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# Enhancing thermal negative expansion with hierarchical beam structures

Ioannis Ioannou Sougleridis<sup>\*1,2,3</sup>, Michele Brun<sup>†3</sup>, Giorgio Carta<sup>‡3</sup>, and Antonio Baldi<sup>3</sup>

<sup>1</sup>Laboratoire d'Acoustique de l'Université du Mans – Laboratoire d'Acoustique de l'Université du Mans LAUM – UMR CNRS 6613 – Avenue Olivier Messiaen, 72085 LE MANS Cedex 09, FRANCE, France

<sup>2</sup>National and Kapodistrian University of Athens – DEPARTMENT OF PHYSICS NATIONAL AND KAPODISTRIAN UNIVERSITY OF ATHENS University Campus GR-157 84 Zografou, Athens, Greece

<sup>3</sup>University of Cagliari, Department of Mechanical, Chemical and Materials Engineering, Cagliari, 09123, Italy – Italy

## Abstract

Thermal expansion in solids has long been a focus in materials science, with growing attention to mechanical metamaterials that feature tunable coefficients of thermal expansion. The goal of most of these studies is to design structures exhibiting coefficients of thermal expansion that can reach extreme positive values compared to those of the composite materials, and most importantly zero and negative values. This study introduces a novel mechanical lattice composed of a periodic arrangement of structural frames made of beams. The latter presents a highly tunable effective coefficient of thermal expansion, varying from positive to negative values. Our analytical approach demonstrates that the effective coefficient of thermal expansion depends on the geometric characteristics of the frame, the elastic constants and the coefficients of thermal expansion of the constituent elastic elements. Employing a hierarchical approach, based on substituting each elastic beam with a frame, enables the effective coefficient of thermal expansion to reach values far exceeding those of the base materials. Furthermore, the results of the numerical simulations are verified with experimental tests. The proposed tunable model opens up potential applications in energy storage and the control of elastic instabilities in mechanical systems.

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\*Speaker

†Corresponding author: michele.brun@unica.it

‡Corresponding author: giorgio.carta@unica.it