range. Using a simple scalar model (derived from Maxwell's equations), we show that contrarily to the case of a cavity filled with a usual dielectric, whose spectrum is purely discrete, the presence of a negative material is responsible for various unusual resonance phenomena related to various components of an essential spectrum. One of the main difficulty follows from frequency dispersion (the permittivity and permeability of a negative material necessarily depend on the frequency) which leads to a nonlinear eigenvalue problem. We show how to get rid of this difficulty using an augmented formulation technique which consists in introducing suitable additional unknowns.

10h00 – 10h40 Numerical modelling: benchmarks II

10h00 – 10h10 : Modélisation numérique de réseaux résonnants sub-longueur d'onde en cavité étendue

Anne-Laure Fehrembach
Université d'Aix-Marseille, Institut Fresnel, Marseille

Récemment, les CRIGF, pour Cavity-resonator-integrated grating filters sont apparus comme potentiellement très intéressants pour le filtrage en longueur d'onde. Ils présentent en effet des résonances spectralement très étroites excitables efficacement avec un faisceau focalisé. Ils se composent d'un réseau coupleur sub-longueur d'onde, d'une quinzaine de longueur d'onde de long, flanqué de deux réseaux de Bragg. La longueur totale de la structure est de l'ordre de 150 longueurs d'onde. De part leurs dimensions, la finesse de la structuration, et l'amplitude forte de la résonance, ce sont des composants relativement difficiles à modéliser. Nous comparerons la modélisation d'un CRIGF 1D (une direction d'invariance) par la méthode modale de Fourier (FMM), la méthode des éléments finis (FEM), la méthode des différences finies dans le domaine temporel (FDTD), et la méthode des dipôles couplés (DDA). Nous montrerons que parmi ces méthodes, seule la DDA permet de modéliser un CRIGF 2D (pas de direction d'invariance).

10h10 – 10h20 : Beyond the Drude model : simulating plasmonic structures with spatial dispersion

Antoine Moreau
Université Clermont Auvergne, Institut Pascal, Clermont-Ferrand

Drude's model is more than 100 years old, but it is still very accurate. The only experiment whose results could not be accurately predicted relying on Drude's model was published only 5 years ago. Now we have a more precise idea of why plasmonics structures may be sensitive to nonlocality. The excitation of a high-wavevector guided mode, like a gap-plasmon, is the guarantee that spatial dispersion will kick in. To demonstrate that this is actually the case, two simulations have to be compared : one with spatial dispersion, one without (ie with Drude's model only). Determining whether spatial dispersion has an impact on the response of a structure thus completely relies on simulation. We present a test case corresponding to an actual experiment, that has been published a few years ago. It requires to simulate the optical response of 65nm wide nanocubes, with rounded corners, strongly coupled to a metallic film - and using a hydrodynamic model to take spatial dispersion into account. Doing so is often not within the reach of standard codes. Relying on a DG solver made by the Nachos team from INRIA Sophia-Antipolis, we were able to obtain these results and think they can be used as a benchmark for simulation tools taking spatial dispersion into account.

10h20 – 10h30 : An efficient DDM with cross-points for the parallel finite Element solution of scattering problems

Axel Modave, collaboration with Christophe Geuzaine and Xavier Antoine
CNRS, POEMS, Palaiseau

Solving high-frequency time-harmonic scattering problems using finite element techniques is challenging, as such problems lead to very large, complex and possibly indefinite linear systems. Optimized Schwarz domain decomposition methods (DDMs) are currently a very promising approach, where subproblems of smaller sizes are solved using sparse direct solvers, and are combined with iterative Krylov subspace techniques.

It is well-known that the convergence rate of these methods depends on the transmission condition enforced on the interfaces between the subdomains. Local conditions based on high-order approximations of the free-space Dirichlet-to-Neumann (DtN) operator have proved well suited. However, a direct application of this approach for domain decomposition configurations with cross-points, where more than two subdomains meet, leads to disappointing convergence results.

We will present a novel strategy to efficiently address configurations with cross-points. Preliminary 2D results obtained with the GetDP and GetDDM environments will be proposed.

10h30 – 10h40 : Calculation of quasinormal modes in dispersive resonant structures

Christophe Sauvan
CNRS, Laboratoire Charles Fabry, Palaiseau

Interaction of light with optical micro and nanoresonators is often driven by the interaction with a few eigenmodes of the system. Because of the presence of energy dissipation (by absorption and radiative leakage), optical nanoresonators are non-Hermitian systems and their eigenmodes are quasinormal modes with a complex eigenfrequency (finite lifetime). They can be calculated either by looking for poles of the scattering matrix in the complex frequency plane or by solving an eigenvalue problem. However, in the case of dispersive structures such as plasmonic nanoresonators or photonic cavities with doped semiconductors, the eigenvalue problem becomes non-linear because of the frequency-dependence of the dielectric permittivity. In the frame of the ANR project Resonance, we propose a benchmark for the calculation of the quasinormal modes supported by a cylindrical nanopatch resonator made of a thin dielectric layer sandwiched between a gold substrate and a silver nanocylinder (structure with two different dispersive materials).

11h30 – 12h30 Numerical modelling of complex media I

11h30 – 12h00 : Rigorous modal analysis of plasmonic nanoresonators

Philippe Lalanne and Wei Yan, joint work with ANR resonance
CNRS, Laboratoire Photonique, Numérique et Nanosciences, Bordeaux

The control of light at the nanoscale is ultimately limited by our capability to engineer electromagnetic near-fields with several nanoresonances, enable energy transfers between them, and model how every individual mode precisely interfere to create new resonant states that overlap in space and energy. Resonance-state-expansion formalisms, a new path in nanoresonator modeling, overcome limitations of classical Maxwell solvers in terms of efficiency and physical insight, and have thus witnessed a tremendous attention in recent years. Here, by accounting for material dispersion with auxiliary fields, we considerably extend their capabilities, in terms of computational effectiveness, number of states handled and range of validity. We implement an efficient finite element solver to compute the resonance states all at once, and derive new closed-form expressions of the modal excitation coefficients for reconstructing the scattering fields. Together, these two achievements allow us to perform rigorous modal analysis of complicated plasmonic resonators, being not limited to a few resonance states, while enjoying remarkable computation speeds and straightforward physical interpretations. We particularly show that, when the number of states retained in the expansion increases, the formalism becomes exact and offers a solid theoretical foundation for analyzing important issues, e.g. Fano interference, quenching, coupling with the continuum, which are nowadays critical in nanophotonic research.
The work belongs to a large project supported by the ANR: http://www.lp2n.fr/resonance/
Recent publications by the group:

[1] W. Yan, R. Faggiani and P. Lalanne, *Modal analysis of plasmonic resonances*
https://arxiv.org/abs/1711.05011
[2] P. Lalanne, W. Yan, K. Vynck, C. Sauvan and J.-P. Hugonin, Accepted Laser & Photonics Rev., Review article, *Light interaction with photonic and plasmonic resonances*
https://arxiv.org/abs/1705.02433

12h00 – 12h30 : A brief review of methods for computing singular electromagnetic fields

Patrick Ciarlet
ENSTA ParisTech, POEMS, Palaiseau

When one is solving numerically the Maxwell's equations, in a nonsmooth and nonconvex bounded domain A of R^d (d = 2 ; 3), it is well-known that the electromagnetic _elds do not belong in general to the function space $H^1(A)^d$. This situation occurs even with smooth coefficients. In addition, the space of H^1-regular fields is not dense in the space of solutions. As a result, an H^1-conforming Finite Element Method fails, even with mesh refinement : the sequence of discrete solutions does not converge to the exact solution. The situation is completely di_erent than in the case of the Laplace problem or of the Lamé system, for which H^1-conforming discretizations converge to the exact solution. To cope with this di_culty and approximate accurately the electromagnetic fields, a number of approaches are possible. They can be roughly categorized as follows : either one computes explicitly the part of the solution that does not belong to $H^1(A)^d$; or, one can relax the measure of the fields. In the first part of this talk, we will recall the non-density result, and its numerical consequences. In the second part, we will describe some of the approaches that address the issue, by considering examples from the two categories, such as the Singular Complement Method, the Edge Finite Element Method, and the Weighted Regularization Method.

14h00 – 15h00 Numerical modelling of complex media II

14h00 – 14h30 : Formulations stables pour des ondes résonantes dans un plasma magnétisé

Martin Campos Pinto, joint work with Bruno Després and Anouk Nicolopoulos
Université Pierre et Marie Curie, Laboratoire Jaques Louis-Lions, Paris

The linearized cold plasma model is a powerful tool to study the anisotropic response of a magnetized electron plasma to an incident time-harmonic EM wave. In the context of fusion plasmas, it can be used to describe the resonant heating of the plasma, which corresponds to an energy transfer from the wave to the background ion bath in the limit of a vanishing ion-electron collisionality.
However at the mathematical level, the limit permettivity tensor presents singular terms which make the resulting Maxwell equation ill-posed : at zero collisionality, one loses both the integrability and the uniqueness of the solutions.
In this talk I will describe several techniques to construct new weak formulations of such singular wave equations. Our approach follows the limiting absorption principle and combines standard weak formulations of PDEs with properties of elementary special functions adapted to the singularity of the solutions, called manufactured solutions. The resulting formulations obtained by these means can be shown to be well-posed for the limit problem, and they are well suited for its numerical approximation by standard finite element methods.

14h30 – 15h00 : Stable perfectly matched layers for anisotropic metamaterials

Maryna Kachanovska, joint work with Eliane Bécache
INRIA, POEMS, Palaiseau

We consider the problem of the numerical simulation of the wave propagation in large (unbounded) 2D metamaterial media. In order to bound the computational domain, we will use the perfectly matched layer (PML) method. As it is well-known, the PML can exhibit instabilities when applied to models with anisotropy and/or dispersion, which is the case for metamaterials. For anisotropic metamaterial media, described by the Maxwell TM system with a diagonal tensor of the dielectric permittivity and scalar magnetic permeability, we will show how such instabilities can be overcome by the use of a new PML change of variables, adapted to the parameters of the model. The stability analysis is based on a novel (in the context of the PML analysis) Laplace domain technique, which can be easily extended to obtain the energy estimates for the resulting models.

15h00 – 16h00 Metamaterials II

15h00 – 15h30 : Modeling phononic crystals

Vincent Laude
CNRS, Institut FEMTO-ST, Besançon

Phononic crystals are artificial periodic structures that can alter efficiently the flow of sound, acoustic waves, or elastic waves. One of their most appealing property is the existence of complete band gaps, or frequency ranges for which the propagation of waves is forbidden. They are best characterized by their band structure, or the dispersion relation between frequency and wavenumber, often plotted in the first Brillouin zone of the crystal. In this talk, I will describe how Bloch waves and band structures can be obtained with finite element analysis, and discuss the specific issues that this problem raises : Bloch wave equations, weak forms, the coupling of elastic and acoustic waves, loss and the complex band structure of evanescent Bloch waves. Some open problems will be introduced as well, especially with regards to the description of surface waves and leaky guided waves. The talk will be completed by a poster discussing the stochastic band structure, a method specially conceived to answer the latter types of problems.

15h30 – 16h00 : PT symmetric scattering and acoustics

Vincent Pagneux
CNRS, Laboratoire d'acoustique de l'université du Maine, Le Mans

We consider the propagation of acoustic waves with viscous losses that can also gain energy due to interaction with a mean flow. More particularly, we show that the propagation of an acoustic wave in an airflow duct going through a pair of diaphragms, with balanced mean-flow-induced effective gain and loss, corresponds to a parity-time (PT) symmetric system. With a scattering matrix formalism, experimental results allow us to observe the properties which reflect the PT symmetry of the scattering acoustical system : the existence of spontaneous symmetry breaking with symmetry-broken pairs of scattering eigenstates displaying amplification and reduction, and the existence of points with unidirectional invisibility. Besides, we will also discuss how a the simple properties of a finite series of such PT symmetric cells can be used to enhance the effect of PT symmetry.

Résumés des Posters

Mardi 13 mars et Mercredi 14 mars 2018

Poster 1

Fast and adaptative boundary element methods for 3D acoustic and elastodynamic problems

S. Chaillat, F. Amlani, P. Ciarlet, F. Kpadonou, A. Loseille
POEMS, Palaiseau

The main advantage of the Boundary Element Method (BEM) [1] is that only the domain boundaries (and possibly interfaces) are discretized leading to a drastic reduction of the total number of degrees of freedom. In traditional BE implementation the dimensional advantage with respect to domain discretization methods is offset by the fully-populated nature of the BEM matrix, with set-up and solution times rapidly increasing with the problem size.

In the last couple of years, fast BEMs have been proposed to overcome the drawback of the fully populated matrix. The Fast Multipole Method (FMM) is a fast, reliable and approximate method to compute the linear integral operator and is defined together with an iterative solver. The efficiency of the method has been demonstrated for 3D wave problems. However, the iteration count becomes the main limitation to consider realistic problems.

Other accelerated BEMs are based on hierarchical matrices. When used in conjunction with an efficient rank revealing algorithm, it leads to a data-sparse and memory efficient approximation of the original matrix. Contrary to the FM-BEM it is a purely algebraic tool which does not require a priori knowledge of the closed-form expression of the fundamental solutions and it is possible to define iterative or direct solvers.

Mesh adaptation is an additional technique to reduce the computational cost of the BEM. The principle is to optimize (or at least improve) the positioning of a given number of degrees of freedom on the geometry of the obstacle, in order to yield simulations with superior accuracy compared to those obtained via the use of uniform meshes. If an extensive literature is available for volume methods, much less attention has been devoted to BEMs.

In this contribution, we give an overview of recent works to speed-up the solution of 3D acoustic and elastodynamic BEMs. More precisely, we will present

- some preconditioning technics for iterative solvers;
- iterative and direct solvers based on H-matrices [2];
- an *anisotropic metric-based mesh* adaptation technic [3].

References :

[1] M. Bonnet, *Boundary integral equation methods for solids and fluids*, John Wiley, 1995.

[2] S. Chaillat, L. Desiderio, P. Ciarlet*, Theory and implementation of H-matrix based iterative and direct solvers for Helmholtz and elastodynamic oscillatory kernels,* Journal of Computational Physics 351 (2017), pp 165-186.

[3] S. Chaillat, S. P. Groth, A. Loseille, *Metric-based anisotropic mesh adaptation for 3D acoustic boundary element methods*, submitted.

Poster 2

Analyse en couplage de modes de la « Symétrie Parité-Temps » dans un coupleur directionnel en cavité résonnante

Yann G. Boucher et Patrice Féron
Institut FOTON, Lannion

On considère un coupleur directionnel constitué de deux guides d'ondes monomodes en accord de phase (même partie réelle de l'indice effectif), l'un amplificateur et l'autre atténuateur. Lorsque le gain modal (alpha) de l'un est égal, en valeur absolue, aux pertes modales de l'autre, le système manifeste une intéressante propriété dite de "symétrie parité-temps" : bien que non hermitique, son opérateur d'évolution présente (sur une certaine gamme de fonctionnement) des valeurs propres réelles. En augmentant progressivement la valeur de alpha, on met en évidence un "point critique" pour lequel l'opérateur n'est pas diagonalisable, et au-delà duquel les valeurs propres deviennent complexes.

Nous avons recours au puissant formalisme du couplage de modes pour décrire un tel système-modèle. Nous présenterons quelques conséquences de ces effets subtils dans le cas où le coupleur est inséré dans une cavité résonnante : en particulier, nous établirons l'expression explicite de ses paramètres de répartition ainsi que son diagramme de fluence, récapitulatif de tous les chemins possibles d'un accès à un autre.

Poster 3

Producing regular structures through global optimization strategies

Antoine Moreau
Institut Pascal, Clermont Ferrand

For years now, optimization algorithms have been used in the field of photonics - quite a few specific algorithms have been designed explicitly for photonic structures. Yet, none of them has ever produced the kind of very regular architectures that can be found in nature. Using state-of-the-art optimization algorithms that have been tested on artificial problems, we have been able to retrieve some naturally occuring photonic structures. This suggest that i) an optimization producing messy results should not be considered as a successful optimization in photonics and ii) there is no need to invent algorithms specifically designed for photonics. That may even be detrimental to the process.

Poster 4

Towards a robust experimental evidence and calibration of spatial dispersion models

Nikolai Schmitt, Armel Pitelet, Dimitrios Loukrezis, Antoine Moreau, Claire Scheid, Stéphane Lanteri and Herbert De Gersem
NACHOS, Sophia-Antipolis

This contribution bridges theoretical predictions of spatially dispersive metals and experimental data. First, we have proposed a thorough protocol for model calibration purposes. The proposed strategy enables an a priori extraction of the spatial dispersion weighting parameter of a linearized hydrodynamic Drude-model for noble metals. The second result compares 3D full-wave simulations of rounded nano-cubes. In line with analytical gap plasmon theory, our simulation results predict a non-negligible impact of nonlocality for small gap sizes. Our contribution concludes with a very good agreement of 3D simulations and experimental data.

Poster 5

A continuation method for building invisible obstacles in waveguides

Antoine Bera
POEMS, Palaiseau

We are interested in building invisible obstacles in waveguides, at a given frequency. The invisibility is characterized by the nullity of the scattering coefficients associated to propagating modes. In previous papers, a method has been proposed to prove the existence of invisible obstacles and to build them. But its main drawback was its limitation to small obstacles. In order to get larger invisible obstacles, we have developed a new approach which combines the previous idea with a continuation method : we are building a sequence of invisible obstacles, each of them being a small perturbation of the previous one. This algorithm is based, at each step, on the ontoness of an application and on the fixed-point theorem. We have implemented the method in the finite element library XLiFE++, in the case of penetrable obstacles of a two-dimensional acoustic waveguide, in multi-modal regime. A remarkable result is that the ontoness condition can be ensured in many cases, so that the algorithm can be iterated as long as required. Another interesting feature of our approach is that it allows to prescribe some properties of the obstacle (shape of the obstacle, piecewise constant index, ...), but a drawback is that the algorithm can produce non-realistic negative indices. This is a question that we are currently working on. Finally, let us emphasize that the formalism of the method is very general and flexible. In particular, it can be directly extended to 3D waveguides, or to the scattering in free space.

Poster 6

Homogénéisation enrichie de l'équation des ondes en présence de bords

Clément BENETEAU, Sonia FLISS et Xavier CLAEYS
POEMS, Palaiseau

Nous nous intéressons dans ce poster à l'homogénéisation de l'équation des ondes dans un milieu périodique en présence de bords ou d'interface. Cette étude dans le cas d'un milieu périodique infini a déjà fait l'objet de plusieurs travaux. Ainsi on peut montrer que la solution de l'équation des ondes dans le milieu homogénéisé est proche en "temps court" de la solution du problème de départ quand la période est petite. Il s'avère qu'en "temps long", on observe une différence entre ces deux solutions qui est liée à la dispersion des ondes dans le milieu périodique qu'on ne retrouve pas dans le milieu effectif. Il a été démontré qu'on pouvait traiter ce problème en considérant un modèle homogénéisé enrichi qui fait intervenir, en plus du modèle homogénéisé, des opérateurs d'ordre 4 dont les coefficients sont calculés à partir de solutions de problèmes de cellules. Cet enrichissement du modèle est parfaitement adapté sauf en présence de bords où la précision est détériorée par ces derniers et où il faut trouver la condition adaptée à la nouvelle nature de l'équation.
En utilisant la méthode présentée par Sonia Fliss, nous proposons un modèle enrichi avec des conditions de bords adéquates. La définition de ce modèle nécessite la résolution de problèmes de cellules et de bandes périodiques.

Poster 7

Numerical study of Second Harmonic Generation in periodic poled waveguides with stitching errors

Carlos Montes, Pascal Baldi and Marc De Micheli
Laboratoire Physique de la Matière Condensée, Nice

Whatever be the chosen fabrication process, nonlinear waveguides realized in periodically oriented material such as Periodic Poled Lithium Niobate (PPLN) can present different stitching errors [1]. We perform a numerical study of the impact on the nonlinear performances (efficiency and spectral response) of one or several stitching errors occurring during the realization of the periodic domains by e-beam writing or by another method. In particular, this study shows that contrarily to what was expected, a single finite stitching error does not simply decrease the nonlinear efficiency, but splits the Second Harmonic (SH) signal into a double peak spectrum, where the position of the peaks and their width at half maximum depend not only on the poling period, the total length of the grating, and the waveguide parameters but also on the amplitude and the position of the defect.

[1] M. Neradovskiy, E. Neradovskaia, D. Chezganov, E. Vlasov, V. Ya. Shur, H. Tronche, F. Doutre, G. Ayenew, P. Baldi, M. de Micheli, and C. Montes, "Second harmonic generation in periodically poled lithium niobate waveguides with stitching errors".

Poster 8

Modal analysis of wave propagation in dispersive media

Mohamed Ismail Abdelrahman and Boris Gralak
Institut Fresnel, Marseille

The analytical treatment of wave propagation in dispersive media is restricted by the branch-cut in the integral expression of the wave function. Here, we establish a branch cut-free method using the modal analysis. Therefore, a closed-form expression for the transmitted field is derived in terms of discrete poles contributions. This substantially advances the physical interpretation of transient waves, where the different transient components are physically interpreted as the contributions of distinct sets of modes and characterized accordingly. Then, the modal expansion is used to derive an improved analytical expression of the Sommerfeld precursor that could efficiently describe the amplitude and the oscillating period up to the arrival of the Brillouin precursor. The proposed method and results apply to all waves governed by the Helmholtz equations.

Poster 9

Propagation des ondes mécaniques dans des milieux périodiques multi-hélicoïdaux

Changwei ZHOU[1], Fabien TREYSSÈDE[1], Patrice CARTRAUD[2]
1) IFSTTAR, GERS, GeoEND, Bouguenais. 2) GeM, Centrale Nantes, Nantes

L'objectif de ce travail est de modéliser la propagation des ondes élastiques dans des milieux périodiques multi-hélicoïdaux, constitués de deux couches de brins hélicoïdaux. Ce type de structure est rencontré dans les armures des câbles de transport d'électricité par exemple. Chacune des deux couches possède ses propres caractéristiques hélicoïdales et tourne en sens opposés, si bien que les symétries du milieu ne sont plus continues mais deviennent discrètes. Pour traiter le problème, un système de coordonnées curvilignes ayant deux directions hélicoïdales est proposé. On montre que le tenseur métrique associé à ce système est indépendant des deux coordonnées hélicoïdales. Ceci permet de définir des bases de projection, pour les champs de déplacement et de contrainte, dans lesquelles les conditions de Bloch-Floquet s'appliquent. Le système de coordonnées ainsi construit donne les surfaces de coupe de la cellule unitaire, qui est ainsi délimitée par deux surfaces non planes correspondant à des hélicoïdes (propres à chaque couche). La cellule ainsi obtenue, tridimensionnelle, est discrétisée par éléments finis. La démarche de résolution adoptée ensuite est celle de la méthode des éléments finis ondulatoires et aboutit au calcul des modes guidés dans le milieu.

Poster 10

Ion cyclotron hybrid resonances : mixed variational formulations for Maxwell's equations

Anouk Nicolopoulos
Laboratoire Jaques Louis-Lions, Paris

We study the propagation of a wave into a plasma to model the resonant heating of fusion plasma in a tokamak. It is a wave-particle model with Maxwell's equations with linear current for the electromagnetic phenomena and Newton's equation for the dynamic of the electrons. We want to neglige the viscosity parameter between ions and electrons, which should be very small at the core of the plasma, but this viscosity is regularizing the equations and putting it to 0 the solution is singular and there is no unicity to our solution. The problem is to characterize the physical solution at the limit, and to be able to approximate it numerically.
Applying a limiting absorption method, we first show that there exists a weak limit in H1 of the viscosity solution. Then we construct some functions mimicking the expected behaviour of our solution, which should have a 1/x singularity. Energy relations can then be derived, and lead to well posed (in the sense of existence and uniqueness) mixed variational formulations for the problem at the limit as well as for the problem with viscosity. These results will be illustrated by numerical simulations.

Poster 11

XLiFE++, a FEM/BEM multi-purpose library

Nicolas Kielbasiewicz
POEMS, Palaiseau

XLiFE++, whose name is the acronym for eXtended Library of Finite Elements in C++, is a multi-platform library dedicated to solve any PDE problem on any 1D, 2D or 3D mesh using FEM, BEM, or FEM / BEM coupling. XLiFE++ can solve stationary, harmonic or transient problems, bounded or unbounded problems using DtN operators or PMLs, essential conditions like Dirichlet, periodic, quasi-periodic or transmission conditions (actually, any set of linear essential conditions). In particular, it adresses scattering problems related to any kind of wave, in homogeneous or heterogeneous media (acoustic, electromagnetism, elasticity, …). Computation libraries proposing FEM, BEM both and such a various set of coupling tools are quite rare. XLiFE++ users have to write simple C++ programs, mainly describing approximation spaces and variational formulations, so that you can easily get started with it, without having a relative advanced background in scientific programming. Because its large capacities, some more complex applications or methods can be attacked: building large invisible obstacles in waveguides; implementing the Half-Space Matching Method for the diffraction by polygonal scatterers; coupling High-Frequency methods and Boundary Element techniques for scattering problems with several obstacles; studying Maxwell problems with sign-changing coefficients; …
XLiFE++ is developed since 2010, by a collaboration between POEMS team (ENSTA-ParisTech) and IRMAR team (Université de Rennes).
For more information: http://uma.ensta-paristech.fr/soft/XLiFE++/

Poster 12

Vers une approche aux modes quasi-normaux d'un système optique : de l'analyse complexe vers l'analyse spectrale

Lamis Al Sheikh
Institut de Mathématiques de Bourgogne, Université de Bourgogne, Dijon

Nous discutons les premiers éléments d'une approche pour étudier des aspects qualitatifs (et quantitatifs) des modes quasi-normaux d'un système optique. Dans un premier pas, et d'une perspective méthodologique, nous revisitons le traitement des modes quasi-normaux d'une équation d'onde à dimension 1 avec diffusion décrite par un potentiel d'interaction. En particulier, nous discutons l'expansion résonante (dans le temps) du champ de diffusion en modes quasi-normaux. Dans un deuxième temps, nous considérons le problème optique sans potentiel mais avec une permittivité dépendant de l'espace et la fréquence. Plus précisément, en développant la permittivité au premier ordre dans l'inverse du carré de la fréquence (dans le modèle de Drude), on revient au problème précédent avec potentiel et on explore la complétude des modes quasi-normaux. Finalement, dans un troisième pas, nous signalons l'existence des résultats généraux de l'analyse spectrale qui « généralisent » cette discussion (en termes d'un potentiel) aux dimensions impaires arbitraires.

Poster 13

Numerical method for multiple light scattering by complex nanostructured surfaces

Maxime Bertrand, Alexis Devilez, Jean-Paul Hugonin, Kevin Vynck et Philippe Lalanne
Laboratoire Photonique, Numérique et Nanosciences, Bordeaux

Disordered ensembles of resonant nanoparticles deposited on or embedded in optical thin-film stacks are expected to exhibit rich optical properties due to their high number of degrees of freedom, provided by the nanoparticles, their interaction with a structured environment, and their mutual interaction. The deployment of such complex nanostructured surfaces in photonics research and technology is contingent on the development of appropriate modeling tools to explore their optical phenomena and learn engineering them. While such tools exist for periodic structures, the modeling of complex nanostructured surfaces containing many nanoparticles and exhibiting both strong near-field interaction (e.g., between nanoparticles and an interface) and far-field interaction (e.g., between nanoparticles via the guided modes of a stack) has however remained largely elusive so far.

Here, we propose a numerical method that has the potential to solve this issue. In essence, our approach consists in finding a representation of an arbitrary nanoparticle by *only a few* numerical dipoles that reproduce accurately its scattered *near-field* for any excitation. We will present the first results of our research, highlighting some technical challenges in solving this inverse problem, and provide some perspectives for multiple scattering studies.

Poster 14

Outils mathématiques pour la description des ondes dans les milieux périodiques

J. Gazalet, S. Dupont, J.C. Kastelik
Institut d'électronique de microélectronique et de nanotechnologie, Université de Valenciennes et du Hainaut-Cambrésis

Un cristal photonique ou phononique est un milieu structuré présentant une modulation périodique de ses propriétés physiques. Cette modulation perturbe la propagation des ondes optiques ou élastiques, ce qui mène à un comportement particulier. L'effet de bande interdite par exemple, qui traduit l'incapacité des ondes optiques ou élastiques à se propager pour certaines plages de fréquences.
La formulation du problème de propagation des ondes dans les milieux périodiques mène à une équation différentielle partielle du second degré à coefficients périodiques. Différentes méthodes existent pour déterminer la structure des modes propres se propageant dans le matériau, certaines dans le domaine direct et d'autre dans celui de Fourier. Brillouin interprète la périodicité de la structure de bande à partir de la périodicité du cristal dans le domaine réel. Prolongeant la vision de Brillouin, nous présentons des outils de traitement numérique du signal développés dans le cadre de la théorie des distributions et nous appliquons ces outils au cas des ondes dans les milieux périodiques. Ces outils mathématiques s'avèrent être bien adaptés au traitement des ondes dans les milieux périodiques : ils préservent l'analogie mathématique avec la description physique de l'état cristallin. Cette adéquation entre l'outil mathématique et le modèle physique, quelle que soit la nature de l'onde, mène à des relations simples et explicites qui facilitent l'interprétation physique et qui précise la correspondance entre le domaine direct et de Fourier. Nous présentons à titre d'exemple un cas pratique de cristal phononique à deux dimensions et mettons l'accent sur les raccourcis appréciables apporté par la méthode et les avantages qu'elle procure pour l'interprétation physique des résultats.

Poster 15

Quasi-normal modes of a metallic wire grating

Alexandre Gras and Philippe Lalanne
Laboratoire Photonique, Numérique et Nanosciences, Bordeaux

Optical micro- and nano- resonators are widely used in modern photonic resonators. Their spectral responses are fundamentally driven by their innate resonances, called quasinormal modes(QNMs) which are characterized by complex frequencies. Due to their complex frequencies, the quasinormal modes of a system, that are excited by a driving field, decay in time due to power leakage or absorption. Here, using a rigorous modal analysis and COMSOL software, we can find the quasinormal modes of a one dimensional metallic grating whose permittivity is described by a Lorentz pole model, and we are able to reconstruct the scattered field of the system as a sum of its QNMs, as well as describe its spectral response with select QNMs.

Poster 16

Revealing the dispersion of phonons from stochastic excitation of wave propagation

Vincent Laude
Institut FEMTO-ST, Besançon

The band structure is a central concept in the field of phononics. Indeed, capturing the dispersion of Bloch waves gives invaluable information on allowed propagation modes, their velocity, the existence of local resonances, and the occurrence of band gaps. A band structure are usually obtained by solving an eigenvalue problem that is defined on a closed and bounded domain, resulting in a discrete spectrum. As the wavenumber is varied continuously, the eigenvalues form bands in the dispersion relation. There are at least two cases, however, that resist reduction to a linear eigenvalue problem : first, when dispersive material loss is taken into account and second, when the unit-cell of the crystal extends beyond any bound, as in the case of phononic crystal of holes or pillars on a semi-infinite substrate. We introduce a technique to obtain the phononic band structure that does not rely on searching for eigenvalues, but instead produces a mapping of the resolvent set in dispersion space. In spectral theory, indeed, the spectrum is the singular complement of the resolvent set in the complex plane. The idea is then to obtain the resolvent set of the dynamical Helmholtz equation as a function of wavenumber. The method has been implemented with finite element analysis and has been applied to several problems in phononic crystal theory. In the case of dispersive loss, the complex poles of the density of states give a direct account of propagation loss of each dispersion branch as a function of frequency and wavenumber. In the case of phononic crystals of finite-depth holes or of finite-height pillars sitting on a semi-infinite substrate, the dispersion inside the sound cone - or radiative region - is obtained and leaky guided waves can be identified.

Poster 17

Numerical modal analysis of dispersive and dissipative plasmonic structures.

Guillaume Demésy, Yoann Brûlé and Boris Gralak
Institut Fresnel, Marseille

Modal analysis is an essential tool since it straightly provides the lighting conditions under which a plasmonic structure can « sing ». Modes appear as solutions of source free Maxwell's equations. For dispersive and dissipative structures, the associated spectral problem is not standard, being generally non-linear in frequency and not selfadjoint. We developed and implemented a finite element formulation based on a Drude-Lorentz model for the involved materials permittivity and the so-called « Auxiliary fields formalism » to tackle this non standard eigenvalue problem. Results on 1D closed cavities and 2D metallic photonic crystals are provided.