Strain-Amplifying Metamaterials for Multifunctional Mechano-Luminescence-Optoelectronic Composites

George Hoover[1] and Donghyeon Ryu[1*]
[1]Department of Mechanical Engineering
New Mexico Tech, Socorro, NM 87801-4796
*Corresponding author: donghyeon.ryu@nmt.edu

Abstract

Mechano-luminescence-optoelectronic composites (MLO) show potential as a self-powered sensor and a mechanical-electrical energy harvester. MLO function by converting light emissions caused by mechanical strain to an electric signal. One of the bottlenecks limiting MLO-based sensor use is the high strain threshold to produce light in mechano-luminescent (ML) constituent. To overcome the material limitation, design principles of mechanical metamaterial are employed to lower the strain threshold. In this study, strain amplifying metamaterials (SAMs) are designed to locally amplify strain to lower the global strains needed to trigger light emissions in ML copper-doped zinc sulfide (ZnS:Cu)-polydimethylsiloxane (PDMS) composites. Quasi-2D structures are designed to amplify strain within ZnS:Cu-PDMS and analyzed using finite element method (FEM).

Introduction

Structural health monitoring (SHM) was suggested to ensure safety of structural systems to reduce reliance on manual inspection. As reliable sensors are essential to the SHM framework for successful damage detection, there has been growing interest to suggest novel sensor technologies [1,2]. Ryu[3] invented MLO to be used as a self-powered strain sensor for unmanned aerial vehicles to minimize energy consumption by the sensor network. While MLO-based sensors show potential for broad future use, further design optimization is needed to overcome primary limitation of MLO, such as the high strain threshold for ML light emission limiting readiness level for monitoring of aerospace structures.

In this study, a conceptual design of a functional building block for SAMs is presented to achieve global-to-local strain amplifications within the ML constituent. SAM can reduce the strain threshold to widen application of multifunctional MLO as a self-powered strain sensor as well as a mechanical-electrical energy harvester.

Methods and Discussion

First conceptual design of a functional building block was drafted for SAM as shown in Figure 1(a). Global-to-local strain amplification of the designed building block was validated using COMSOL Multiphysics® in Figure 1(b). The ML constituent was modeled as pure PDMS and the connecting pieces modeled as acrylic plastic. One end piece was fixed in space, as the acrylic is relatively rigid compared to PDMS, this is considered a reasonable assumption. A mesh convergence was done using COMSOL's predefined parameters from 'normal' to 'extra fine.' Modeling the first iteration SAM shows a maximum local strain well above 100% with a globally applied strain of 15%. Typical local

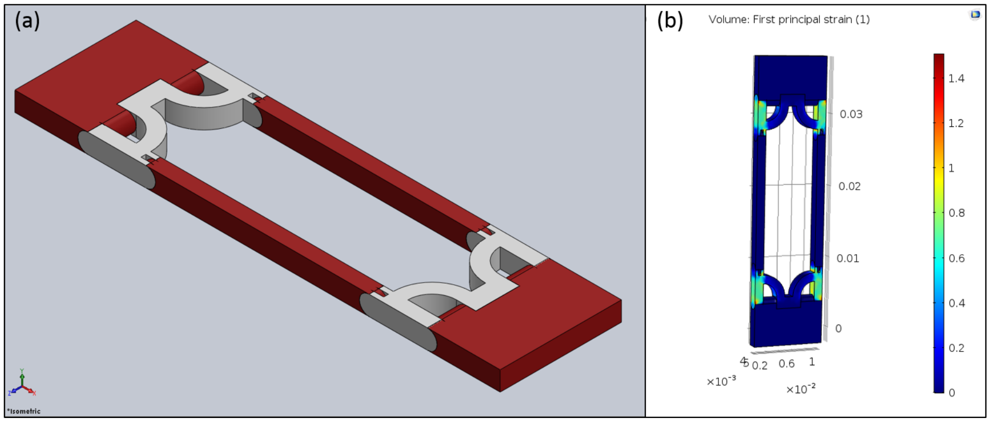

Figure 1. (a) Solidworks model of first iteration SAM. (b) COMSOL model at 15% global strain.

strain levels are shown to be ~80%, which is a 5.3 times amplification that can reduce the global strain threshold for the ML light emissions from ~15% to ~2.8%.

Summary and Future Work

A conceptual design of a functional building block for SAM is presented, and global-to-local strain amplification capability of the building block is validated using FEM. It shows a promising result to lower the ML light emitting global strain threshold from ~15% to ~2.8% to observe light emission in ML composites. Next steps following this study include fabrication of a SAM specimen for validation of its strain amplifying capability and comparison to FEA results. On-going research is to 3D-print the complex geometry of the designed building block. The 3D-printed building block will then be tested under uniaxial tensional loadings. Video footages will be recorded during the testing for conducting comparison studies between experimental and theoretical results.

Acknowledgement

The authors would like to thank NASA EPSCoR CAN (grant #: 80NSSC17M0050) and NASA's Space Grant College and Fellowship Program for supporting this research.

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GEORGE HOOVER
Mr. Hoover is currently pursuing a Master of Science in the Department of Mechanical Engineering at New Mexico Tech, with an emphasis in Solid Mechanics. His work includes mechanical metamaterial design, characterization of light emissions from mechano-luminescent materials, and damage prognosis using machine learning.

DONGHYEON RYU, PH.D., P.E.
Dr. Ryu currently serves as an Assistant Professor of Mechanical Engineering at New Mexico Tech. His research interests include multifunctional materials, photonoic metamaterials, sensor technologies, energy harvesters, polymeric thin films, deep learning, and diagnosis and prognosis of structural systems, among others.