Course - Prof. Chiara Daraio

Title: Materials by design – How structure meets function

Topic 1: Metamaterials with locally addressable properties: from vibration absorption to autonomous propulsion

Mechanical metamaterials are materials with a tailored, architected structure, designed to achieve properties that depart from those found in natural or more "conventional" engineering materials. Initial realizations of these materials were periodic and derived their properties from an interplay of the constitutive material responses and the architected geometry. More recently, increasing the design complexity allowed the realization of materials with anisotropic constitutive and structural properties, and added functionalities. Current trends suggest a growing interest in the creation of metamaterials with programmable responses and metamaterials with autonomously adapting morphology. In this talk, I will highlight some of our recent work in the control of stored energy in structured materials, to create programmable, nonlinear metamaterials and their possible application to engineering problems.

Topic 2: Morphing materials in freeform objects, at the micro- and macro-scales

Morphing two-dimensional sheets into three-dimensional objects is a classical problem in mechanics, mathematics and art, pursued over centuries of human history. Today, the ability to manufacture materials with an almost arbitrary microstructure, architecture and pre-stress distribution opens the door to new approaches for bending sheets into complex forms or actuating complex three-dimensional structures. In this talk, I will discuss recent progress in the design of micro- and macro-scale, nonuniform materials that can bend into freeform objects, in response to environmental stimuli or with simple application of point loads. Engineering the distribution of residual stresses, stiffness gradients and/or cut patterns, we control the sheets' buckling at both local and global scales. The designed distribution of responsive materials in the sheets provides a time dependent control of the developing shapes. Programming 2D sheets into rigid, 3D geometries expands the potential of existing manufacturing tools for efficient and versatile production of 3D objects and may allow the creation of autonomous soft robots.

Topic 3: Tunable, on-chip phononic devices operating at MHz frequencies

Abstract: Nanoelectromechanical systems (NEMS) that operate in the megahertz (MHz) regime allow energy transducibility between different physical domains. For example, they convert optical or electrical signals into mechanical motions and vice versa. This coupling of different physical quantities leads to frequency-tunable NEMS resonators via electromechanical non-linearities. In this talk, I will describe one- and two-dimensional, non-linear, nanoelectromechanical lattices (NEML) with active control of the frequency band dispersion in the radio-frequency domain (10–30 MHz). Our NEMLs consist of a periodic arrangement of mechanically coupled, free-standing nanomembranes with circular clamped boundaries. This design forms a flexural phononic crystal with a wide and well-defined bandgap. The application of a d.c. gate voltage creates voltage-dependent on-site potentials, which can significantly shift the frequency bands of the device. Additionally, I will discuss the experimental realization of topological nanoelectromechanical metamaterials with protected edge states. These on-chip integrated acoustic components could be used in unidirectional waveguides and compact delay lines for high-frequency signal-processing applications.

Topic 4: Plant nanobionic materials with ultra-high temperature response

Abstract: Bionic materials are a class of materials that aims to preserve, enhance, and exploit properties of living systems for engineering purposes. The fabrication of such materials, which bridge the living and inanimate world, has been a longstanding challenge for material scientists, chemists and mechanicians. Attempts have focused on reverse engineering biological structures, biomimicking, and bioinspiration. In most cases, however, creating synthetic materials that reproduce or surpass the performance of natural materials has been elusive. We fabricate synthetic materials that combine carbon nanoparticles in a matrix of plant cells. These materials have mechanical and structural properties resembling wood. Unlike wood, however, they are exquisitely thermally active: they are electrically conducting, and their conductivity changes with temperature, with sensitivity that is two orders of magnitude greater than other materials. In extensions of this work, we extract the active molecule responsible for the temperature sensitivity in plants, and create soft, transparent hydrogels. We use these gels to form ultra-sensitive, flexible membranes that can detect temperature changes from a distance. These new bionic hydrogels augment properties of synthetic skins for robotics and prosthesis and can find applications in consumer electronics.

Seminar – Antonio Palermo

Title: Elastic metamaterials for surface waves control

Elastic metamaterials are artificial composites with resonant elements hosted in a medium able to manipulate the propagation of elastic waves. When the resonant elements are placed on the free surface of an elastic medium, they form a “metasurface” that allows to fully control the dynamics of surface waves. In this talk, I will discuss the use of resonant metasurfaces to manipulate the propagation of vertically and horizontally polarized surface waves and their possible applications across different length scales, i.e. from seismic waves attenuation to SAW devices. First, by combining analytical, numerical, and experimental studies, I will describe the interaction of Rayleigh waves with a metasurface of vertical resonators and the design of large-scale barriers to deflect damaging seismic Rayleigh waves into the medium bulk. Additionally, I will discuss the effect of material inhomogeneity on the metasurface dynamics by analyzing the propagation of surface waves in granular media with depth-dependent stiffness profile. Finally, I will show how these same concepts can be applied to control the propagation of shear polarized waves, e.g. Love waves, and translated to higher frequency regimes to design tunable systems for surface waves filtering.

Bio: Professor Daraio received her undergraduate degree in Mechanical Engineering from the Universita' Politecnica delle Marche, Italy (2001). She received her M.S. (2003) and Ph.D. degrees (2006) in Materials Science and Engineering from the University of California, San Diego. She joined the Aeronautics and Applied Physics departments of the California Institute of Technology (Caltech) in fall of 2006 and was promoted to full professor in 2010. From January 2013 to August 2016, she joined the department of Mechanical and Process Engineering at ETH Zürich, with a chair in Mechanics and Materials. She returned to Caltech in August 2016, as a Professor of Mechanical Engineering and Applied Physics. She received a Presidential Early Career Award from President Obama (PECASE) in 2012, was elected as a Sloan Research Fellow in 2011 and received an ONR Young Investigator Award in 2010. She is also a winner of the NSF CAREER award (2009), of the Richard Von Mises Prize (2008) and received the Hetenyi Award from the Society for Experimental Mechanics (2015). She was selected by Popular Science magazine among the "Brilliant 10" (2010). She serves as a Board Editor for Science (AAAS) and as an Associate Editor for the journals Extreme Mechanics Letters (Elsevier), Multifunctional Materials (IOP) and Frontiers in Materials (Frontiers).

Bio: Antonio Palermo is a Postdoctoral Fellow in the Department of Civil, Chemical, Environmental and Materials Engineering at the University of Bologna. He received his Civil Engineering degree from the University of Bologna (2011), a MSc in Earthquake Engineering from Imperial College (2013), UK, and a Ph.D in Structural Engineering from the University of Bologna (2017). In 2018, he joined the Department of Mechanical and Civil Engineering at the California Institute of Technology as a "Cecil and Sally Drinkward Postdoctoral Fellow". His research interests lie at the intersection between solid mechanics, applied physics, and civil engineering with the aim of designing novel materials and structures for elastic wave propagation control. He is the recipient of the "Claudio Bonivento Thesis Prize for Research and Technological Innovation- ISA" (2018) and the "Medaglia Leonardo Da Vinci- MIUR" (2019).