

Colloquium Final Report

N. 616 – Unification of microsystems and metamaterials for new generation engineering solutions

Dates and location: **10/10/2022 - 12/10/2022, Milan, Italy**

Chairperson **Valentina Zega**

Co-Chairperson **Varvara Kouznetsova, Slava Krylov**

Conference fees

- Registration fee **450.0 €**

What other funding was obtained? **Registration fee paid by participants: 450 euros**

What were the participants offered? **The registration fee included:**

- **access to all sessions**
- **book of abstract (30 invited talks + 6 poster presentations)**
- **shared folder + jamboard to follow-up the colloquium**
- **2 lunches at the colloquium venue**
- **1 lunch at a typical pizzeria in Milan, La Cuccuma, via Pacini 26, Milan (Wednesday October 12nd)**
- **3 morning coffee breaks**
- **1 afternoon coffee break (Monday October, 10th)**
- **1 guided tour at the Duomo Cathedral + Terraces (Tuesday October 11st)**
- **1 dinner at the restaurant A'Riccione Terrazza 12, via Durini 28, Milan (Tuesday October 11st)**
- **1 gala concert with the best overtures and arias of the Italian repertoire (Monday October 10th)**

Number of members of Euromech (reduced registration fee) **41**

Number of non-members of Euromech (full registration fee) **0**

Applicants (members)

- Alessandro Annessi
- Marco Antonacci
- Sebastien Baguet
- Edoardo Belloni
- Paolo Han Beoletto
- Michele Brun

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- Attilio Frangi
- Pavel Galich
- Chiara Gazzola
- Sefi Givli
- Giorgio Gobat
- Oded Gottlieb
- Guillaume James
- Varvara Kouznetsova
- Slava Krylov
- Giacomo Langfelder
- Michael Leamy
- Ron Lifshitz
- Milena Martarelli
- Marco MINIACI
- Alessandro Nastro
- Antonio Palermo
- Nicola Pugno
- Ondrej Rokos
- Michele Rosso
- Stephan Rudykh
- Marc Serra Garcia
- Yair Shokef
- Carlo Valzasina
- Dana Weinstein
- Valentina Zega
- Bao Zhao

Scientific Report

The colloquium was devoted to create a bridge between the micro/nano-electromechanical systems (MEMS/NEMS) and elasto-acoustic and mechanical metamaterials communities and put the seeds for a new network among researchers working in these areas. Both communities possess skills in linear and nonlinear static and dynamic modelling, optimization and multi-physics problems solving. They share the interest in finding innovative applications and in exploiting new exotic phenomena such as zero/negative effective material properties, highly nonlinear behaviors and many others. At the same time, they often look at the problems from different perspectives.

The colloquium provided a forum for the discussion of the numerical modelling and experimental validation of MEMS/NEMS devices incorporating metamaterials and metamaterials containing MEMS/NEMS devices. Other interconnected topics such as the numerical full-order and reduced order modelling and/or analytical predictions of linear and non-linear dynamics of resonant components in MEMS/NEMS and metamaterials, the topology and shape optimization of resonant components in MEMS/NEMS and metamaterials and the numerical modelling and/or experimental evidence of emergent phenomena in MEMS/NEMS and

metamaterials have been discussed.

During the colloquium, indeed, MEMS/NEMS devices incorporating and/or exploiting METAMATERIALS have been presented and deeply discussed such as for example, mechanical tunable filters, auxetic coupling springs in gyroscopes, high-Q resonators, delay lines, energy harvesters, vibration isolation platforms, waveguides, energy focusing mechanisms, signal processing mechanisms. Metamaterials exploiting innovative mechanisms such as the gyroscopic effect, the rainbow effect or tunable stiffness have been also presented and discussed. Predictive tools based on model order reduction techniques, homogenizations, nonlinear normal modes, mass-spring models, multiple scales methods or structural theories have been discussed and proposed as valid alternatives when the computational costs of the full order model are too high or when an efficient predictive tool is necessary to design MEMS and METAMATERIALS. Significant interest has been also addressed to nonlinear phenomena arising in both MEMS/NEMS and METAMATERIALS such as for example, the subharmonic bandgap induced by autoparametric resonance or the bi-stability. Topology and shape optimization techniques have been proposed to guide the design of both MEMS and METAMATERIALS. Finally, experimental techniques employed in both the MEMS and METAMATERIALS fields have been proposed and discussed.

A total of 39 participants have attended the Colloquium. Among them, 36 were from Academia and 3 from companies working on either MEMS and metamaterials, i.e. STMicroelectronics, TDK InvenSense, Phononic Vibes. Prof. James and Prof. Martarelli could not join the Colloquium for personal issue.

30 Invited talks of 25 minutes plus 5 minutes for questions have been organized in nine oral sessions.

6 Poster Presentations have been organized in one poster session on Monday October 10th afternoon.

Most importantly, there was ample time for informal discussions among the participants during coffee breaks, lunches and social activities. A shared folder and a Jamboard have been also created after the end of the colloquium to share presentations/papers, but also suggestions, requests and information between participants with the final goal to initiate a new set of future collaborations.

First oral session (Monday October 10th 9:20 am – 10:50 am)

The session focused on the design of innovative metamaterials that exhibit peculiar properties not available in nature. In particular, geometry, combinatorics and topology of personalized mechanical metamaterials have been discussed together with metamaterials with controllable macroscopic stiffness and non-reciprocal gyroscopic microstructured media.

Second oral session (Monday October 10th 11:15 am - 1:15 pm)

The session focused on nonlinearities in the microsystems community. In particular, numerical, classical and quantum nonequilibrium dynamics of nonlinear nanomechanical systems have been discussed together with the influence of combined thermal and radiation stresses on the bifurcation structure of a nonlinear optomechanical micro-resonator. A model order reduction technique for nonlinear MEMS structures based on the invariant manifold approach has been proposed together with nonlinear normal modes and bifurcation tracking to guide the design of resonant MEMS sensors/actuators.

Third oral session (Monday October 10th 2:30 pm – 5:00 pm)

The session focused on nonlinearities in the metamaterials community. In

particular, breathers in strongly nonlinear oscillator chains have been discussed together with the study of localized modes in continuous elastic media under evolving boundary conditions. Interest has been also addressed to the softening of shear wave modes in nonlinear composites on the edge of elastic instability as well as to the instability-driven microstructure transformations in soft (meta-) materials. The session ended with the investigation of emergent phenomena in locally resonant acoustic metamaterials due to subharmonic energy exchange.

Fourth oral session (Tuesday October 11st 8:45 am – 10:25 am)

The session focused on the integration of metamaterials and MEMS in particular on the role of metamaterials in MEMS. The session started with the keynote presentation of Carlo Valzasina from STMicroelectronics, entitled 'MEMS: the ingredients for success'. The keynote speaker proposed an overview on the MEMS future trends and underlined the crucial role that metamaterials can play in this field. The session continued with the discussion of zero-power speech processing in passive elastic metastructures and with the discussion of the role of acoustic metamaterials in standard Integrated Circuit platforms.

Fifth oral session (Tuesday October 11st 11:00 am – 1:00 pm)

The session focused on innovative MEMS solutions for both the readout and the integration of metamaterials in microsystems. In particular, the feedthrough capacitance issues in metamaterial-based MEMS has been discussed in details since these strongly affect the performances of integrated MEMS and metamaterials. A new method for driving electrostatic double-sided comb drives and a new method for characterizing their response based in zero-power consumption has been proposed as a promising solution for microsystems and possibly integrated microsystems and metamaterials. Finally, a CMOS-compatible piezoelectric microacoustic metamaterials for Radio Frequency Applications has been proposed together with a resonant micro-arrays for frequency signal amplification.

Sixth oral session (Tuesday October 11st 2:00 pm - 3:30 pm)

The session focused on innovative solutions in the field of metamaterials. In particular, a whirling string actuator has been proposed as a promising solution toward dynamically amplified active mechanical metamaterials. Some insights on the non-intuitive behavior of bistable lattices have been also provided during the session. The session ended with the presentation of a multi-material metastructure for vibration isolation.

Seventh oral session (Wednesday October 12nd 9:00 am – 11:00 am)

The session focused on MetaMEMS which are microsystems exploiting metamaterials for achieving better performances. In particular, an overview of the new trend of metaMEMS in Microsystems technology has been proposed together with the design and experimental characterization of electrically-tunable MEMS periodic auxetic structures and energy harvesters. Homogenization in microsystems and metamaterials is finally proposed as a promising simulation tool to reduce computational costs for periodic media.

Eighth oral session (Wednesday October 12nd 11:30 am – 1:00 pm)

The session focused on acoustic metamaterials. In particular, advanced modelling and design of vibro-acoustic metamaterials has been proposed together with the design and modeling of a Periodic Single-Phase Sandwich Panel for Acoustic Insulation Applications and electroacoustic reconfigurable topological insulators.

Ninth oral session (Wednesday October 12nd 3:00 pm – 4:30 pm)

The last session focused on the design, simulation and testing of innovative

metamaterials. In particular, the laboratory experiments with multi-resonant metamaterials for broad band frequency piezoelectric energy harvesting has been discussed in details together with bioinspired tonotopic micro-resonators. The dynamics of quasiperiodic elastic metasurfaces has been finally investigated using a multiple scattering formulation.

Number of participants from each country

COUNTRY	PARTICIPANTS
Italy	20
Netherlands	3
Israel	8
France	3
United States	3
Belgium	1
United Kingdom	1
Switzerland	2
TOTAL	41

Please send this report in electronic form to the Secretary General of EUROMECH, within one month after your Colloquium.