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An efficient way of harvesting mechanoluminescent light: Flexible pressure sensor application

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Highlights

- Flexible Pressure Sensor is constructed through the novel combination of ML material with perovskite.
- Sensor can generate consistent signal under the mechanical bending test.
- Sensor demonstrates distinct signal over 450 cycles and has the potential for long-term, nondegrading performance.

Abstract

Mechanoluminescent (ML) materials are used for fabricating sensors and other devices such as artificial skin, colorful displays, and energy harvesting devices. However, a key challenge in developing ML-based sensors is the ability to effectively capture and efficiently transmit ML light from the sensing location. Here we report a flexible and sensitive thin film pressure sensor, created using a novel combination of ML material and perovskite. In this work, we adopted a simple lateral type design of a thin pressure sensor primarily consisting of (i) a sensing layer of copper-doped zinc sulfide (ZnS:Cu)/polydimethylsiloxane (PDMS) composite and (ii) a light absorbing layer of perovskite. The mixed halide perovskite, a light absorbing material, fully absorbs the green light emitted from ZnS:Cu. The sensor demonstrated consistent signal output under the mechanical bending test. A thin encapsulation layer of PMMA on the perovskite layer prevents moisture inclusion. This innovative technique of utilizing integrated thin perovskite to efficiently harvest ML light has the potential to open up new avenues for advanced research in ML-perovskite-based sensor systems.

Introduction

Recent research in mechanoluminescence has shown the potential of the utilization of mechanoluminescent (ML) materials for fabricating sensors [[1], [2], [3], [4], [5], [6], [7], [8]] and other devices such as artificial skin, colorful displays, and energy harvesting devices [[9], [10], [11], [12], [13], [14], [15], [16], [17], [18], [19], [20], [21]]. ML materials can also be used for load sensing in dynamic structures [4,22], dynamic pressure mapping [23,24], and structural health monitoring (SHM) by embedding them in composites [1,5,25]. Most of the abovementioned sensors or devices require unique, complex measurement systems including costly photo collector devices such as photomultiplier tube (PMT) [1,26], spectrometer [10,11,23,27], or CCD camera [5,28]. One major challenge during developing ML-based sensing system is the ability to effectively capture and transmit ML light from the sensing location. In order to solve this issue, in situ triboluminescent optical fiber (ITOF) sensor utilized optical fibers to transfer light from the sensing location whereas crystals are side-coupled with optical fibers [1,29,30]. A significant amount of light is lost during transmission from crystals to optical fiber due to the side-coupling. The ML devices using photo collector devices, with or without optical fibers, are inefficient due to the loss of light from the light source to the detector. Furthermore, these devices are nonintegrated structures and require a customized setup for capturing and transmitting light from ML materials to photo collector devices, restricting them in real-world applications.

Herein, we report an efficient ML light harvesting method to create a pressure sensor by combining the ML device with perovskite. The pressure sensor has two primary functional layers: the light emitter (ML crystals) and photo collector (perovskite). This study considers copper-doped zinc sulfide (ZnS:Cu) as the ML light source as it is one of the brightest ML yield inorganic materials. When combined with soft materials, ZnS:Cu demonstrates high performance, which makes it a more desirable material in ML-based flexible sensors. As a photo collector, here we utilized low-temperature solution-processed perovskite material. In recent years, there has been a growing interest in photovoltaics based on organo-lead halide perovskites, owing to their relatively high power conversion efficiencies (PCEs) and low manufacturing costs [[31], [32], [33], [34], [35], [36]]. 3D perovskite such as $CH_3NH_3PbI_3$ has been used as a photo-absorbing material but it suffers from poor phase stability under a humid environment [[37], [38], [39], [40], [41]]. It has been established by many research groups that mixed halide and/or cation perovskites exhibit higher moisture stability with increased photovoltaic performance [[42], [43], [44]]. Therefore, in this study, we utilized mixed halide $MAPb(Br_{0\cdot1}I_{0.9})_3$ perovskite as a photo absorbing material to fabricate a flexible pressure sensor. Recently, flexible pressure sensors have found many promising applications such as ulcer detection on the foot, structural health monitoring, soft robotics, energy harvesting, artificial electronic skins, and other wearable technologies [[45], [46], [47]].

The type of our sensor architecture is a lateral structure, enabling relatively easy manufacturing and efficient ML harnessing. The use of lateral type device architecture reduces the layers compared to the previous work [48]. A pressure sensor is fabricated with a simple device architecture of “PET/perovskite/Au/PMMA/ZnS:Cu-polydimethylsiloxane (PDMS)” is constructed in this study, where ML light is immediately absorbed by perovskite without any transmission loss as there is no gap between the light-generating layer (ZnS:Cu/PDMS) and light-absorbing layer (perovskite). Here, the use of an ultra-thin perovskite film provides flexibility. It is expected that the flexible sensor with the mixed halide perovskite and the encapsulation will be sensitive, stable, and durable. Unlike traditional sensors, ML-based sensor has a high response time [48] and does not require any power at the sensing location. Our approach of seamlessly integrating ML material with the photo collector device restricts ML light loss from the source (ZnS:Cu), enabling our pressure sensor with comparatively higher efficiency than other traditional ML-based sensors. This work unravels the practicability of ML harvesting with the integrated thin film perovskite. The working mechanism demonstrated in this article can be further applied to potentially harvesting ML lights of other mechanoluminescent materials such as ZnS:Mn, $SrAl_2O_4$:Eu^{2+}, and $LiNbO_3$:Pr^{3+}. Our ML-perovskite sensor has a promising practical applications in pressure sensing and structural health monitoring.

Section snippets

Architecture and fabrication of pressure sensor

Fig. 1a depicts a schematic diagram of our sensor architecture, which consists of two primary functional layers: (i) ZnS:Cu/PDMS composite as a light source and (ii) perovskite as a photoactive layer. ML light is emitted by ZnS:Cu particles due to applied stress or strain and is transmitted through the translucent PMMA to the perovskite layer. Fig. 1b shows a schematic of the mechanism of the photo-sensing material as a hole-only device where the electrons are trapped and the holes are mobile […

Conclusions

In conclusion, we have demonstrated an efficient method of harnessing ML light via a mixed halide perovskite that is solution-processed at a low temperature. The high quality, defect-free crystalline perovskite thin films on PET substrates were achieved by using the solvent-solvent extraction method as confirmed by various material characterization techniques such as XRD, SEM, and AFM. The enlarged grain size of perovskite was obtained, which is beneficial for device performance. Additionally,…

Materials

ZnS:Cu was purchased from Phosphor Technology, UK, while all other chemicals were procured from Sigma Aldrich, unless explicitly mentioned otherwise.…

Perovskite and ZnS:Cu characterizations

At room temperature, UV–vis absorption spectra ranging from 400 to 850nm were recorded using a Cary 5000 UV–vis FM-NIR spectrophotometer (Agilent, USA). Morphologies of perovskite films and ZnS:Cu particles were investigated using a JEOL 7401F scanning electron microscope. XRD patterns of perovskite films were collected using a Scintag XRD Powder …

Author statement

Md Abu Shohag: Conceptualization, writing and experimentation, Geoffrey Adams: experimentation, Vincent Eze: experimentation, Lucas Braga Carani: experimentation, Tony Ichite: experimentation, and Okenwa Okoli: Supervision.…

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.…

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