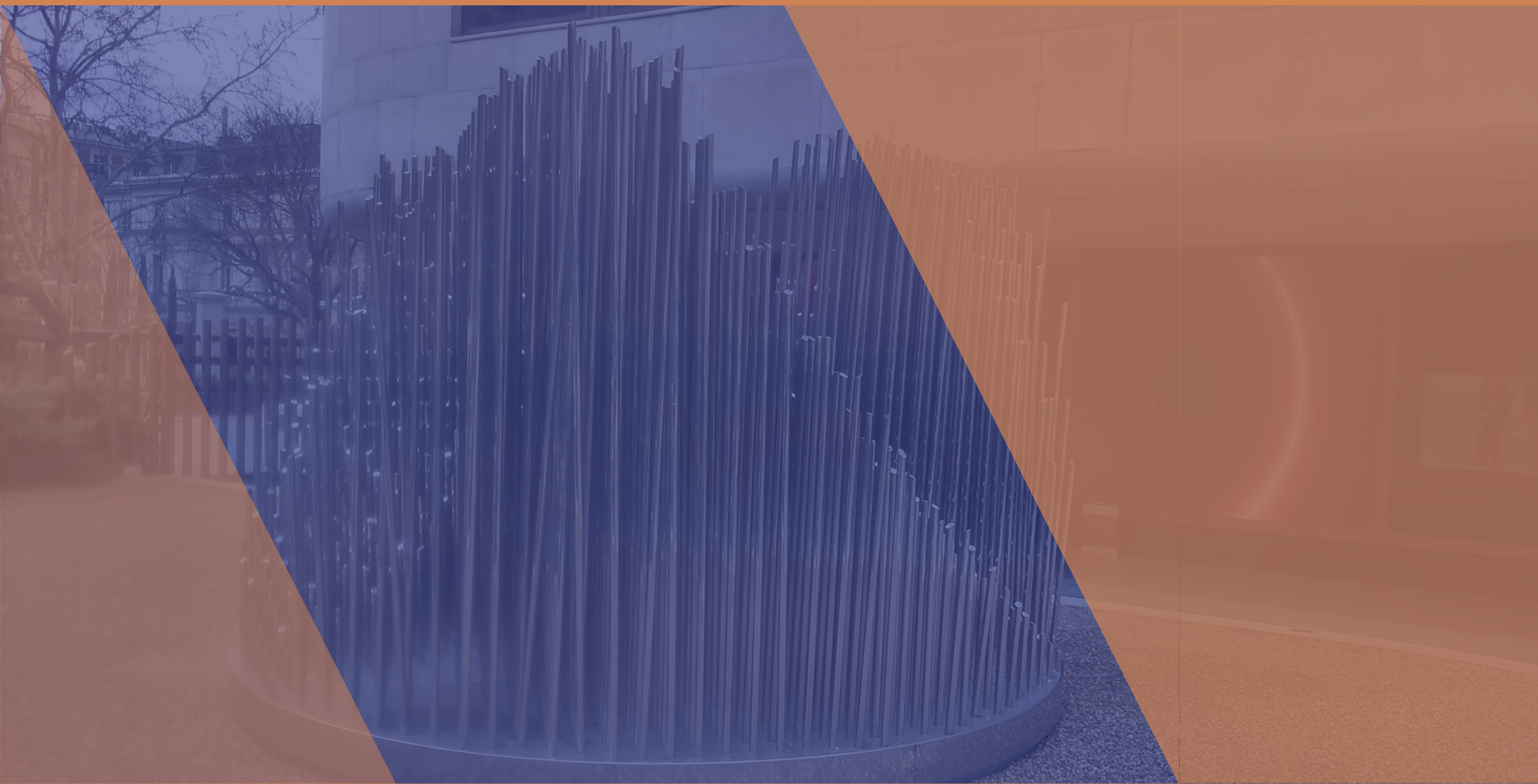
Symposium on Acoustic Metamaterials

09-11 October 2019, Ischia (Italy)



Book of abstracts

sam-2019@sciencesconf.org

http://sam-2019.sciencesconf.org

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Welcoming words

It is our great pleasure to wish you a warm welcome to this second Symposium on Acoustics Metamaterilas (SAM), co-organised by the Young Researchers in Acoustic Metamaterials (YRAM) network, COST Action DENORMS CA 15125, and the University of Salerno.

The Scientific Committee has prepared an exciting programme including 5 plenary and 32 regular presentations selected on a novelty basis.

Apart from the scientific content, the SAM also aims at networking in a friendly environment. Several social activities are scheduled all along the week. All the attendee are invited to join the visit of the Castle of Aragonese as well as the scientific dissemination event that will take place on Thursday 10th October afternoon. An extra social visit of the spectacular Naples undergrounds will be proposed on Saturday.

Finally, we would like to thank Andrea Bergamini, Richard Craster, Jean-Philippe Groby, Jensen Li, and Angela Madeo for having accepted to give a plenary talk. We would also like to thank all our sponsors, committee members, volunteers who have helped with the organization and make this edition possible.

Welcome to the volcanic island of Ischia. We hope you will have a very pleasant and fruitful time.

The organizing committee

Organizing Entities

Young Researchers in Acoustic Metamaterial network

Created under the impetus of the DENORMS Action CA15125, YRAM is a recently founded network dedicated to Ph.D. candidates and ECIs (Early Career Investigators) working on acoustic and elastic metamaterials and aims at enhancing collaboration between young researchers in this field.
Contact: yram.contact[at]gmail.com
Website: https://yramnetwork.wordpress.com.
YRAM is also on LinkedIn, Facebook and Twitter

University of Salerno

The University of Salerno is one of the largest universities in Southern Italy, with 17 departments and over 43,000 students. The Department of Civil Engineering has been active as a research structure in the University of Salerno since 1995, replacing the former Institute of Civil Engineering (established in 1983). It is composed of 15 scientific sectors, about 50 faculty members and deals with educational and research activities in the areas of Civil and Environmental Engineering.

DENORMS CA15125

DENORMS (Designs for Noise Reducing Materials and Structures) - CA 15125, is funded by the European Cooperation in Science and Technology (COST). DENORMS activities were launched on 9th March 2016 for 4 years. DENORMS aims at designing multifunctional, light and compact noise reducing treatments. In order to achieve this, DENORMS brings together skills and knowledge of the complementary, but still disconnected, communities of scientists working on acoustic metamaterials, sonic crystals and conventional acoustic materials across Europe and overseas. Our Action provides a framework for an efficient information exchange, helps to avoid duplication of research efforts and channel the work of groups involved in different projects towards our common goal. The participation of European companies in the network will facilitate the knowledge transfer from the academia to industry. Action page: https://denorms.eu

LAUM UMR CNRS 6613

The acoustic laboratory of Le Mans University is a Joint Research Unit of Le Mans University and the CNRS (UMR 6613).The laboratory's workforce is about 140 people (teacher-researchers, researchers, IATOS, ITA, doctoral students, post-docs and guests). The Laboratory's activities are mainly focused on acoustics "of the audible" but the laboratory has integrated in recent years new research topics in the field of vibrations and ultrasound.

Committees

Scientific committee

- Fernando Fraternali (University of Salerno, IT)
- Jean-Philippe Groby (LAUM, UMR CNRS 6613, FR)
- Marco Miniaci (EMPA, CH)
- Vicent Romero-García (LAUM, UMR CNRS 6613, FR)
- José Sanchez-Dehesa (Universitat Politècnica de València, ES)
- Daniel Torrent (Universitat Jaume I, ES)
- Olga Umnova (University of Salford, UK)
- Martin Wegener (Karlsruhe Institute of Technology, DE)

Organizing committee

- **YRAM**:
  - Giulia Aguzzi (ETH Zürich, CH)
  - Joseph Beadle (Exeter University, UK)
  - Eric Ballestero (London South Bank University, UK)
  - Barbara Cappello (Politecnico di Torino, IT)
  - Théo Cavalieri (LAUM, UMR CNRS 6613, FR)
  - Matthieu Malléjac (LAUM, UMR CNRS 6613, FR)
- **Local organisers**:
  - Ada Amendola (University of Salerno, IT)
  - Marco Miniaci (EMPA, CH)
- **DENORMS Action CA15125**:
  - Jean-Philippe Groby (DENORMS Chair)
  - Olga Umnova (DENORMS Vice-Chair)
  - Daniel Torrent (Working Group 1 Leader)
  - Paola Bertelli (LAUM, UMR CNRS 6613, FR)

Venue and practical information

Venue

The symposium will be held in Grand Hotel delle Terme Re Ferdinando, located near the port, the promenade of Via Roma and Corso Colonna and also the beach of San Pietro.

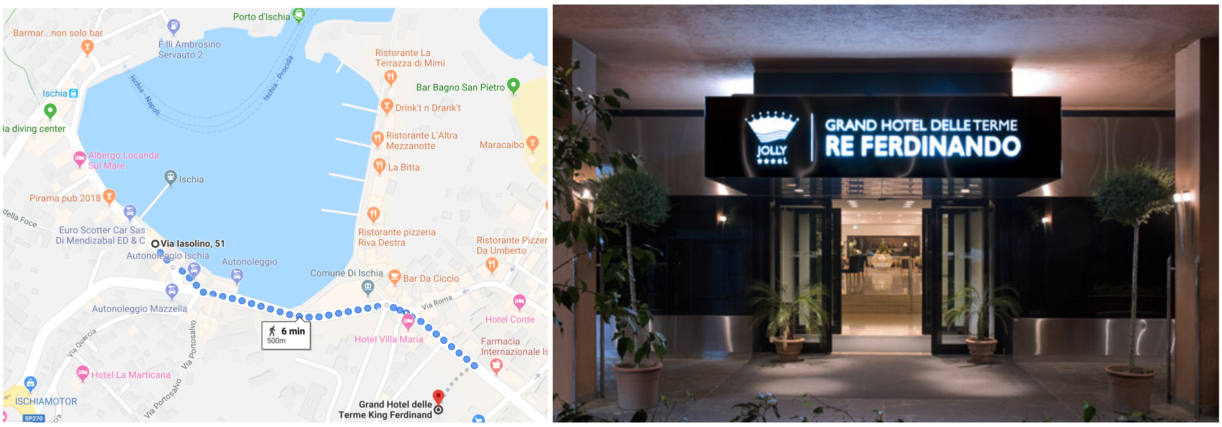


Figure 1: Location and photo of the conference venue

The wifi is accessible. The password will be given during the Symposium.

About Ischia

Ischia is a volcanic island in the Tyrrhenian Sea and the name of its main commune (5 in total). It lies at the northern end of the Gulf of Naples, about 30 km from the city of Naples. It is the largest of the Phlegraean Islands. More information is available on https://www.infoischia.com/.

How to reach Naples port from Napoli airport?

- by Alibus: The BUS takes 30 minutes. The fare is EUR. 5 one way. Tickets have to be ordered on board.
  - Napoli Capodichino Airport to Naples port:
    06:00 - 06:20 - 06:40
    07:00 - 07:15 - 07:35 - 07:55
    08:15 - 08:35 - 08:50
    09:00 - 09:15 - 09:30 - 09:45
    10:00 - 10:05 - 10:15 - 10:30 - 10:45
    11:00 - 11:15 - 11:30 - 11:35 - 11:45 - 11:55
    12:05 - 12:15 - 12:25 - 12:35 - 12:50 - 12:55
    13:05 - 13:15 - 13:25 – 13:35 - 13:45 - 13:55
    14:10 - 14:15 - 14:25 - 14:35 - 14:50
    15:00 - 15:15 - 15:30 - 15:40 - 15:45 - 15:50
    16:00 - 16:10 - 16:20 - 16:30 - 16:40 - 16:55
    17:00 - 17:05 - 17:20 - 17:30 - 17:40 - 17:55
    18:10 - 18:30 - 18:35 - 18:40 - 18:55
    19:10 - 19:25 - 19:45 - 19:50
    20:00 - 20:10 - 20:20 - 20:30 - 20:50
    21:00 - 21:15 - 21:40 - 21:55
    22:15 - 22:40
    23:00 - 23:20
  - Naples port to Napoli Capodichino Airport:
    05:30 - 05:50
    06:05 - 06:25 - 06:40 - 06:55
    07:15 - 07:35 - 07:55
    08:15 - 08:40
    09:00 - 09:15 - 09:30 - 09:45
    10:00 - 10:15 - 10:30 - 10:45 - 10:50
    11:00 - 11:15 - 11:30 - 11:40 - 11:55
    12:10 - 12:15 - 12:25 - 12:35 - 12:45 - 12:55
    13:05 - 13:15 - 13:30 - 13:35 - 13:45 - 13:55
    14:05 - 14:15 - 14:30 - 14:41 - 14:55
    15:00 - 15:05 - 15:15 - 15:30 - 15:40 - 15:51
    16:06 - 16:15 - 16:20 - 16:25 - 16:40 - 16:50
    17:00 - 17:10 - 17:25 - 17:40 - 17:46 - 17:50
    *18:00 - 18:10 - 18:25 - 18:35 - 18:45
    19:05 - 19:10 - 19:15 - 19:30 - 19:45
    20:00 - 20:15 - 20:20 - 20:30 - 20:40 - *20:50
    21:05 - 21:20 - *21:30 - 21:45
    22:10 - 22:25 - 22:45
    *23:10 - *23:25 - *23:50
    * !! From the port to the central station without reaching the airport !!
- by taxi: The TAXI takes 20 minutes. The fare is 19,00 euro. For those who are eligible for a grant, the taxi can only be reimbursed in the case of no public transport available. See more info in the section 5.1.4 (LOCAL TRANSPORT EXPENSES) of the COST Vademecum.

How to reach Ischia from Naples port

The Hydrofoil to ISCHIA leaves hourly and takes 50 minutes. The fare is around 20 euro one way. The following timetable is given as an information, it may change weekly. Please check out before planning your return.

- Naples to Ischia (Departure time (Ferry type, duration), Company - departure point, price 07:05-07:55, Napoli Beverello-Ischia , Alilauro, Escluso Sab. e festivi 07:35-08:25, Napoli Beverello-Ischia , Alilauro
  07:35-08:45, Napoli Beverello-Ischia-Forio , Alilauro
  08:25-09:25, Napoli Beverello -Procida-Casamicciola, Snav
  08:40-09:50, Napoli Beverello -Procida-Ischia , Caremar
  09:40-10:25, Napoli Beverello-Ischia,Alilauro
  09:40-10:50, Napoli Beverello-Ischia-Forio , Alilauro
  10:50-11:40, Napoli Beverello-Ischia , Alilauro
  10:50-12:00, Napoli Beverello-Ischia-Forio , Alilauro
  11:45-12:45, Napoli Beverello-Procida -Ischia , Caremar
  12:10-13:10, Napoli Beverello-Ischia , Alilauro
  12:30-13:30, Napoli Beverello-Procida-Casamicciola, Snav
  12:30-12:50 Procida-Ischia , Caremar
  12:55-13:40, Napoli Beverello-Ischia , Alilauro
  13:10-14:15, Napoli Beverello-Procida-Ischia , Caremar
  13:55-14:15 Procida-Ischia , Caremar
  14:35-15:20, Napoli Beverello-Ischia , Alilauro
  14:35-15:45, Napoli Beverello-Ischia-Forio , Alilauro
  14:45-15:50, Napoli Beverello-Procida-Ischia , Caremar
  15:30-15:50 Procida-Ischia , Caremar
  15:40-16:30, Napoli Beverello-Ischia , Alilauro
  15:40-16:40, Napoli Beverello-Ischia-Forio , Alilauro
  16:20-17:20, Napoli Beverello-Procida-Casamicciola, Snav
  17:20-18:10, Napoli Beverello -Ischia , Alilauro
  17:20-18:30, Napoli Beverello-Ischia-Forio , Alilauro
  17:55-19:00, Napoli Beverello-Ischia , Alilauro
  18:15-19:20, Napoli Beverello-Procida-Ischia, Caremar
  19:00-20:00, Napoli Beverello-Procida-Casamicciola, Snav
  20:20-21:05, Napoli Beverello-Ischia , Alilauro

- Ischia to Naples TimeTable Ferries and Hydrofoyls from Ischia to Napoli

  06:30-07:20, Ischia-Napoli Beverello, Alilauro
  06:45-07:50, Ischia-Napoli Beverello, Caremar
  06:45-07:50, Ischia-Napoli Beverello, Alilauro
  07:10-08:00, Ischia-Napoli Beverello, Alilauro
  07:10-08:15,Casamicciola-Napoli Beverello, Snav
  08:05 -09:05, Ischia -Napoli Beverello , Alilauro, Escluso Sabato
  08:05-08:45, Ischia-Napoli Mergellina , Alilauro, Escluso Sabato
  08:40-09:30, Ischia-Napoli Beverello , Alilauro
  09:15-10:15 Forio-Ischia-Napoli Beverello , Alilauro
  09:35-10:25, Ischia -Napoli Beverello , Alilauro
  09:45-10:45, Casamicciola-Napoli Beverello, Snav

10:15 -11:20, Ischia-Napoli Beverello, Caremar
10:40-11:40, Ischia-Napoli Beverello , Alilauro, Sabato, festivi e lunedì
11:45-12:35, Ischia -Napoli Beverello, Alilauro
13:00-14:00, Ischia-Napoli Beverello,Caremar
13:00-14:00 Forio-Ischia-Napoli Beverello , Alilauro
13:20-14:10, Ischia -Napoli Beverello , Alilauro
13:50-14:50 Casamicciola-Napoli Beverello, Snav
14:05-15:05, Ischia-Napoli Beverello , Alilauro
14:05 -14:45, Ischia -Napoli Mergellina , Alilauro
14:30-15:35, Ischia-Napoli Beverello,Caremar
15:40-16:30, Ischia-Napoli Beverello, Alilauro
15:55-17:00, Forio-Ischia-Napoli Beverello, Alilauro
16:15-17:05, Ischia-Napoli Beverello , Alilauro
16:25-17:25, Ischia-Napoli Beverello,Caremar
16:30-17:20 Forio-Napoli Beverello , Alilauro
16:50-17:40, Ischia -Napoli Beverello , Alilauro
17:40-18:35 Casamicciola-Napoli Beverello, Snav
17:50-19:00 Forio-Ischia-Napoli Beverello , Alilauro
18:10-19:00, Ischia -Napoli Beverello , Alilauro
18:50-19:40, Forio -Napoli Beverello , Alilauro
19:10-20:10, Ischia-Napoli Beverello , Alilauro
19:10-19:50, Ischia-Napoli, Mergellina

Information about the talks

Regular talks will be 20 min long. Therefore, 15 min presentation plus 5 min question is expected.
Plenary talks will be 1 hour long, with 45 min presentation plus 15 min question.
As it has been done during the first Symposium on Acoustic Metamaterials, the sessions will be chaired by PhDs and ECIs.

Speakers are asked to upload their presentation on the conference computer before the beginning of the session they intervene in.

The symposium will be video-recorded for dissemination purposes. The videos will then be uploaded on the DENORMS website as well as the slides. If you do not agree, please let us know.

Social activities

As mentioned previously, the workshop is also aiming at networking and fostering the community of young researchers. Several social activities are organised during the symposium:

- Social lunches:

  On Wednesday, Thursday, and Friday, lunches are proposed at a fixed amount of 23 Euro in the restaurant of the conference venue. These lunches have to be booked prior to the symposium beginning and have to be paid by cash at the registration desk the first day of the symposium. If you have any diet requirement, please let us know

- Social dinners:

  To end the day in a good way, we propose you to meet every evening in a different restaurant for social dinners. The dinners have to be booked prior to the symposium beginning and have to be paid by cash at the registration desk the first day of the symposium.

  On Wednesday evening, right after the last talk (5:45), a shuttle bus will drive us to a very famous Pizzeria in the center of the Island: Onda Verde. The pizza menu is 20 Euro.

  On Thursday evening, we planning to have dinner in Percaderia Ischitana (to be confirmed) with a menu at 20 Euro.

  Finally on Friday, let meet at Giardino Degli Aranci for a dinner-napolitan show (to be confirmed) with a menu at 23 Euro.

- Thursday afternoon:

  - Visit of the Aroganese castle 4:00-6:00 pm A guided tour of the Aragonese Castle (30 mn walk from Teatro Polifunzionale) is proposed.

  - Dissemination event 6:30-7:30

    After the delightful popularization conference proposed last year in Xatìva by Dr. Vicent Romero-García and AC-DX band, we decided to organize a new dissemination event on Thursday at 4 p.m. on the thematics "Tell me about Physics through movies" at Teatro Polifunzionale (Via delle Ginestre, 41 - 15 mn walk from the conference venue). Pupils from the local schools will take part of this event.

- Extra social day: Visit of Naples underground

  On Saturday, we propose to meet at 9:00 am in Ischia port to take a ferry to Naples or directly at Naples underground (https://www.napolisotterranea.org) in Piazza San Gaetano 68 – Naples.

  Please book and pay (9 Euro) this extra visit at the registration desk on Wednesday morning.

Timetable - 09 to 12 October 2019

Wednesday

8:45 am - 9:30 am	Registration / opening
9:30 am - 10:30 am	**Plenary lecture 1** Chair: M. Malléjac Andrea Bergamini
10:30 am - 10:55 am	Coffee break
10:55 am - 11:55 am	**Session 1-1** Chair: M. Malléjac 10:55 am: E. Glover 11:15 am: S. Bansal 11:35 am: O. Latcham
12:00 pm - 1:00 pm	**Session 1-2** Chair: D. E. Quadrelli 12:00 pm: N. Kherraz 12:20 pm: G. Chaplain 12:40 pm: B. Van Damme
1:00 pm - 2:00 pm	Lunch break
2:00 pm - 3:00 pm	**Plenary lecture 2** Chair: M. Rosendo-Lopez Jean-Philippe Groby
3:00 pm - 4:00 pm	**Session 2-1** Chair: M. Rosendo-Lopez 3:00 pm: T. Cavalieri 3:20 pm: J. Boulvert 3:40 pm: V. Romero-García
4:00 pm - 4:30 pm	Coffee break
4:30 pm - 5:20 pm	**Session 2-2** Chair: T. Cavalieri 4:30 pm: E. Ballestero 4:50 pm: M. Miniaci 5:10 pm: Z. Zang 5:20 pm: M. Gaborit
5:45 pm ...	**Social dinner** (bus departure at 5:45)

Thursday

9:30 am - 10:30 am	**Plenary lecture 2** Chair: G. Aguzzi Richard Craster
10:30 am - 10:55 am	Coffee break
10:55 am - 11:55 am	**Session 3-1** Chair: G. Aguzzi 10:55 am: D. Lee 11:15 am: R. Zaccherini 11:35 am: F. Zeighami
12:00 pm - 1:00 pm	**Session 3-2** Chair: E. Ballestero 12:00 pm: G. Aguzzi 12:20 pm: B. Ungureanu 12:40 pm: J. De Ponti
1:00 pm - 2:30 pm	Lunch break
2:30 pm - 3:30 pm	**Session 4** Chair: J. De Ponti 2:00 pm: G. Mensah 2:20 pm: B. Staples 2:40 pm: M. T. Noman
4:00 pm - 6:00 pm	**Visit of the castle**
6:30 pm - 7:30 pm	**Scientific popularization**
7:30 spm ...	**Social dinner**

Friday

9:30 am - 10:30 am	**Plenary lecture 2** Chair: M. Miniaci Jensen Li
10:30 am - 10:55 am	Coffee break
10:55 am - 11:55 am	**Session 5-1** Chair: M. Miniaci 10:55 am: M. Rosendo-Lopez 11:15 am: P. Gao 11:35 am: E. Riva
12:00 pm - 1:00 pm	**Session 5-2** Chair: J. Boulvert 12:00 pm: D. Tallarico 12:20 pm: M. Malléjac 12:40 pm: D. Enrico-Quadrelli
1:00 pm - 2:30 pm	Lunch break
2:30 pm - 3:30 pm	**Plenary lecture 5** Chair: G. Chaplain Angela Madeo
3:30 pm - 4:50 pm	**Session 6-1** Chair: G. Chaplain 3:30 pm: P. Neff 3:50 pm: S. Demiryurek 4:10 pm: G. Adamashvili 4:30 pm: R. Brandao
4:50 pm - 5:10 pm	Closing / Coffee break
6:30 pm ...	**Social dinner**

Saturday

9:00 am - 10:00 am	**Ferry to Naples**
10:00 am - 12:00 pm	**Free time Naples historic center**
12:00 pm - 1:30 pm	**Visit of Napoli's underground**

Plenary talks

ANDREA BERGAMINI

Laboratory for Acoustics/Noise Control, EMPA

Abstract:

From the point of view of a materials scientist, the present interest in phononic materials is a dream come true: We can easily test the lessons learned about the structure-properties relationship in materials without having to give too much thought about the thermodynamic and kinetic challenges that challenge 'classical' material synthesis. Moreover, in the spirit of the definition of atoms offered by Lapine and Tretyakov, we can introduce in our atoms and atomic links novel and unusual properties and functionalities that will help us synthesize useful phononic materials for engineering applications. This talk offer some examples, from a materials science perspective.

Curriculum Vitae

Dr. Andrea Bergamini is a Senior Scientist at the Laboratory for Acoustics/Noise Control. He received his doctoral degree in mechanical engineering work on the electrostatic modification of the mechanical properties of structures in 2009 and his Masters degree in materials science from ETH Zurich in 1994 with work performed at the University of Reading on mechanical properties of genetically modified tobacco plants. His scientific work from 2000 to 2005 was focused on the development of magnetic methods for the non-destructive evaluation of large diameter steel cables. Since 2003 he has been working on variable stiffness and variable damping structures based on electrostatic mechanical coupling of interfaces. His current activities span devices based on different types electromechanical coupling, with focus on vibration damping and adaptive structures, and structured material (metamaterials, phononic crystals) for wave propagation control. Since 2012 he is a Lecturer at the Swiss Federal Institute of Technology in the Department of Mechanical and Process Engineering, where he teaches a course on adaptive materials for structural applications.

RICHARD CRASTER

Department of Mathematics, Imperial College

Abstract: Elastic metamaterials and topological effects

This talk will review the field of elastic metamaterials, primarily from a personal perspective and place the field in the broader context of optical, electromagnetic and acoustic metamaterials. The difficulties of applying metamaterial ideas in the context of the full elastic equations will be discussed together with the potential and possible applications. Topological ideas have recently come to the fore in classical wave systems where ideas based upon concepts from topological insulators have become popular, here we will discuss their possible application to wave guiding and beam splitting in elastic systems.

Curriculum Vitae

Richard Craster is currently a Leverhulme Research Fellow and has just stepped down as Head of Department of Mathematics at Imperial College. He has been at Imperial since 1998 apart from holding a distinguished chair in Alberta, Canada, 2008-2010 returning to become Head of the Mathematics Department at Imperial. He is a Professor of Applied Mathematics and, in addition to being in the Mathematics Department is also a member of the Mechanical Engineering Department at Imperial College.

He is the co-director of the UK Acoustics Network (UKAN), chair of the special interest group in metamaterials. The network (www.acoustics.ac.uk). UKAN is a highly successful Network with 498 members (as per 9 January 2019). It consists of 12 Special Interest Groups which cover a majority of acoustics related research in the UK. Since its start in November 2017 and with under his co-leadership the EPSRC UK Acoustics Network has organised and run around 30 networking events which brought together and connected hundreds of people working in acoustics in industry and academia in the UK.

He is the co-editor, alongside Guenneau, of the first book on Acoustic Metamaterials published in 2012 by Springer, PI of an EPSRC Programme grant on the Mathematical fundamentals of Metamaterials, and recently co-editor of the volume on Elastic Metamaterials for the Handbook of Metamaterials. He has written over 150 research articles, has an h-index of 45 (according to google scholar), across a wide range of engineering, physics and mathematics, and has a wide range of collaborators nationally and internationally with several of the theoretical metamaterial designs now being built by experimental groups.

In industry he sits on the scientific advisory boards of the Smith Institute and Multiwave (an SME in metamaterials), has undertaken numerous industry consultancy and advisory roles. His research is mainly in the area of acoustic metamaterials, elastic wave propagation and fluid mechanics and ranges from theory through to experiments usually undertaken with collaborators in engineering and physics.

In teaching and education, he chaired the A-level Content Advisory Board for the Russell Group, for Mathematics, reporting to the Department for Education; this advice shaped the content of the current Mathematics A-levels. He currently chairs the A-level Mathematics contact group for ACME reporting to the Royal Society, and chairs the advisory board of Mathematics in Education and Industry a charity supporting mathematics teaching in the UK.

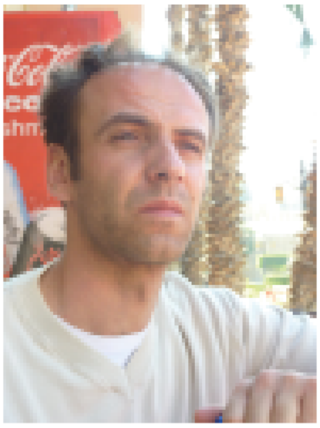
JEAN-PHILIPPE GROBY

LAUM UMR CNRS 6613

Abstract:

It is now widely accepted that structured materials exist in nature for optical or electromagnetic purposes, while being multifunctional. In acoustics (and elasticity), some structures are bio-inspired or human-modified but no natural acoustic metamaterial has yet been found to the author's knowledge. In this presentation, two structures will be investigated as possible candidates for natural acoustic metamaterials: straw balls, used for centuries as building materials mainly for thermal (and acoustic) insulation, and Aegagropilae, also known as posidonia balls.

Curriculum Vitae



Jean-Philippe Groby is CNRS researcher at the Acoustic Laboratory of Le Mans University (LAUM, UMR CNRS 6613) since 2009.

His research focuses on the design, characterization and application of complex structures primarily for the control of audible sound, e.g. metamaterials, metasurfaces, and metafluid. He is best known for his work in metaporous /metaporoelastic surfaces, which led to the creation of the Metacoustic company in 2015, and slow-sound metasurfaces for sound absorption and diffusion.

He has co-authored 2 book chapters and over 80 research articles, and is also co-inventor of 2 patents. He is currently Chair of the COST Action DENORMS and principal investigator of several research projects.

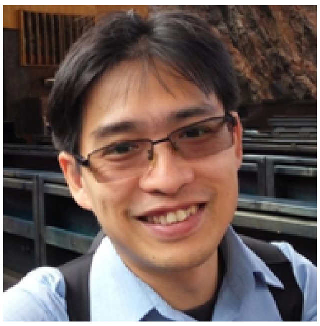
JENSEN LI

Hong Kong University of Science and Technology

Abstract: Space-coilin metamaterials: from negative refraction to generating wave illusion and Willis coupling

The concept of metamaterials has been successfully demonstrated in electromagnetism. The same concept has now been extended to acoustic waves both in fluid and in solid. Radically different designs of structural unit cells, surprisingly rich physics and applications arise. In the current talk, I will show that space-coiling structures can be an effective route for designing acoustic and elastic metamaterials with different examples. These structures simply route sound waves or elastic waves into curled propagation paths, enabling a non-resonant approach to a wide range of applications from super-resolution imaging, negative refraction, and zero-index tunneling. When these structures, being able to be straight-forwardly fabricated, are made to have varying structural parameters for different unit cells, the same route can be used to construct acoustic and elastic metasurfaces for manipulating wavefront and generating wave illusion. We will also discuss our recent progress on employing symmetry breaking on these metamaterial structures to realize Willis coupling for elastic waves in solid, that is the analogy of bianisotropy in electromagnetic waves.

Curriculum Vitae



Jensen Li is currently a professor in Hong Kong University of Science and Technology. Before joining HKUST at the end of 2017, he was a Reader in Photonics at University of Birmingham. His research revolves around various extraordinary wave phenomena given by metamaterials, with prominent examples such as invisibility cloaking and super-resolution imaging. His current interests are in transformation optics, metasurfaces, non-Hermitian optics and complex media. He is best known for his work in carpet cloak, and has authored 4 book chapters and over 70 research articles, with total citations over 6300. He is currently active on extending the concepts of metamaterials to acoustic and elastic waves.

ANGELA MADEO

INSA Lyon

Abstract: Towards the engineering design of metamaterials' structures through micromorphic enriched continuum modeling

n this talk, I will show how the relaxed micromorphic model, which I have contributed to pioneer, can be used to describe the dynamical behavior of anisotropic mechanical metamaterials. I will show to which extent the proposed model is able to capture all the main macroscopic dynamical characteristics of the targeted metamaterials, namely, stiffness, anisotropy, dispersion and band-gaps. The simple structure of our material model, which simultaneously lives on a micro-, a meso- and a macroscopic scale, requires only the identification of a limited number of frequency-independent parameters, thus allowing the introduction of pertinent boundary conditions to be imposed at macroscopic metamaterials' boundaries when the model is framed in the context of Variational Principles. I will show how this modelling approach can be applied to the study of the scattering properties of finite-size metamaterials' structures thus opening new perspectives for metastructural engineering design.

Curriculum Vitae

Angela Madeo is currently Full Professor at the GEOMAS Laboratory of the Institut National des SciencesAppliquées de Lyon. She obtained a Master of Science in Civil Engineering at the University of Rome "La Sapienza" (Italy) in 2005 and a second one in Engineering Science and Mechanichs at the Virginia Polytechnic Institute and State University (USA) in 2006. She obtained her PhD in Theoretical and Applied Mechanics at the University of Rome "La Sapienza" in 2009. She has been Associate Professor at INSA Lyon from 2010 to 2017. Her research expertise seats on the study of Enriched Models in Continuum Mechanics and their applicationsto mechanical metamaterials, as well as to other materials with heterogeneous microstructures. She is member of the prestigious Institut Universitaire de France since 2016, when she was nominated as junior IUF member for her ground-breaking research on enriched continuum modeling of metamaterials. She was recipient of the CNRS Bronze medal in 2015. She coordinates several research projects funded with National French grants (ANR), as well as European grants (RIA, Horizon 2020). She gives lectures in the Civil Engineering Departement of INSA-Lyon, mainly in the field of Applied Mathematics, Continuum Mechanics and Mechanical Behavior of Materials with Microstructure. She co-authored 60 papers in high-level international journals, she is author of a book on Generalized Continuum Mechanics and Engineering Applications, edited by ISTE Editions in 2015 and she has an H-index of 30 (according to Google Scholar). She is member of the Editorial board of 3 high level international journals in the field of Theorethical and Applied Mechanics

Regular talks:

Session 1-1
Wednesday 9 October
11:00-12:00

Tunable Magnetoelastic Phononic Crystals

Emily Glover * [1], Paul Keatley [1], Robert Hicken [1], Alastair Hibbins [1]

[1] School of Physics and Astronomy [Exeter] – Exeter, United Kingdom EX4 4QL, United Kingdom

Magnetoelastic amorphous ribbons exhibit resonant longitudinal modes that can be driven by external alternating magnetic fields. The lowest order resonant longitudinal mode frequency is inversely proportional to the length of the ribbon, and directly proportional to the speed of sound in the material. In this study we consider how the resonance frequency can be controlled by modifying the speed of sound. This can be achieved by periodically patterning the ribbon to create a two-dimensional phononic crystal. We have explored the effect of patterning on the dispersion of the modes supported, and show that a decrease in the phase velocity of the mode occurs as the radius of the hole is increased. We undertook experimental verification of this result using a vector network analyser, which drives a frequency swept radio frequency current through a solenoid to produce an alternating magnetic field that excites the ribbon. The experimental results are in good agreement with the simulated dispersion relations, and demonstrate that the phase velocity of the mode may be reduced within magnetoelastic phononic crystals, which in turn leads to a reduction of their resonance frequency. This allows the resonance frequency of the ribbon to be tuned to a desired frequency by tailoring the size and periodicity of the air-filled holes.

Keywords: magnetoelastic ribbons, phononic crystal, metamaterials

*Speaker

Magnetically Responsive Dynamic Acoustic Meta-cell

Shubhi Bansal * [1], Christabel Cho [1], Sriram Subramanian [1]

[1] University of Sussex – School of Engineering and Informatics, University of Sussex, Brighton- BN19RH, UK, United Kingdom

Background

The acoustic meta-cell, the building block of a meta-material, is a repetitive unit of a specially engineered material designed to control, direct and manipulate sound waves. Acoustic meta-materials define the future to implement acoustic wave manipulation for numerous operations like acoustic tweezing, levitation, cloaking, haptics and many others. Various acoustic metamaterials that use mechanisms such as coiling space1,2, multi-slits3,4, and Helmholtz resonance5–8 have been proposed in literature, however most of these structures are static and non-reconfigurable. The current focus is to fabricate a programmable acoustic meta-surface. Recently, tuneable cavities based Helmholtz resonators were proposed using a passive approach9 for modulating a 3 kHz acoustic wave.

Hypothesis

We propose a composite active sub-wavelength (40 kHz) acoustic meta-cell, which is programmable and dynamically reconfigurable, using magnetically actuated magnetite-PDMS beads for manipulating acoustic waves. The micron-sized ($< 5\ \mu$m) magnetite particles were mixed with the PDMS in a 1:1 ratio for making hemispherical magnetic PDMS beads. Our sub-wavelength meta-cell consists of a slit on a PET substrate which is tuned by moving the magnetic bead over it. A neodymium magnet with a cubic dimension of 4 mm was used to move the bead over the slit. The solid-air interface acts as a spatial sound modulator providing both amplitude and phase modulation.

Novelty

The proposed meta-cell is tuneable, compact, dynamic and programmable. It is controlled using the applied magnetic field. It is capable of spatial acoustic wave front engineering by functioning as an acoustic switch and barrier. Several meta-cells can be combined with multiple phased transducer arrays to provide more degrees of freedom and opens an opportunity to explore complex tuneable meta-material designs.

Keywords: subwavelength, acoustic metacell, switch, barrier, magnetic actuation

*Speaker

Hybrid magneto-acoustic metamaterials for ultrasound control

Oliver Latcham * [1], Yuliia Gusieva [2], Andrey Shytov [1], Oksana Gorobets [2], Volodymyr Kruglyak [1]

[1] School of Physics and Astronomy [Exeter] – Exeter, United Kingdom EX4 4QL, United Kingdom
[2] National Technical University of Ukraine "Kyiv Polytechnic Institute" [Kiev] – 37 Prospect Peremogy, Kiev 03056, Ukraine

We study a novel class of hybrid magnetoacoustic metamaterials in which the signal is carried by the acoustic wave while the applied bias magnetic field controls its propagation in finite sized, thin magnetic inclusions. The building block of this metamaterial is a thin magnetic slab (Fig.1) that features a resonant Kittel mode which can be tuned by biasing it with an external magnetic field. Embedding such a slab inside an elastic, non-magnetic matrix results in a Fano resonance in the reflection (Fig.2(a)) due to the slabs magnetoacoustic coupling. In a periodic array of such slabs, hybridization between magnetic and acoustic modes can be combined with the phononic band gaps (Fig.2(b)) to enhance the acoustic coupling to the Kittel mode. Through the decay channels available to the hybrid magnetoacoustic mode we introduce a figure of merit and use it to evaluate the performance of available magnetostrictive materials. We find the resonance to be particularly sensitive to the magnetic damping for physical systems, but may be enhanced in strength by introducing an oblique incidence to couple to unrestricted magnetization, increasing magnetoelastic coupling. We find significant enhancement when the Kittel mode is also tuned close to the phononic band gap due to the reduction of phonon group velocity. Significant enhancement can also be seen inside the band gap but is also accompanied by a suppression in reflectivity due to the production of slowly propagating magnetoacoustic modes, akin to slow light in electromagnetically induced transparency. We envision the frequency dependent magnetoelastic resonance to be incorporated in energy efficient magnetic computing devices, while retaining a level of tunability still relevant for use in acoustic frequency tuning devices and wave modulators.

Keywords: Magnetic phononic crystal, magneto, elastic waves

*Speaker

Session 1-2
Wednesday 9 October
12:00-1:00

Hybridization bandgap induced by an electrical resonance in piezoelectric metamaterial plates

Nesrine Kherraz * [1], Lionel Haumesser [2], Franck Levassort [2], Paul Benard [3], Bruno Morvan [3]

[1] ISEN – Institut supérieur de l'électronique et du nunérique (ISEN) – 41 Boulevard Vauban, 5900 Lille, France
[2] University of Tours, GREMAN, UMR CNRS 7347 – GREMAN, CNRS – UMR 7347, IUT de Blois – Blois, France – 03 Rue de la Chocolaterie, 41000 Blois, France, France
[3] University of Normandie, UNIHAVRE, Laboratoire Ondes et Milieux Complexes, UMR CNRS 6294 – Normandie Université, UniHavre, CNRS, LOMC, UM 6294 53, rue de Prony, 7608 Le Havre Cedex – 75 Rue Bellot, 76600 Le Havre, France, France

We demonstrate numerically and experimentally the opening of a locally resonant bandgap in an active phononic crystal (PC) made of a homogeneous piezoelectric plate covered by a 1D periodic array of thin electrodes connected to inductive shunts. The application of periodic electrical boundary conditions (EBCs) enables an at will tailoring of the dispersion properties of the PC plate, thus leading to a control of the dispersion of the propagating guided elastic waves in the plate. Depending on the nature of the EBCs, several bandgaps open up, the most important being a Hybridization Bandgap (HBG) in the subwavelength regime. The PC behaves as a locally resonant metamaterial. The HBG originates from the interaction of propagating elastic waves (Lamb modes) with an electrical resonant mode whose dispersion can be effectively described through an equivalent transmission line model.

Keywords: Tunable phononic crystals, piezoelectricity

*Speaker

Graded metasurfaces for wave manipulation: reversed conversion and flat lensing

Gregory Chaplain * , Richard Craster

Department of Mathematics [Imperial College London] (ICL) – Imperial College London, 180 Queenś Gate, London SW7 2AZ, United Kingdom, United Kingdom

Graded metasurfaces and meta-arrays have recently been designed to exhibit unprecedented control over surface waves, allowing rainbow trapping and mode conversion effects to be realised, through simple geometrical changes, in a variety of wave regimes. In this talk I will highlight a new reversed conversion mechanism discovered in thin elastic plates, and translate the ideas to elastic and electromagnetic systems with applications in flat lensing and focussing effects.

Keywords: Metasurface, Umklapp scattering, Flat lenses, Passive Phased Arrays

*Speaker

Wave dispersion in one-dimensional phononic quasicrystals

Bart Van Damme * [1], Louie Matar [2]

[1] Empa, Laboratory for Acoustics/Noise Control – Ueberlandstrasse 129, CH8600 Duebendorf, Switzerland
[2] Empa, Laboratory for Acoustics/Noise Control – Ueberlandstrasse 129 8600 Dübendorf, Switzerland

The dispersion of bending waves in beams with periodic scatterers, such as resonators, masses, or stiffness variations, is characterized by typical phononic crystal effects such as band gaps and pass bands with negative group velocity. Imperfections in the periodicity can destroy the band gaps since they introduce localized modes. However, breaking the translational symmetry can also lead to exotic topological wave modes with interesting applications. We introduce a deterministic aperiodic beam by superposing two non-commensurate periodic arrays of scatterers, namely point masses, spring supports, and stiffness changes. The dispersion of flexural waves in such a structure cannot be retrieved by using periodic boundary conditions in one dimension, but the problem can be defined as a cut of a two-dimensional periodic problem obeying Bloch-Floquet properties. This approach yields the dispersion relation, confirming the existence of localized modes, their shapes, and frequencies for all types of scatterers. Beams with quasiperiodic thickness variations exhibit band gaps at wave numbers k1 and k2, coinciding with the edges of the Brillouin zones of both periods. Additional band gaps are opened at linear combinations of k1 and k2, which can lead to lower frequency attenuation.

Keywords: phononic crystals, Bragg scattering, quasicrystals

*Speaker

Session 2-1
Wednesday 9 October
4:00-5:00

Acoustic wave propagation in effective graded fully-anisotropic fluid layers

Théo Cavalieri *† [1,2], Jean Boulvert [1,2,3], Logan Schwan [1], Gwenael Gabard [1], Jean-Philippe Groby [1], Vicent Romero-García [1], Jacky Mardjono [2], Marie Escouflaire [2]

[1] Laboratoire d'Acoustique de l'Université du Mans LAUM - UMR CNRS 6613 – Le Mans Université, Bât. IAM - UFR Sciences Avenue Olivier Messiaen 72085 LE MANS CEDEX 9, France
[2] Safran Aircraft Engines – SAFRAN (FRANCE) – Villaroche, France
[3] Laboratoire d'Analyse Vibratoire et Acoustique – Département de Génie Mécanique - École Polytechnique de Montréal - C.P. 6079 - Succ. Centre-ville - Montréal, Québec, H3C 3A7, Canada

This work deals with the modeling of sound wave propagation in anisotropic and heterogeneous media. The scattering problem considered in this work involves an infinite layer of finite thickness containing an anisotropic fluid whose properties can vary along the depth of the layer. The specular transmission and reflection of an acoustic plane wave by such a layer is modeled through the state vector formalism for the acoustic fields. This is solved using three different numerical techniques, namely the transfer matrix method, Peano series and the transfer Green's function. These three methods are compared to demonstrate the convergence of the numerical solutions. Moreover, the implemented numerical procedures allow to retrieve the internal acoustic fields and show their dependency along with the fluid's anisotropic properties. Results are then presented to illustrate the changes in absorption that can be achieved by tuning the anisotropy of the fluid as well as the variation of these properties across the depth of the layer. The results presented are in very good agreement across the different methods. Given that many porous materials can be modeled as equivalent fluids, the results presented show the potential offered by such numerical techniques, and can further give more insight on inhomogeneous anisotropic porous materials.

Keywords: acoustic control, anisotropic fluid, heterogeneous fluid, graded porous layer, absorption

*Speaker
†Corresponding author: theo.cavalieri@gmail.com

Numerical optimization method of continuously graded material

Jean Boulvert * [1,2,3], Théo Cavalieri [1,3], Josué Costa-Baptista [2], Logan Schwan [1], Vicent Romero-García [1], Gwénaël Gabard [1], Edith Fotsing [2], Annie Ross† [2], Jacky Mardjono‡ [3], Jean-Philippe Groby§ [1]

[1] Laboratoire d'Acoustique de l'Université du Mans LAUM - UMR CNRS 6613 – Le Mans Université, Bât. IAM - UFR Sciences Avenue Olivier Messiaen 72085 LE MANS CEDEX 9, France
[2] Laboratoire d'Analyse Vibratoire et Acoustique – Département de Génie Mécanique - École Polytechnique de Montréal - C.P. 6079 - Succ. Centre-ville - Montréal, Québec, H3C 3A7, Canada
[3] Safran Aircraft Engines – SAFRAN (FRANCE) – Villaroche, France

This work presents a numerical optimization procedure of continuous gradient porous layer properties to achieve perfect absorption under normal incidence. This design tool is applied on a graded porous medium composed of a periodic arrangement of ordered unit cells allowing to link the effective acoustic properties to its geometry. The best microgeometry continuous gradient providing the optimal acoustic reflection and/or transmission is designed via a nonlinear conjugate gradient algorithm. The acoustic performances of the so-designed continuous graded material are discussed with respect to the optimized homogeneous, i.e. non-graded, and monotonically graded material. The numerical results show an improvement of the targeted acoustic behavior when the properties are graded in comparison to both the non-graded and the monotonically graded materials. The results are validated experimentally on 3D-printed samples therefore confirming the relevance of such gradient along with the efficiency of the control of the entire design process.

Keywords: porous material, gradient, optimization, absorption, acoustics

*Speaker
†Corresponding author: annie.ross@polymtl.ca
‡Corresponding author: jacky.mardjono@safrangroup.com
§Corresponding author: Jean-Philippe.Groby@univ-lemans.fr

Perfect acoustic absorption in deep sub-wavelength structures for the ventilation problems

Vicent Romero-García *† [1], Noé Jiménez [2], Jean Philippe Groby [1], Olivier Richoux [1], Georgios Theocharis [1], Vincent Pagneux [1]

[1] Laboratoire d'Acoustique de l'Université du Mans LAUM - UMR CNRS 6613 – Le Mans Université, Bât. IAM - UFR Sciences Avenue Olivier Messiaen 72085 LE MANS CEDEX 9, France
[2] Instituto I3M – Universitat Poliècnica de València, Spain

In this work we report a mechanisms providing symmetric perfect acoustic absorption by sub-wavelength structures in the ventilation problem. While in the problem of reflection the mechanism consists in critically coupling a single reso- nance independently of its nature, the problem of transmission becomes more complicated and a degenerate resonator with symmetric and antisymmetric resonances should be designed with both resonances critically coupled. The system analyzed in this work is made by a panel with a periodic distribution of slits, the upper wall of which are loaded by Helmholtz Resonators. The propagation in the slit is highly dispersive due to the presence of the resonators, producing a slow sound propagation before the resonance, and down shifting it to low frequencies. By controlling the geometry of the resonator, the visco-thermal losses can be tuned in order to compensate the leakage of the system and fulfill the critical coupling condition so activating the perfect absorption of sound. In the case of transmission, a double slit is needed, one acting as symmetric and the other one as antisymmetric resonators.

Keywords: Acoustic Metamaterials, Perfect absorption, Critical coupling, Degenerate resonators

*Speaker
†Corresponding author: vicente.romero@univ-lemans.fr

Session 2-2
Wednesday 9 October
5:30-7:00

Experimental Validation of a 3D-Printed Quadratic Residue Metadiffuser

Eric Ballestero * [1], Noé Jiménez [2], Jean Philippe Groby [3], Stephen Dance [1], Haydar Aygün [4], Vicent Romero-García [3]

[1] The Acoustics Group, London South Bank University – 103 Borough Road, London SE1 0AA, United Kingdom
[2] Instituto de Instrumentación para Imagen Molecular, Consejo Superior de Investigaciones Científicas (CSIC), Universitat Politècnica de València – Camino de Vera s/n, 46022 València, Spain
[3]Laboratoire d'Acoustique de l'Université du Mans LAUM - UMR CNRS 6613 – Le Mans Université, Bât. IAM - UFR Sciences Avenue Olivier Messiaen 72085 LE MANS CEDEX 9, France

At the previous 2018 Symposium on Acoustic Metamaterials in Xátiva, the importance of acoustic diffusers and metadiffusers was discussed in the context of room acoustics. Different from standard diffusers, metadiffusers are based on locally resonant materials; a strategy first used to design deep-subwavelength absorbers making use of the slow sound induced by the strong dispersion introduced by the resonant building blocks. As such, instead of focusing on absorptive or transmitting properties, metadiffusers emphasize on obtaining a uniform angular scattering distribution. This is accomplished using a slotted panel with thin slits, each one loaded with a set of Helmholtz resonators. Such structures are of particular interest due to their particular scattering patterns, that can be designed on demand by optimizing the geometry of the metamaterial. The deep-subwavelength nature of these metasurfaces can lead to dimensions 20 to 46 times smaller than the design wavelength, i.e. about a 1/20th to 1/10th of the thickness of traditional phase grating designs. A specific design of a Quadratic Residue metadiffuser will be herein studied through an experimental validation of the 3D-printed structure, leading to a discussion on the potential applications of such metasurfaces in critical listening environments.

Keywords: metadiffuser, deepsubwavelength, metasurface, scaterring

*Speaker

Bio-inspired hierarchical metamaterials

Marco Miniaci * [1]

[1] Laboratoire Ondes et Milieux Complexes (LOMC) – Centre National de la Recherche Scientifique : UMR6294, Université Le Havre Normandie – 75 Rue Bellot Le Havre, France

Hierarchical structures with constituents over multiple length scales are found in various natural materials like bones, shells, spider silk and others, all of which display enhanced quasistatic mechanical properties, such as high specific strength, stiffness, and toughness. At the same time, the role of hierarchy on the dynamic behavior of metamaterials remains largely unexplored. This study numerically and experimentally assesses the effect of bioinspired hierarchical organization as well as of viscoelasticity on the wave attenuation properties of continuous elastic metamaterials. Results highlight a number of advantages through the introduction of structural hierarchy. Band gaps relative to the corresponding nonhierarchical structures are mostly preserved in both types of structures, but additional hierarchically-induced band gaps also appear, and the hierarchical configuration allows the tuning of band-gap frequencies to lower frequencies in the crosslike porous geometry, with a simultaneous significant reduction of the global structural weight.

Keywords: Bio, inspiration, hierarchical phononic crystals and metamaterials

*Speaker

Acoustic metasurface for broadband, wide angle of incidence sound absorption via wave manipulation in a sound transmission context

Ze Zhang * [1], Elke Deckers [2], Claus Claeys [2], Wim Desmet [2]

[1] Department of Mechanical Engineering, KU Leuven – Department of Mechanical Engineering, division PMA, KU Leuven, 3000 Leuven, Belgium., Belgium
[2] Department of Mechanical Engineering, KU Leuven – Department of Mechanical Engineering, division PMA, KU Leuven, 3000 Leuven, Belgium., Belgium

This paper aims to achieve broadband sound absorption for a wide range of angle of incidence in a sound transmission context by means of an acoustic metasurface. Hence, the proposed solution is suitable for applications requiring ventilation, where a rigid backing is undesirable.
The metasurface proposed in this work utilizes the Generalized Snell's Law to maximize the absorption coefficient over a broadband frequency range. Firstly, the analytical expression of the phase of both reflection and transmission coefficient of one cell for acoustic plane wave incidence is derived and validated numerically. Moreover, based on the aforementioned model, a unit cell consisting of multiple cells with different geometries is designed.
The design is numerically validated, showing very high absorption with a bandwidth of over 1500 Hz and angle of incidence range of over 120 degrees (symmetric in terms of normal incidence). Additionally, the metasurface is analyzed from a critical coupling point of view, where the presence of the critical coupling condition is confirmed and is found to be induced by the acoustic short-circuiting at the incidence surface.
Compared to existing designs, the proposed design possesses the advantage of being able to address both reflection and transmission, very broadband for absorption and very robust regarding the angle of incidence. Our work opens new ways of addressing reflection and transmission, enabling promising device applications in acoustics and related fields.

Keywords: acoustic meta, surface, generalized snell's law, wave manipulation

*Speaker

Merging acoustic film characterisation data and full system responses for efficient envelope determination

Mathieu Gaborit * [1,2], Olivier Dazel [1], Peter Göransson [2], Luc Jaouen [3]

[1]Laboratoire d'Acoustique de l'Université du Mans LAUM - UMR CNRS 6613 – Le Mans Université, Bât. IAM - UFR Sciences Avenue Olivier Messiaen 72085 LE MANS CEDEX 9, France
[2] Marcus Wallenberg Laboratory – Teknikringen 8D, SE 100 44, Stockholm, Sweden, Sweden
[3] Matelys – Matelys – 7 rue des Maraîchers Bâtiment B 69120 Vaulx-en-Velin, France

In a large number of poroelastic laminates used as acoustic absorbers, the top-most layer is a very thin poroelastic film or screen that allows to tune the system's response, protect the system or adjust its appearance. The films are often subject to uncertainties which in turns might lead to large variations of the laminates' response. In this work, the link between uncertainties in the film and the effect on the response of the whole system is established for each of the possible parameters. Based on these relations, this work introduces a technique to combine a statistical characterisation of the film and a single measurement of the assembled system to estimate envelope responses. It is shown that the resulting envelopes are fast to compute and accurate with respect to the responses of a large number of samples from the complete laminate. The approach is validated on numerical results and on experiments. A large number of film and laminate samples are measured to assess the accuracy of the method and support the claims of variability of the films' parameters.

Keywords: acoustic, film, envelope, uncertainties

*Speaker

Session 3-1
Thursday, 10 October
11:00-12:00

Seismic phononic crystals by elastodynamic Navier equation

Dongwoo Lee * [1]

[1] Pohang University of Science and Technology – POSTECH77 Cheongam-Ro. Nam-Gu. Pohang. Gyeongbuk. Korea 3, South Korea

The phenomenon, known as complete band gap in photonic crystals consisting of periodically arranged man-made nano structures, caused a huge sensation in photonics. Inspired by the physical methodology, we extend it to large-scale wave propagation for seismic waves. In particular, we exploit the elastodynamic Navier equation in the media for seismic phononic crystals inducing complete band gaps of primary (P) and secondary (S) waves. The technique via weak formulation for analysis of band structures is also shown. In addition, following the estimation of evanescent modes for complex-valued wavevector, it gives rise to propagation length and we redesign the phononic crystals into miniaturized one as thin as possible. We also investigate the material property dependency for the relation between eective particle velocity and propagation length. This study would be more contributed to seismic-resistant technique in seismology.

Keywords: Phononic crystals, Band, gap, Weak formulation, Propagation length

*Speaker

Elastic metasurfaces for shear waves control

Rachele Zaccherini * [1], Andrea Colombi [1], Antonio Palermo [2], Vasilis Dertimanis [1], Alessandro Marzani [2], Eleni Chatzi [1]

[1] ETH Zürich – Stefano-Franscini-Platz 5, Switzerland
[2] University of Bologna – Viale del Risorgimento 2, Bologna, Italy

Elastic metasurfaces composed of arrays of subwavelength mechanical oscillators located at the free surface of an elastic medium have been proposed to manipulate the propagation of surface waves at diverse length scales. In particular, metasurfaces of vertical resonators embedded in homogeneous elastic substrates can forbid the propagation of in-plane polarized waves, i.e., Rayleigh waves, generating bandgaps at specific frequencies. This ability has led to emergence of a new research area, which focuses on the design of meter-scale metasurfaces to shield buildings and infrastructures from undesired ground-borne vibrations. In this work, we investigate experimentally and numerically the interaction between a metasurface of horizontal resonators with polarized shear waves localized at the surface of a granular medium with an inhomogeneous depth-increasing elastic profile. A strong hybridization between the fundamental SH mode and the mechanical oscillators occurs and a frequency zone of quasi-zero displacements is found in proximity of the resonant frequency of the metasurface. Our outcomes reveal that SH waves, impinging the horizontal resonators, are steered downwards and channeled between the resonant boundary and the in-depth stiffer layers. Finally, we study the dynamic of these SH waves when traveling through a resonant metasurface of increasing frequency, shortly referred to as ”inverse metawedge". We numerically show how the stiffness gradient induced by gravity in granular substrates impedes the surface-to-shear wave-conversion phenomenon, preserving the wave localization at the surface.

Keywords: Surface wave attenuation, Elastic metasurfaces, Metamaterials

*Speaker

Rayleigh waves bandgap tuning via inertial amplified metasurfaces

Farhad Zeighami * [1], Antonio Palermo [1], Alessandro Marzani† [1]

[1] 1Department of Civil, Chemical, Environmental, and Materials Engineering - DICAM, University of Bologna – Viale Risorgimento, 2 - 40136, Bologna, Italy

Elastic metasurfaces are thin interfaces composed of locally resonant structures placed at the free surface or across the boundaries of elastic waveguides [1]. The units which form this interface have sub-wavelength feature size and exploit their resonances to manipulate the dispersive properties of the hosting medium. When metasurfaces are constructed over an elastic half-space, they can be used to control the propagation of Surface Acoustic Waves. In particular, the collective resonant modes of the metasurface can open narrow bandgaps in the spectrum of Rayleigh Waves, which are filtered out as shear modes propagating in the medium bulk [2,3].
One of the current limitations in the exploitation of such resonant band gaps is the need for large masses to widen their bandwidth. To overcome this drawback, we here investigate the possibility of designing an inertial amplified mechanism able to tune the natural frequency of the metasurface resonators. Our resonant unit exploits two lateral inerters, i.e., kinematical devices made by two inclined rigid links connected to an additional mass to modify the inertia of the resonator.
After discussing the dynamic of the proposed resonator, here named as the Inertial Amplification Resonator (IAR), we unveil the properties of a metasurface composed by an array of IARs. By employing an effective medium approach [4], we investigate the interaction between Rayleigh waves and the metasurface deriving its closed-form analytical dispersion law. We show that the dynamic response of inertially amplified metasurfaces can be controlled by the added mass and geometrical configuration of the IARs and highlight the possibility of shifting the bandgap spectrum of the metasurfaces by modifying their design parameters without changing the mass and stiffness of the oscillators. We take advantage of the tunability feature of inertially amplified metasurfaces for designing multi-frequency (metawedges) metasurfaces to achieve broadband attenuation of Rayleigh waves [5]. We analyze the transmission performance of the metasurface using 2D FE simulations and confirm the analytical predictions.

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Keywords: Elastic Metasurfaces, Rayleigh waves, Inertial amplification resonator

*Speaker
†Corresponding author: alessandro.marzani@unibo.it

Session 3-2
Thursday 10 October
12:00-1:00

Design of layered base foundations for elastic wave mitigation in buildings

Giulia Aguzzi *† [1], Panagiotis Martakis‡ [1], Andrea Colombi§ [1], Eleni Chatzi¶ [1]

[1] Institute of Structural Engineering (IBK) - ETH Zürich – Stefano-Franscini-Platz 5, 8093 Zürich, Switzerland

The effect of seismic excitations and ground vibrations on the structural performance of buildings has always been a controversial topic. Existing practical solutions envisage the adjustment of anthropic vibration sources, the strengthening of structural members and the employment of passive or active protection systems. In this project, we propose an innovative type of composite foundation intended to protect newly constructed buildings and address the drawbacks of traditional measures. Its particular design, comprising alternated layers of lead rubber bearings and reinforced concrete blocks, ensures the dual function of retaining vertical bearing capacity and attenuating elastic wave propagation. Indeed, the vibration remains localized at the level of the foundation and it is significantly dissipated before reaching the superstructure. This study focuses on the investigation of seismic wave transmission and mitigation through the designed foundation by means of a dedicated software for elastic wave propagation. By performing 3D time-domain numerical simulations we are able to analyze the effect of various influencing factors (e.g. soil type, source directivity) which are normally disregarded by traditional structural engineering software.

Keywords: elastic wave attenuation, layered foundations.

*Speaker
†Corresponding author: aguzzi@ibk.baug.ethz.ch
‡Corresponding author: martakis@ibk.baug.ethz.ch
§Corresponding author: colombi@ibk.baug.ethz.ch
¶Corresponding author: chatzi@ibk.baug.ethz.ch

The interaction of large scale metamaterials with seismic and elastic surface waves

Bogdan Ungureanu * [1], Sébastien Guenneau [2], Stephane Brule [2], Richard Craster [3]

[1] Imperial College London – South Kensington, London, United Kingdom
[2] Institut FRESNEL – Aix Marseille Univ, CNRS, Centrale Marseille, Institut Fresnel, – 13013 Marseille, France
[3] Imperial College London (ICL) – South Kensington, London, United Kingdom

The idea of implementing the effective properties of the large scale metamaterials for the seismic protection of the urban infrastructure is a consequence of the fact that they allow an impressive control of the energy transported by elastic waves.
A significant substitution of soils by inclusions, acting as foundations, raises the question of the effective dynamic properties of these structured soils. We investigate the seismic wave trajectories in soils structured with some elements of different geometries. Buildings, in the case of perfect elastic conditions for both soil and buildings, are shown to interact and strongly influence elastic surface waves; such site-city seismic interactions, and we investigate a variety of scenarios to illustrate the variety of behaviours possible. The challenge now is to imagine other possibilities to apply the effective properties of metamaterials at a very large scale for the seismic protection, and for us, another promising method to produce a change of the seismic reverberations is the creation of an artificial anisotropy by including, into the soil, some elements of different geometries, which are either full or empty.
We would like to push this analogy one step further by designing new cities of the future thanks to transformed urbanism, metacities that could protect themselves just by the spatially varying index. This model consists in a square network of streets and structures that we transform into a quasi-conformal network.
So our last results are about analysing this type of SIDE CITY INTERACTION, in the context of earthquakes of small amplitude (without going out from the linear elasticity domain) and we characterised the differences between shielding vs concentration vs cloaking effects.

Keywords: Seismic metamaterial / Site, City Interaction / Elastic Cloaking

*Speaker

GRADED METASURFACE FOR ENHANCED SENSING AND ENERGY HARVESTING

Jacopo M. De Ponti *† [1], Andrea Colombi [2], Raffaele Ardito [1], Francesco Braghin [3], Alberto Corigliano [1], Richard V. Craster [4]

[1] Politecnico di Milano – Dept. of Civil and Environmental Engineering, Piazza Leonardo da Vinci, 32, 20133 Milano MI, Italy
[2] ETH Zürich – Dept. of Civil, Environmental and Geomatic Engineering, Stefano-Franscini-Platz 5, 8093 Zürich, Switzerland
[4] Imperial College London – Dept. of Mathematics, South Kensington Campus, London, U.K., United Kingdom

Abstract. Metamaterials, in their modern guise, emerged about two decades ago in optics [1] and their potential in creating artificial media, with properties not found in nature, and the consequent opportunities in wave physics, have triggered intense research activity. Metamaterial concepts have now become a paradigm for the control of waves across much of physics and engineering and are widely used in electromagnetism, acoustics and elasticity [2].
In elastic wave systems, combining the powerful concepts of resonance and spatial grading within structured surface arrays enable resonant metasurfaces to exhibit broadband wave focusing, mode conversion from surface (Rayleigh) waves to bulk (shear) waves, and spatial frequency selection [3]. Devices built around these concepts allow for precise control of surface waves, often with structures that are subwavelength, and utilise rainbow trapping that separates the signal spatially by frequency. Rainbow trapping yields large amplifications of displacement at the resonator positions where each frequency component accumulates. We investigate whether this amplification, and the associated control, can be used to create energy harvesting devices; the potential advantages and disadvantages of using graded resonant devices with respect to conventional metamaterials concepts for energy harvesting [4] are considered. We concentrate upon elastic plate models for which the A0 mode dominates and take advantage of the large displacement amplitudes in graded resonant arrays of rods, to design innovative metasurfaces that focus waves for enhanced piezoelectric sensing and energy harvesting. Numerical simulation allows us to identify the advantages of such graded metasurface devices and quantify its efficiency, we also develop accurate models of the phenomena and extend our analysis to that of an elastic half-space and Rayleigh surface waves.
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Keywords: Metasurfaces, Rainbow trapping, Piezoelectric Materials, Energy Harvesting, Sensing

*Speaker
†Corresponding author: jacopomaria.deponti@polimi.it

Session 4-1
Thursday 10 October
2:00-3:00

Adjoint-based calculation of shape-gradients for acoustic metamaterials with application to thermoacoustic-instability damping

Georg A. Mensah *† [1], Nicolas Noiray [1]

[1] Combustion and Acoustics for Power and Propulsion Systems Laboratory – Institute of Energy Technology , ETH Zürich, Sonneggstrasse 3, 8092 Zürich, Switzerland

Geometrical shape is the most important parameter defining acoustic spectra. Shape optimization is, therefore, a universal task in acoustics. This talk will present an adjoint-based technique for computation of shape-gradients of thermoacoustic systems. The methodology is meant to be used as key input for gradient-based optimization of acoustic metamaterials for application as broadband dampers in modern gas turbines. The discussion, covers the key challenges of thermoacoustics in gas turbines, application of metamaterials as dampers in gas-turbines, the mathematical fundamentals as well as the implementation of the shape-gradient computation in a modern FEM-based framework. Three-dimensional numerical examples validate the approach.

Keywords: shape sensitivity, adjoints, broadband damping

*Speaker

†Corresponding author: gmensah@ethz.ch

Coupled Scholte Modes in Plastic Plates Underwater

Bethany Staples * [1], Alastair Hibbins† [1], Roy Sambles‡ [1]

[1] School of Physics and Astronomy [Exeter] – Exeter, United Kingdom EX4 4QL, United Kingdom

The Scholte mode is a localised, trapped surface acoustic wave that exists at the boundary between a fluid and a solid. It evanescently decays away from the interface, and propagates along it with a velocity that is less than the bulk speeds of sound in both the fluid and the solid[1]. In a thin plate, the surface waves that exist on each interface can couple to form a symmetric and antisymmetric pair[2].
For "metal-fluid", or hard-solid interfaces, the Scholte phase velocity is approximately equal to the speed of sound in the fluid. This is because the speed of sound in the fluid is less than both bulk speeds of sound in the metal[3]. In this case, the energy of the Scholte wave is largely localised within the fluid, and its character is dictated primarily by the fluid properties. Because of this, previous studies, which explored the modes of metal plates underwater, have examined only the antisymmetric coupled Scholte mode. Since for a 'hard' solid the symmetric coupled Scholte is almost non-dispersive and almost sits on the water sound line at all frequencies some studies neglect its existence entirely[4]. This has unfortunately been then taken as a general property of the Scholte mode in numerous studies, rather than being exclusive to 'hard' solid-water interfaces. This present study examines "plastic-solid", or 'soft' solid-water interfaces. For 'soft' solids, the transverse speed of sound is less than the speed of sound in the surrounding fluid. This results in the velocity of the Scholte interface wave being notably less than the speed of sound in the liquid with much of the energy of the Scholte wave now localised within the 'soft' solid[5]. Under these conditions, the symmetric coupled Scholte exhibits dispersive behaviour, and deviates from the Scholte velocity at low frequencies. This behaviour is demonstrated, and experimentally verified using Acrylic plates underwater.

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Keywords: Scholte, plastic, plate modes, non, radiative, near, field, solid, liquid interface, surface acoustic waves

*Speaker
†Corresponding author: a.p.hibbins@exeter.ac.uk
‡Corresponding author: j.r.sambles@exeter.ac.uk

Effect of ultrasonic waves on the surface properties of cotton

Muhammad Tayyab Noman * [1], Michal Petru [1], Jiri Militky [2]

[1] Department of Machinery Construction, Institute of Nanomaterials, Advanced Technologies and Innovation (CXI) – Technical University of Liberec, Czech Republic
[2] Department of Material Engineering, Faculty of Textile Engineering – Technical University of Liberec, Czech Republic

Cotton-titania (CT) nanocomposites with multifunctional properties were synthesized via a novel in-situ ultrasonic acoustic method (UAM). Ultrasonic irradiations were used as a potential tool to develop CT nanocomposites at low temperature in the presence of titanium tetrachloride and isopropanol. The synthesized samples were characterized by X-ray diffraction, Scanning electron microscope, Energy dispersive X-ray and Inductive couple plazma methods. Functional properties i.e. Ultraviolet protection factor (UPF), self-cleaning, antimicrobial and tensile strength of the CT nanocomposites were evaluated by different methods. Central composite design and response surface methodology were employed to evaluate the effects of selected variables on responses. The results confirm the simultaneous formation and incorporation of anatase TiO2 with average crystallite size of 4 nm on cotton fabric with excellent photocatalytic properties. The sustained self-cleaning efficiency of CT nanocomposites even after 30 home launderings indicates their excellent washing durability. Significant effects were obtained during statistical analysis for selected variables on the formation and incorporation of TiO2 nanoparticles (NPs) on cotton and photocatalytic properties of the CT nanocomposites.

Keywords: Ultrasonic waves, Cotton, Nanostructure, Self, cleaning

*Speaker

Session 5-1
Friday 11 October
11:00-12:00

Multiple Scattering Theory in the study of Non-Hermitian Sonic Second Order Topological Insulators

María Rosendo-López * [1], Zhiwang Zhang [2], Daniel Torrent [3], Johan Christensen† [1]

[1] Department of Physics, Universidad Carlos III de Madrid – Avenida de la Universidad, 28911, Leganés (Madrid), Spain
[2] Department of Physics, MOE Key Laboratory of Modern Acoustics, Collaborative Innovation Center of Advanced Microstructures, Nanjing University – Nanjing 210093, China
[3] GROC, UJI, Institut de Noves Tecnologies de la Imatge (INIT), Universitat Jaume I – Universitat Jaume I, 12080, Castellón, Spain

Topological insulators (Tis) with unique edge states have been broadly studied in the fields of condense matter physics and classical systems such as photonics acoustics [1] and mechanics. Recently, the concept of TIs has been generalized to higher-order topological insulators (HOTIs), a family of topological phases of matter that obey an extended topological bulk-boundary correspondence principle. HOTIs were mainly focused on electronic materials, but new numerical and experimental researches have been carried out in photonic [2-4] and sonic crystals (SC) [5-6]. Here, we make use of the Multiple Scattering Theory in order to study the topological states of both Hermitian and Non Hermitian Sonic Second Order Topological Insulators. Our findings reveal that the sound is trapped in the corners of the Concentric Square Crystal considered, which is based on an inner SC made up of a topological non-trivial region enclosed by a topological trivial region. Besides, this semi-analytical approach allows us to prove the robustness of the corner states against perturbations.

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Keywords: High Order Topological Insulators, Sonic Crystals, Parity Time Symmetry, Corner States, Multiple Scattering Theory

*Speaker
†Corresponding author: jchriste@inst.uc3m.es

Majorana bound state in Kekule distorted sonic lattices

Penglin Gao * [1], Daniel Torrent [2], Francisco Cervera [3], Pablo San-Jose [4], Jose Sanchez-Dehesa [3], Johan Christensen† [1]

[1] Department of Physics, Universidad Carlos III de Madrid – ES-28916 Leganes, Madrid, Spain
[2] GROC, UJI, Institut de Noves Tecnologies de la Imatge (INIT), Universitat Jaume I – 12071, Castello, Spain
[3] Wave Phenomena Group, Department of Electronic Engineering, Universitat Politecnica de Valencia – Camino de vera s.n. (Building 7F), ES-46022 Valencia, Spain
[4] Materials Science Factory, Instituto de Ciencia de Materiales de Madrid (ICMM-CSIC) – Sor Juana Ines de la Cruz 3, 28049 Madrid, Spain

Topological phases of matter have recently been unveiled in bosonic systems to facilitate the manipulation of waves in unprecedented ways. What appears highly useful for optical [1], mechanical [2, 3], and acoustic waveguiding [4, 5] is the hallmark to resist against structural imperfections and flaws provided that the states are engineered at the interfaces of domains having unequal topological invariants. Here we aim to demonstrate a new type of matter supporting nonpropagating localized state that is topologically protected and robust against any parameter perturbations given that the intrinsic particle hole symmetry is preserved, ie., an acoustic analogue of Majorana bound state [6]. By making the cylinders radii position dependent, a Kekule distortion is introduced into the sonic lattice so as to make the intervalley coupling complex and position dependent, thus mimicking the well-known Jackiw-Rossi vortex in spinless p-wave superconductors [7]. It is numerically shown that a sonic Majorana-like state is spatially bind to the topological vortex and pinned exactly at the Dirac frequency immune to symmetry preserving imperfections as simulated by large areas of impurity-cylinders. We demonstrate our prediction experimentally by 3D printing the vortex pattern in a plastic matrix and measuring the spectrum of the acoustic response of the device. Despite viscothermal losses, the measured topological resonance remains robust, with its frequency closely matching our simulations. Our work might broaden exciting avenues for robust sound confinement and energy harvesting in industries.

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Keywords: Majorana bound state, topological protection, particle hole symmetry, Dirac cones, Jackiw Rossi vortex

*Speaker
†Corresponding author: johan.christensen@uc3m.es

Nonreciprocal phonon transport in space-time discretely modulated beams

Emanuele Riva * [1], Quadrelli Davide [1], Jacopo Marconi [1], Gabriele Cazzulani [1], Francesco Braghin [1]

[1] Department of mechanical engineering, Politecnico di Milano – Via La Masa,1, Italy

Breaking reciprocity in wave propagation problems is of great interest within the research community, given the opportunity to design new devices for one-way communication with unprecedent performances. In the context of mechanics and phonon transport, directional wave manipulation can be achieved exploiting space-time periodic materials. Namely, structures whose elastic or physical properties are functions of space and time, mimicking the propagation of a wave or a wave packet. In particular, spatial periodicity allows for the generation of frequency gaps, called bandgaps, in which wave propagation occurs with attenuation. The addition of temporal periodicity results into a frequency shift, which moves the bandgap location at different frequencies for counterpropagating waves. In our research, we investigate both theoretical and experimental aspects. We first developed a generalization of the *Plane Wave Expansion Method* (PWEM) which allows to compute the wave propagation properties of an arbitrary spatiotemporal (ST) unit cell. This generalization is required to study, for instance, discrete time-space modulations, for which the physical realization is more feasible compared to the state of the art. Based on that, we designed and experimentally tested one-way elastic wave propagation in a space-time discretely modulated beam. The system under analysis is made of an aluminum substrate with bonded array of piezoelectric patches. Each of them is connected with negative capacitance shunts to provide effective Young's modulus decrease in time, using switching circuits. Moreover, nonreciprocity is induced upon the application of a 120◦ phase delay between consecutive active elements, generating an elastic modulus that mimics the propagation of a wave along the beam. With this configuration we are able to achieve approximately 1kHz directional bandgap that can be moved within a 3kHz range.

Keywords: Nonreciprocal wave propagation, Bandgap, Mechanical diode, Spatiotemporal modulation.

*Speaker

Session 5-2
Friday 11 October
12:00-1:00

Superelement modelling of elastic metastructures

Domenico Tallarico * [1], Gwenael Hannema [1], Andrea Bergamini [1], Marco Miniaci [1], Armin Zemp [1], Bart Van Damme [1]

[1] EMPA, Laboratory for Acoustics/Noise control – Überlandstr. 129, 8600 Dübendorf, Switzerland

Man-made elastic structures (often referred to as metastructures) are promising in applications where filtering, focusing or channeling of elastic waves is required. Besides their academic appeal, metastructures are gradually permeating the industrial sector and several associated mathematical notions are entering engineering practice. However, the design of metastructures generally still relies on structural periodicity and bulk behavior, whereas finite-size effects are often not controlled at the design stage. Spatially-resolved finite-element models of large collections of unit-cells inevitably call for mathematical approximations and reduction methods. In this talk, we introduce two well-known finite-element model order reduction techniques, namely the Exact superelement and the Component Mode Synthesis superelement. In the context of metastructural design, we highlight their benefits in terms of reduced computational time and size with respect to standard full-size finite-element solutions. Specifically, we define the superelements starting from unit cells of three-dimensional metastructures and use those to solve mathematical problems of general interest: (i) polynomial Bloch-Floquet eigenvalue problems associated with complex dispersion diagrams (i.e. complex Bloch vector as a function of frequency), and (ii) time-harmonic response of finite assemblies of unit cells.

Keywords: superelement method, dynamics, metastructural design

*Speaker

Experimental evidence of a non-delayed propagation through a Density-Near-Zero plate-type metamaterial

Matthieu Malléjac * [1], Aurélien Merkel [3,2], José Sánchez-Dehesa [4], Johan Christensen [2], Vincent Tournat [1], Vicent Romero-García [1], Jean-Philippe Groby [1]

[1] Laboratoire d'Acoustique de l'Université du Mans LAUM - UMR CNRS 6613 – Le Mans Université, Bât. IAM - UFR Sciences Avenue Olivier Messiaen 72085 LE MANS CEDEX 9, France
[3] Institut Jean Lamour – UMR CNRS 7198 – Université de Lorraine. Campus Artem 2 allée André Guinier BP 50840 54011 Nancy Cedex, France
[2] Universidad Carlos III de Madrid – Avenidad de la Universidad, 30, 28916 Leganés (Madrid), Spain
[4] Wave Phenomena Group , Universitat Politècnica de València – Camino de vera s.n., ES-46022 Valencia, Spain

We theoretically, numerically, and experimentally analyze the Density-Near-Zero (DNZ) regime of a 1D Plate-type Acoustic metamaterial (PAM). The analyzed system is composed of thin elastic plates periodically clamped in an air-filled waveguide. The effective dynamic zero mass density is obtained from the strong dispersion around the band gaps associated with the resonances of the plates. Three distinct frequencies can be used to characterize the entire system. We emphasize the importance of the impedance mismatch occurring at the frequency of the zero effective density in addition to the consequences of the inherent losses. As a result, the frequency of the zero-phase propagation, i.e., the acoustic propagation with zero phase delay, is not exactly the frequency of the zero density and lies into the negative effective density frequency range. Although the transmission at the zero-phase frequency is affected by the losses and the number of unit cells, this peculiar propagation is still experimentally observable with a careful design of the PAM. Finally, we investigate the feasibility of acoustic doping of a DNZ PAM (analogously to electromagnetic ENZ doping) in order to delete the frequency offset between impedance matching, zero-phase, and zero density frequencies.

Keywords: Plate type metamaterial, Acoustics metamaterials, Density Near Zero, Zero phase propagation

*Speaker

Bound States in the Continuum in a Periodic Double Array of Elastic Defects

Omer Haq * [1]

[1] University of Florida Department of Physics – 2001 Museum Rd, Gainesville, FL 32611, United States

Diffraction of elastic waves is considered for a system consisting of a periodic double array of thin infinitely long cylindrical defects embedded in an isotropic background material. This system supports two transverse and one longitudinal polarization; normal traction boundary condition at the boundary of the defect results in mixing between the longitudinal and in plane transverse polarization, the transverse mode parallel to the defect propagates independently of the in plane modes. It is shown that for specific values of the distances between the array and specific values of the Bloch parameter, which plays the role of the component of the wave vector in direction of periodicity, this system supports a bound states in the continuum (BSC) that has no specific polarization, that is, there are standing waves localized in the scattering structure whose frequency lies in the first open longitudinal and transverse diffraction threshold. Exact analytical solutions are constructed via Lippmann–Schwinger integral formalism for linear elastic theory; it is shown that this solution agrees with a Fabry-Perot partial wave summation modified for multiple coupled polarizations with different group velocities in the appropriate region of applicability. It is demonstrated that this BSC pertains to a zero width resonance by explicit tuning of the lifetime to zero along a specific parameter curve, demonstrating the far field can be tuned to zero as a result of the destructive interference of the resonances radiation from each array. Finally it is shown that the elastic energy of the BSC is concentrated on the cylindrical defects, these hotspot are explained via constructive interference of the resonance radiation on the cylindrical defects.

Keywords: Bound States in the Continuum, Embedded Modes, Trapped Modes, Resonance, Fabry, Perot Interferometer, Elastic Metamaterials, Scattering Theory, Partial Wave Analysis

*Speaker

A Reconfigurable Topological Waveguide Exploiting Negative Capacitance Shunting Circuits

Davide Enrico Quadrelli * [1], Emanuele Riva [1], Gabriele Cazzulani [1], Francesco Braghin [1]

[1] Department of mechanical engineering, Politecnico di Milano – Via La Masa,1, Italy

The analysis of topological properties of band structures in phononic crystals has recently become an established tool to study the occurrence of robust edge states protected against backscattering at sharp bends and lattice defects. Several design paradigms have been exploited ranging from periodic structures equipped with active elements mimicking the Quantum Hall effect, to passive ones showing helical or valley edge states.

As an example, the Kagome lattice is known to exhibit topologically protected edge states in analogy with the Quantum Valley Hall effect when its spatial inversion symmetry is lowered. According to the bulk edge correspondence principle, these modes can be employed to design elastic waveguides joining together phases characterized by distinct topological order.

In this work, we adopt a continuum implementation of the Kagome geometry to show how it is possible to use piezoelectric inserts combined with negative capacitance shunting circuits in order to induce at need a topological phase transition by local adjustment of the stiffness properties of each unit cell. The proposed design thus allows to reshape edge channels created between topologically distinct phases, i.e. to obtain a waveguide that combines all the promising features provided by topological protection with reconfigurability of the path followed by a traveling signal. Moreover, being able to alter the stiffness of the structure allows also for control of the working frequencies.

Finally, we show how the described system can be used to implement a quantum point-like switch: this device can be employed to send elastic signals along two prescribed paths at need requiring a reduced effort in terms of tuned unit cells.

Keywords: Topological Metamaterials, Negative Capacitance, Tunable waveguide

*Speaker

Session 6-1
Friday 11 October
3:30-4:30

A priori identification of material parameters in the relaxed micromorphic model

Patrizio Neff * [1]

[1] University of Duisburg-Essen – Essen, Germany

The relaxed micromorphic model is an extended continuum model able to describe band gap phenomena in metamaterials.
In this talk we show how size independent static material parameters in this model can be determined a priori for metamaterials with periodic structures.
To this aim the rational of the relaxed micromorphic model is presented. Classical periodic homogenization predicts the large scale response and is one ingredient of the identification process; another ingredient is the maximal stiffness of representative unit cells under affine Dirichlet conditions and lastly we need to invoke a homogenization formula reminiscent of a series of spring stiffness which is unique to the relaxed micromorphic model. The program is probed in 2D for a tetragonal metamaterial.

Keywords: relaxed micromorphic model, metamaterials, band, gaps

*Speaker

Non-linear metamaterial structures: array of particle dampers

Sifa Gul Demiryurek *† [1], Anton Krynkin [1], Jem Rongong [1]

[1] Department of Mechanical Engineering [Sheffield] – 36-38 Victoria Street, Sheffield, S3 7QB, United Kingdom

Passive dampers to treat the excessive structural vibration has long been researched and used in the industry. Multiple particles placed in a container can be used to dissipate excessive vibration through the inelastic collisions between particles and the cavity of the damper has been shown. However, their application is usually limited to treating certain modes of structural vibration and their performance is highly dependent on location. Another limitation of the particle dampers is nonlinear character caused by discontinuity and randomness of the collisions and velocity of the particles. In this paper, it is proposed to modify a particle damper into a metamaterial type structure in order to expand the applicability range. Metamaterials are known to exhibit subwavelength performance offering superior vibro-acoustic properties over a wide range of frequencies. To maintain metamaterial properties, the casing of the particle damper is designed to resonate near selected modal frequencies. The Bloch-Floquet theory is applied in studying the doubly and singly periodic arrangement of the resonating damper shells with and without particles. Finally, the nonlinear effects observed in the metamaterial structure made of particle dampers are modelled numerically to predict their vibroacoustic effects in finite structures. The theoretical, numerical predictions are compared with the experimental results.

Keywords: acoustic, metamaterials, damping, particle dampers, passive damping, vibroacoutics, structural vibration

*Speaker

†Corresponding author: sgdemiryurek1@sheffield.ac.uk

Two-component nonlinear elastic waves

Guram Adamashvili * [1]

[1] Technical University of Georgia – Kostava str.77. Tbilisi, Georgia

A theory of an elastic two-component nonlinear pulse of self-induced transparency is constructed. By using the generalized perturbative reduction method the magnetic Bloch equations and the equation of motion for the displacement field for the small area pulse are reduced to a system of two coupled nonlinear Schrodinger equations. The profile of an elastic two-component nonlinear pulse with the sum and difference of the frequencies is presented. Explicit analytical expressions for the parameters of an elastic two-component nonlinear pulse are obtained as well as simulations of an acoustic vector soliton presented with realistic parameters which can be reached in experiments. It is shown that the of an elastic two-component nonlinear pulse in the special case can be reduced to the breather solution and these nonlinear waves have different profiles.

Keywords: acoustic solitons, vector solitons, acoustic self, induced transparency

*Speaker

Resonant acoustic scattering from superhydrophobic metasurfaces

Rodolfo Brandao *† [1], Ory Schnitzer [1], Ehud Yariv [2]

[1] Imperial College London – South Kensington, London, SW7 2AZ, United Kingdom
[2] Technion – Haifa, Israel

Acoustic metamaterials formed by locally resonant structures posses remarkable capabilities of enhancing, focusing and guiding the propagation of sound waves. Micro-bubbles are often employed as the locally resonant elements, given their strong subwavelength resonance; bubbles clusters, however, are naturally disordered, mobile and polydisperse, which complicates the fabrication of stable bubbly metamaterials. In this talk, we suggest to consider so-called "superhydrophobic surfaces" as natural candidates for realising highly tuneable bubble-based acoustic metasurfaces. We focus our attention on a canonical superhydrophobic configuration formed of a solid substrate decorated with a periodic array of micro-grooves; it is assumed that each groove traps an air bubble whose meniscus is pinned to the groove's corners. While such superhydrophobic surfaces been widely explored in the context of wetting and drag reduction, their acoustic properties have not been previously investigated. We begin by discussing the scattering by a single trapped bubble. We exploit the smallness of the gas-toliquid density ratio and employ matched asymptotic expansions to obtain the complex amplitude of the emitted cylindrical wave, as well as a reduced description of the meniscus oscillation and the near-field pressure fields. Due to the combination of compressibility, surface tension, and pinning effects, the acoustic response of the trapped bubble exhibits a rich frequency response, which includes a fundamental resonance followed by a sequence of closely spaced resonance and anti-resonance pairs. Building on the above theory for a single bubble, we proceed to investigate arrays of trapped bubbles. By employing Foldy's point-scatterer approximation, we find that, for infinite arrays, strong inter-bubble interactions shift, and diminish the amplitude of, the resonance peaks. The frequency response of long-finite arrays exhibits highly oscillatory deviations from that of an infinite array in a sequence of shrinking frequency intervals. These deviations are shown to be associated with edge-excitation of surface "spoof-plasmon" waves. I will also comment on how matched asymptotic expansions can be used to systematically study arrays of Helmholtz resonators and grooves, even in the presence of thermal viscous losses.

Keywords: Acoustic metamaterials, superhydrophobic surfaces, bubbly materials, bubbles, matched asymptotic expansions

*Speaker
†Corresponding author: r.brandao18@imperial.ac.uk

List of participants

- Amendola Ada
- Adamashvili Guram
- Aguzzi Giulia
- Ballestero Eric
- Bansal Shubhi
- Beadle Joseph
- Bergamini Andrea
- Bertelli Paola
- Boulvert Jean
- Brandao Rodolfo
- Cavalieri Théo
- Chaplain Gregory
- Choi Christabel
- D'Alessandro Luca
- Dangelo Marco
- Craster Richard
- De Ponti Jacopo Maria
- Demiryurek Sifa Gul
- Fabra Rodríguez Miguel
- Gaborit Mathieu
- Gao Penglin
- Gavrilov Anton
- Glover Emily
- Groby Jean-Philippe
- Haq Omer
- Hwang Dong-Uk
- Jung Jaesoon
- Kook Junghwan
- Kherraz Nesrine
- Latcham Oliver
- Lee Dongwoo
- Li Jensen
- Madeo Angela
- Magnani Aurora
- Malléjac Matthieu
- Mensah Georg A.
- Miniaci Marco
- Moeini Samaneh
- Mori Francesco
- Neff Patrizio
- Noman Muhammad Tayyab
- Oh John J.
- Pettersson Maria
- Quadrelli Davide Enrico
- Riva Emanuele
- Romero-García Vicent
- Rosendo López María
- Singh Ravi
- Staples Bethany
- Tallarico Domenico
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UK Acoustics Network

The vision of the UK Acoustics Network is to bring together the internationally leading, but disparate UK acoustics, research community, to promote acoustics in the UK both nationally and internationally and to provide a coherent single point of access to acoustics research for industry and governmental agencies

The main aim of acoustics.ac.uk is to bring together researchers working in different areas of acoustics to enhance communication between groups, provide a focus for collaboration and innovation, and to maximise the future impact of acoustics based research in the UK.

Phononic Vibes S.R.L.

Phononic Vibes introduces a new patented technology with unprecedented performances in the vibration and noise control and isolation, with a circular economy approach.

Doctoral School SPI - Bretagne Loire University (FRANCE)

The Engineering Sciences (SPI) Doctoral School oversees the training and research of 576 PhD students at 15 laboratories.

MetAcoustic

MetAcoustic is an engineering and R&D company in acoustics. Our studies range from the audit step to the industrial implementation of advanced solutions.

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