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1. Energy harvesting through thermoelectrics: topological designs and materials jetting technology

Review Full-Text PDF RIS

Copy here to cite this article: Zhang D, Sia SA, Solco SFD, Xu J, Suwardi A. Energy harvesting through thermoelectrics: topological designs and materials jetting technology. *Soft Sci* 2023;3:1. http://dx.doi.org/10.20517/ss.2022.29

Abstract

The vast amount of waste heat released into the environment, from body heat to factories and boilers, can be exploited for electricity generation. Thermoelectrics is a sustainable clean energy solution that converts a heat flux directly into electrical power and vice versa and therefore has the potential for both energy harvesting and cooling technologies. However, the usage of thermoelectrics for large-scale applications is restrained by its device topologies and energy conversion cost efficiency trade-offs. The increase in complex topological designs reported in literature shows a shift towards customizability and improvement of thermoelectric devices for maximum energy conversion efficiency. Increasing design complexity will require an innovative, cost-effective fabrication method with design freedom capabilities. In light of this, this review paper seeks to summarize various thermoelectric topological designs as well as how 3D Printing technology can be a solution to the fabrication of cost- and performance-efficient thermoelectric devices. Specifically, as a process category of 3D Printing technology, Materials Jetting will be elaborated for its usefulness in the fabrication of thermoelectric devices. With in-depth research in materials jetting of thermoelectrics, the gap between small-scale materials research and scaled-up industry applications for energy harvesting through thermoelectric devices is expected to be bridged.

Keywords：3D Printing, materials jetting, thermoelectrics, topological designs, energy harvesting

2. Applications of flexible polyimide: barrier material, sensor material, and functional material

Review Full-Text PDF RIS

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Abstract

Polyimide (PI), as an advanced polymer material, possesses the intrinsic merits of excellent resistance to extreme temperatures, good dielectric properties, flame resistance, strong processibility, biocompatibility, and flexibility. The outstanding performances of flexible PI have led to a wide range of applications in aerospace, medical, intelligent electronic devices, energy storage devices, and more. Notably, due to the swift progress of various flexible and soft devices, flexible PI has become ubiquitous in the form of thin films, fibers, and foam and gradually plays an indispensable role in all sorts of those devices. This review mainly focuses on the current advances in the usage of flexible PI for barrier, sensor, and functional purposes. Firstly, the key features of various methods for synthesizing and processing PI, as well as the relationship with their respective applications, are summarized. Secondly, to give

readers a comprehensive view of the various applications of flexible PI materials, the applications are broken down into three categories: flexible barrier applications, flexible sensing applications, and flexible function applications, and the current research of each application is introduced in detail. Finally, a summary of the challenges and possible solutions in some flexible applications is present.
Keywords: Polyimide, flexible materials, applications

3. Electro-assisted assembly of conductive polymer and soft hydrogel into core-shell hybrids

Research Article Full-Text PDF RIS
Copy here to cite this article: Da Silva AC, Paterson TE, Minev IR. Electro-assisted assembly of conductive polymer and soft hydrogel into core-shell hybrids. *Soft Sci* 2023;3:3. http://dx.doi.org/10.20517/ss.2022.25
Abstract
Soft hydrogels have become an important class of materials for mimicking and interfacing biological soft tissues with potential applications in drug delivery, tissue engineering and bioelectronics. Creative methods for integrating hydrogels with other materials such as organic conductors are highly desired. Here, we describe the single-step electrosynthesis of PEDOT/alginate into core-shell hybrid structures via an electrochemical-chemical-chemical mechanism. Using a pulsed electropolymerisation protocol, we generated PEDOT in either oxidized or reduced form. By-products of this electrochemical step trigger the chemical reactions for the concomitant assembly of alginate hydrogels. Characterization evidences that PEDOT (core) and alginate (shell) compartments form an electrochemically integrated interface. During growth, both can be loaded with useful cargo. We loaded a negatively charged small molecule and investigated passive and electroactive release mechanisms from the two compartments. Our electro-assisted assembly/crosslinking of integrated PEDOT/alginate hybrids contributes a promising approach to the design of functional interfaces for applications in controlled release and soft electronics.
Keywords: Conducting polymer, soft hydrogel, bioelectronics, hybrid materials

4. Laser-induced direct graphene patterning: from formation mechanism to flexible applications

Review Full-Text PDF RIS
Copy here to cite this article: Yu H, Gai M, Liu L, Chen F, Bian J, Huang Y. Laser-induced direct graphene patterning: from formation mechanism to flexible applications. *Soft Sci* 2023;3:4. http://dx.doi.org/10.20517/ss.2022.26
Abstract
Laser-induced graphene (LIG), which is directly fabricated by laser carbonization of polymers, has gained much attention in recent years since its first discovery in 2014. Specifically, featuring native porosity, good mechanical properties, and excellent electrical/electrochemical properties, it is considered a promising material for flexible electronic devices. Meantime, LIG can be processed in the atmosphere within a few seconds, thereby significantly reducing the fabrication cost of graphene. Facilitated by these features, this methodology has received great development with worldwide efforts in the following years, including the formation mechanism of LIG, the diversity of laser

sources (from infrared laser to ultraviolet laser), the diversity of carbon sources (thermoset polymers, thermoplastic polymers, and natural polymers), and property modulation of LIG (porosity, electrical property, hydrophilic/hydrophobic property, electrochemical property), along with the broad applications of LIG in various flexible electronic devices. Here, the recent advances in the mechanism studies and preparation methods of LIG are comprehensively summarized. The various technologies for the modification of LIG are reviewed. A thorough overview of typical LIG-based flexible electronic devices is presented. Finally, the current challenges and future directions are discussed.

Keywords: Laser-induce graphene, flexible electronics, laser carbonization, flexible sensor

5. Shape memory behaviors of 3D printed liquid crystal elastomers

Research Article Full-Text PDF RIS

Copy here to cite this article: Dai L, Wang L, Chen B, Xu Z, Wang Z, Xiao R. Shape memory behaviors of 3D printed liquid crystal elastomers. Soft Sci 2023;3:5. http://dx.doi.org/10.20517/ss.2022.28

Abstract

As soft active materials, shape-memory polymers (SMPs) and liquid crystal elastomers (LCEs) have attracted considerable research interest due to their potential applications in various areas. SMPs refer to polymeric materials that can return to their permanent shape in response to external stimuli, such as heat, light, and solvent. In this sense, LCEs can exhibit intrinsic shape-memory behaviors since LCEs can switch between two shapes with temperature change due to the order-disorder transition of liquid crystals. In this work, we fabricate both the polydomain and monodomain nematic LCEs through direct ink writing 3D printing. With increasing the temperature of the substrates, the printed LCEs change from the monodomain state to the polydomain state. For polydomain LCEs, a reversible shape change can occur upon constant loading, while the monodomain can switch the shape with temperature in the stress-free state. This two-way shape-memory behavior is caused by the nematic-isotropic phase transition. We further show that the printed LCEs exhibit a good one-way shape-memory effect due to glass transition. The shape recovery region increases with the programming temperature, which is a typical temperature memory effect. Finally, it is demonstrated that complex shape-memory performance can be designed by combining one-way and two-way shape-memory effects. Specifically, for the monodomain LCEs, with increasing temperature, the programmed shape first recovers, and a second shape change can further occur due to the nematic-isotropic transition.

Keywords: Liquid crystal elastomers, shape-memory polymers, two-way shape-memory effect, glass transition, nematic-isotropic transition, 3D printing

6. Wearable plasmonic biofluid sensors as your photonic skin

Perspective Full-Text PDF RIS

Copy here to cite this article: Liu L, Ahn JH, Wang B. Wearable plasmonic biofluid sensors as your photonic skin. *Soft Sci* 2023;3:6. http://dx.doi.org/10.20517/ss.2022.31

Abstract
Noninvasive monitoring of markers in biofluids is of paramount significance for health and welfare, which is being integrated into the next-generation consumable wearables. Movement-free sweat extraction and continuous monitoring of fresh sweat are two major challenges for wearable plasmonic sweat sensors. In this perspective, we highlight recent approaches that integrated an electronic sweat extraction system and a microfluidic system with plasmonic sensors to address the challenge. The future directions of systematic integration and miniaturization are discussed.
Keywords: Wearable electronics, surface-enhanced Raman spectroscopy, sweat sensor, biomarkers, noninvasive monitoring, health status

7. Organic biodegradable piezoelectric materials and their potential applications as bioelectronics

Review Full-Text PDF RIS
Copy here to cite this article: Dai F, Geng Q, Hua T, Sheng X, Yin L. Organic biodegradable piezoelectric materials and their potential applications as bioelectronics. *Soft Sci* 2023;3:7. http://dx.doi.org/10.20517/ss.2022.30
Abstract
Biodegradable piezoelectrics represent an intriguing category of electroactive materials combining the mechanical-electrical coupling characteristics with a unique biodegradable feature that eliminates unnecessary materials retention and minimize associated infection risks. Here, we review the piezoelectric properties of representative organic biodegradable piezoelectric materials including amino acids, peptides, proteins, synthetic polymers and polysaccharides. Strategies to promote the piezoelectric activity are summarized, and recent progress in the utilization of biodegradable piezoelectric materials for bioelectronics is discussed, with perspectives and challenges provided at the end to enlighten possible future directions.
Keywords: Organic piezoelectric materials, biodegradation, bioelectronics

8. Progress on flexible tactile sensors in robotic applications on objects properties recognition, manipulation and human-machine interactions

Review Full-Text PDF RIS
Copy here to cite this article: Jin J, Wang S, Zhang Z, Mei D, Wang Y. Progress on flexible tactile sensors in robotic applications on objects properties recognition, manipulation and human-machine interactions. *Soft Sci* 2023;3:8.
http://dx.doi.org/10.20517/ss.2022.34
Abstract
The robotic with integrated tactile sensors can accurately perceive contact force, pressure, vibration, temperature and other tactile stimuli. Flexible tactile sensing technologies have been widely utilized in intelligent robotics for stable grasping, dexterous manipulation, object recognition and human-machine interaction. This review presents promising flexible tactile sensing technologies and their potential applications in robotics. The significance of robotic sensing and tactile sensing performance requirements are first described. The commonly used six types of sensing mechanisms of tactile sensors are briefly illustrated, followed by the progress of novel

structural design and performance characteristics of several promising tactile sensors, such as highly sensitive pressure and tri-axis force sensor, flexible distributed sensor array, and multi-modal tactile sensor. Then, the applications of using tactile sensors in robotics such as object properties recognition, grasping and manipulation, and human-machine interactions are thoroughly discussed. Finally, the challenges and future prospects of robotic tactile sensing technologies are discussed. In summary, this review will be conducive to the novel design of flexible tactile sensors and is a heuristic for developing the next generation of intelligent robotics with advanced tactile sensing functions in the future.

Keywords: Intelligent robotic, tactile sensing, object recognition, human-machine interaction, tactile sensor, electronic skin

9. A comprehensive survey of ionic polymer metal composite transducers: preparation, performance optimization and applications

Review Full-Text PDF RIS

Copy here to cite this article: Tang G, Mei D, Zhao X, Zhao C, Li L, Wang Y. A comprehensive survey of ionic polymer metal composite transducers: preparation, performance optimization and applications. *Soft Sci* 2023;3:9.
http://dx.doi.org/10.20517/ss.2023.01

Abstract

Ionic polymer metal composite (IPMC) transducers, as one of the typical electroactive polymers with excellent electromechanical coupling properties, have tremendous potential to achieve high-performance actuators and sensors for flexible electronic and soft robotics. In this survey, after briefly describing the energy conversion mechanism of IPMC, we divided the history of IPMC into three stages based on the published papers, and then introduced the preparation technologies of IPMC in detail, which mainly include the selection of ionomer membrane and formation of electrodes. From the point of view of optimization, we summarized and analyzed the performance improvement methods of IPMC and the problems when it is used as actuators and sensors, respectively. The latest and typical applications of IPMC are widely presented as actuators and sensors, such as actuation in robots, grippers, medical and wearable devices, underwater perception and energy harvesting. Moreover, the challenges and opportunities of IPMC were envisioned for future prosperity. This survey will provide an overall general outline for the categorization, mechanism, precursors, and preparation methods of IPMC, which is helpful in facilitating the rapid development and application of IPMC.

Keywords: IPMC, development, preparation, performance, optimization, applications

10. Portable green energy out of the blue: hydrogel-based energy conversion devices

Review Full-Text PDF RIS

Copy here to cite this article: Liu C, Wang S, Feng SP, Fang NX. Portable green energy out of the blue: hydrogel-based energy conversion devices. *Soft Sci* 2023;3:10.
http://dx.doi.org/10.20517/ss.2022.32

Abstract

To alleviate the escalating global demands for electricity with a low carbon footprint,

we can resort to a green energy source that is conveyed by tiny temperature or moisture gradients. A tremendous source of low-grade energy scatters around us and remains unutilized, which is why thermoelectric and hydrovoltaic devices were invented. Our review focuses on a growing trend of implementing hydrogel-based ionic thermoelectric systems and hydrovoltaic devices as they hold the promise of electric outputs that are several times higher than conventional solid-state inorganic counterparts. This is due to the molecular-level tailorable features of hydrogel polymers and their interactions with water and other functional additives, which provide an ideal platform for low-grade heat and water energy harvesting from fundamental and practical perspectives. This review is divided into three sections. We present working principles, engineering concepts, state-of-art designs, and urgent challenges for hydrogel-based (i) ionic thermoelectric systems; (ii) hydrovoltaic devices; and (iii) their hybrids.

Keywords: Low-grade heat, ionic thermoelectric, hydrovoltaic energy, hydrogel, power generation

11. Recent advances in the design, fabrication, actuation mechanisms and applications of liquid crystal elastomers

Review Full-Text PDF RIS

Copy here to cite this article: Xiao Y, Wu J, Zhang Y. Recent advances in the design, fabrication, actuation mechanisms and applications of liquid crystal elastomers. *Soft Sci* 2023;3:11. http://dx.doi.org/10.20517/ss.2023.03

Abstract

Liquid crystal elastomers (LCEs), as an intriguing class of soft active materials, exhibit excellent actuation performances and biocompatible properties, as well as a high degree of design flexibility, which have been of increasing interest in many disciplines. This review summarizes recent developments in this inspiring area, providing an overview of fabrication methods, design schemes, actuation mechanisms, and diverse applications of LCEs. Firstly, two-stage and one-pot synthesis methods, as well as emerging fabrication techniques (e.g., 3D/4D printing and top-down microfabrication techniques) are introduced. Secondly, the design and actuation mechanisms are discussed according to the different types of stimuli (e.g., heat, light, and electric/magnetic fields, among others). Thirdly, the representative applications are summarized, including soft robotics, temperature/strain sensors, biomedical devices, stretchable displays, and smart textiles. Finally, outlooks on the scientific challenges and open opportunities are provided.

Keywords: Liquid crystal elastomers, fabrication, actuation, stimuli, applications

12. Recent progress in thermal management for flexible/wearable devices

Review Full-Text PDF RIS

Copy here to cite this article: Yun JH, Yoo YJ, Kim HR, Song YM. Recent progress in thermal management for flexible/wearable devices. *Soft Sci* 2023;3:12. http://dx.doi.org/10.20517/ss.2023.04

Abstract

Thermal management for wearable devices is evolving to make ubiquitous applications possible based on advanced devices featuring miniaturization, integration, and ultrathin

designs. Thermal management and control integrated with wearable devices are highly desirable for various applications for human body monitoring, including external heat exposure and metabolic heat generation, in various activities. Recently, dynamic change materials have been integrated with micro/nano thermal management platforms to address the potential for active thermal management. In this article, recent advances in the architecture of effective thermal management in wearable devices are reviewed, along with the essential mechanisms for managing thermal conditions for users in external/internal thermal environments. Appropriate thermal management approaches are proposed for the design and integration of materials/structures tailored to specific targets in wearable devices. In particular, this review is devoted to materials/structures based on five thermal management strategies: conduction, radiation, evaporation/convection, heat absorption/release, and thermoelectric (TE). Finally, the challenges and prospects for practical applications of thermal management in wearable devices are discussed.

Keywords: Thermal management, wearable devices, thermal conductors, radiative coolers, evaporative textiles, thermoelectric devices

13. Stretchable flexible sensors for smart tires based on laser-induced graphene technology

Research Article Full-Text PDF RIS

Copy here to cite this article: Yue Y, Li X, Zhao Z, Wang H, Guo X. Stretchable flexible sensors for smart tires based on laser-induced graphene technology. *Soft Sci* 2023;3:13. http://dx.doi.org/10.20517/ss.2023.02

Abstract

Continuous feedback on a tire is an essential means to ensure tire safety. Smart tires are an important part of the future vehicle control system, which affects the safety and comfort of vehicles by combining sensors with traditional tires to achieve continuous monitoring of real-time dynamic parameters. A stretchable and flexible sensor made of laser-induced graphene (LIG) and PDMS, designed for use in smart tires, is presented in this work. The sensor is known as a LIG-PDMS sensor. Using transfer printing, LIG is formed on a commercial polyimide film under the scribing of a laser beam following the predesigned route before being transferred to a PDMS film. This technology is used to successfully prepare flexible sensors for measuring the tire road interaction at different driving speeds due to its flexibility and shape-following characteristics. The real-time monitoring of the wheel speed and the shape of the tire grounding mark during the driving process is realized by embedding multiple LIG sensors in the tire to monitor the strain information of the tire grounding. Results show that the tire deformation can be accurately feedbacked with the LIG sensors, demonstrating our method's capability for designing and manufacturing intelligent tires.

Keywords: Laser-induced graphene (LIG), stretchable strain sensor, shape-following characteristic, smart tire

14. Recent progress in soft electronics and robotics based on magnetic nanomaterials

Review Full-Text PDF RIS

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nics and robotics based on magnetic nanomaterials. *Soft Sci* 2023;3:14. http://dx.doi.org/10.20517/ss.2023.05

Abstract

Recent advancements in soft electronics and robotics have expanded the possibilities beyond the capabilities of traditional rigid devices, indicating promise for a range of applications in electronic skins, wireless biomedical devices, and others. Magnetic materials exploited in these soft systems can further broaden the modalities in sensing and actuation. These magnetic materials, when constructed in the forms of nanoparticles, nanomembranes, or other types of nanostructures, exhibit some unique characteristics, such as the magnetoresistance effect and size-dependent coercivity. Soft electronics and robotics employing such magnetic nanomaterials offer a variety of functions, including the detection of the intensity and direction of magnetic fields, measurement of various types of mechanical deformations, manipulation and transport at small scales, and multimodal complex locomotion in a controllable fashion. Despite recent advancements in soft electronics and robotics, challenges remain in developing advanced materials and manufacturing schemes to improve performance metrics and facilitate integration with other devices. This review article aims to summarize the progress made in soft electronics and robotics based on magnetic nanomaterials, with an emphasis on introducing material and device performance. The discussions focus on soft electronics and robotics based on magnetic nanomembranes/nanostructures and magnetic composites. As a concluding remark, this article summarizes the current status of the field and discusses opportunities that underpin future progress.

Keywords: Soft electronic, soft robotics, magnetic nanomaterials

15. Stretchable synaptic transistors based on the field effect for flexible neuromorphic electronics

Perspective Full-Text PDF RIS

Copy here to cite this article: Wang X, Qi L, Yang H, Rao Y, Chen H. Stretchable synaptic transistors based on the field effect for flexible neuromorphic electronics. *Soft Sci* 2023;3:15. http://dx.doi.org/10.20517/ss.2023.06

Abstract

Using flexible neuromorphic electronics that emulate biological neuronal systems is an innovative approach for facilitating the implementation of next-generation artificial intelligence devices, including wearable computers, soft robotics devices, and neuroprosthetics. Stretchable synaptic transistors based on field-effect transistors (FETs), which have functions and structures resembling those of biological synapses, are promising technological devices in flexible neuromorphic electronics owing to their high flexibility, excellent biocompatibility, and easy processability. However, obtaining stretchable synaptic FETs with various synaptic characteristics and good stretching stabilities is challenging. Significant efforts to produce stretchable synaptic FETs have been undertaken, and remarkable advances in materials, fabrication processes, and applications have been achieved. From this perspective, we discuss the requirements for neuromorphic devices in flexible neuromorphic electronics and the advantages of stretchable synaptic FETs. Moreover, representative methods used to implement stretchable synaptic transistors, including the structural design and development of intrinsically stretchable devices, are introduced. Additionally, the application of stretchable synaptic transistors in artificial sensory systems such as light, tactile, and

multisensory artificial nervous systems is also discussed. Finally, we highlight the possible challenges in implementing and using stretchable synaptic transistors, propose solutions to overcome the current limitations of these devices, and suggest future research directions.

Keywords: Flexible neuromorphic electronics, stretchable synaptic transistors, field-effect transistors, artificial sensory systems

16. Applications of flexible and stretchable three-dimensional structures for soft electronics

Review Full-Text PDF RIS

Copy here to cite this article: Kim JH, Lee SE, Kim BH. Applications of flexible and stretchable three-dimensional structures for soft electronics. *Soft Sci* 2023;3:16. http://dx.doi.org/10.20517/ss.2023.07

Abstract

The development of devices that can be mechanically deformed in geometrical layouts, such as flexible/stretchable devices, is important for various applications. Conventional flexible/stretchable devices have been demonstrated using two-dimensional (2D) geometry, resulting in dimensional constraints on device operations and functionality limitations. Accordingly, expanding the dimensions in which such devices can operate and acquiring unique functionality that is difficult to implement in 2D planar structures remain challenging. As a solution, the development of a flexible/stretchable device embedding a three-dimensional (3D) structure fabricated through the precise control of a 2D structure or direct construction has been attracting significant attention. Because of a significant amount of effort, several 3D material systems with distinctive engineering properties, including electrical, optical, thermal, and mechanical properties, which are difficult to occur in nature or to obtain in usual 2D material systems, have been demonstrated. Furthermore, 3D advanced material systems with flexibility and stretchability can provide additional options for developing devices with various form factors. In this review, novel fabrication methods and unprecedented physical properties of flexible/stretchable 3D material systems are reviewed through multiple application cases. In addition, we summarized the latest advances and trends in innovative applications implemented through the introduction of advanced 3D systems in various fields, including microelectromechanical systems, optoelectronics, energy devices, biomedical devices, sensors, actuators, metamaterials, and microfluidic systems.

Keywords: Flexible, stretchable, three-dimensional (3D), soft electronics

17. Multimodal electronic textiles for intelligent human-machine interfaces

Review Full-Text PDF RIS

Copy here to cite this article: Wei X, Liang X, Meng C, Cao S, Shi Q, Wu J. Multimodal electronic textiles for intelligent human-machine interfaces. *Soft Sci* 2023;3:17. http://dx.doi.org/10.20517/ss.2023.09

Abstract

Smart wearable electronic devices capable of information exchanging (such as human-machine interfaces) have developed into key carriers for the interconnection, intercommunication, and interaction between humans and machines. Multimodal electronic textiles that incorporate multifunctional sensors into daily clothing are an

emerging technology to realize smart wearable electronics. This has greatly advanced human-machine interface technology by bridging the gap between wearing comfort and traditional wearable electronic devices, which will facilitate the rapid development and wide application of natural human-machine interfaces. In this article, we provide a comprehensive summary of the latest research progress on multimodal electronic textiles for intelligent human-machine interfaces. Firstly, we introduce the most representative electronic textile manufacturing strategies in terms of functional fiber preparation and multimodal textile forming. Then, we explore the multifunctional sensing capability of multimodal electronic textiles and emphasize their advanced applications in intelligent human-machine interfaces. Finally, we present new insights on the future research directions and the challenges faced in practical applications of multimodal electronic textiles.

Keywords: Electronic textiles, multimodal sensing, human-machine interfaces, intelligent applications

18. Injectable and tissue-conformable conductive hydrogel for MRI-compatible brain-interfacing electrodes

Research Article Full-Text PDF RIS

Copy here to cite this article: Kim SD, Park K, Lee S, Kum J, Kim Y, An S, Kim H, Shin M, Son D. Injectable and tissue-conformable conductive hydrogel for MRI-compatible brain-interfacing electrodes. *Soft Sci* 2023;3:18. http://dx.doi.org/10.20517/ss.2023.08

Abstract

The development of flexible and stretchable materials has led to advances in implantable bio-integrated electronic devices that can sense physiological signals or deliver electrical stimulation to various organs in the human body. Such devices are particularly useful for neural interfacing systems that monitor neurodegenerative diseases such as Parkinson's disease or epilepsy in real time. However, coupling current brain-interfacing devices with magnetic resonance imaging (MRI) remains a practical challenge due to resonance frequency variations from inorganic metal-based devices. Thus, organic conductive materials, such as poly(3,4-ethylenedioxythiophene)-poly(styrenesulfonate) (PEDOT:PSS), have recently been considered as promising candidates. Nonetheless, their conformability on curvilinear tissues remains questionable. In this study, we developed an injectable conductive hydrogel (ICH) composed of tyramine-conjugated hyaluronic acid (HATYR) and PEDOT:PSS for MRI-compatible brain-interfacing electrodes. Our ICH produced low impedance around 5 kΩ even under 10 Hz, demonstrating high confidence volumetric capacitance. Due to HATYR's biocompatibility, histological and cytotoxicity assays showed almost no inflammation and toxicity, respectively; in addition, ICH was able to degrade into 40% of its original volume within four weeks in vivo. An electrocorticogram (ECoG) array was also patternable by syringe injections of ICH on a stretchable and flexible elastomeric substrate layer that conformed to curvy brain tissues and successfully recorded ECoG signals under light stimulation. Furthermore, MRI imaging of implanted devices did not show any artifacts, indicating the potential of the MRI-compatible hydrogel electrodes for advanced ECoG arrays. This study provides a promising solution for MRI-compatible neural electrodes, enabling the advancement of chronic neural interfacing systems for monitoring neurodegenerative diseases.

Keywords: Injectable conducting hydrogel, hyaluronic acid, PEDOT:PSS, electrode array, electrocorticogram, MRI

19. Challenges and progress of chemical modification in piezoelectric composites and their applications

Review Full-Text PDF RIS

Copy here to cite this article: Zhang W, Zhang Y, Yan X, Hong Y, Yang Z. Challenges and progress of chemical modification in piezoelectric composites and their applications. *Soft Sci* 2023;3:19. http://dx.doi.org/10.20517/ss.2022.33

Abstract

Piezoelectric materials directly convert energy between electrical and mechanical domains, and have been widely employed in electronic devices as sensors and energy harvesters. Recent research endeavors are mainly devoted to dealing with problems such as high stiffness, brittleness, toxicity, poor durability, and low piezoelectric coefficients. Among developed strategies, chemical modification captures much attention. However, the exact physical properties and direct experimental evidence of chemical modification remain elusive or controversial thus far. In this review, we discuss the recently developed piezoelectric modification strategies for piezoelectric composites and assess the effect of different chemical modification approaches on piezoelectric properties. Moreover, we outline existing challenges and new applications of piezoelectric composites.

Keywords: Piezoelectric materials, composite, sensor, energy harvesting, transducer, flexible electronics

20. A lamellar-ordered poly[bi(3,4-ethylenedioxythiophene)-alt-thienyl] for efficient tuning of thermopower without degenerated conductivity

Research Article Full-Text PDF RIS

Copy here to cite this article: Shen L, Liu M, Liu P, Xu J, Li N, Wan Z, Chen Z, Liu C, Zhou W, Liang Y, Jiang F. A lamellar-ordered poly[bi(3,4-ethylenedioxythiophene)-alt-thienyl] for efficient tuning of thermopower without degenerated conductivity. *Soft Sci* 2023;3:20. http://dx.doi.org/10.20517/ss.2023.10

Abstract

Modulating the structural order of conjugated polymers has emerged as a significant approach to enhance the organic thermoelectric performance. Among these materials, poly(3,4-ethylenedioxythiophene) is considered a promising candidate due to its high conductivity. However, its low thermopower remains a major obstacle to further improve its performance as an organic thermoelectric material. To address this issue, a series of thiophene derivatives with high rigidity and containing dioxyethylene groups were synthesized, and polymer films were prepared through a simple and mild in-situ polymerization method. The polymer molecule containing a thiophene block, named poly[bi(3,4-ethylenedioxy)-alt-thienyl] , exhibits significant self-rigidification due to non-covalent interactions between oxygen and sulfur atoms, resulting in highly ordered assembly. By adding thiophene and thieno[3,2-b]thiophene structures to the intermediate precursor bi(3,4-ethylenedioxy), the 3,4-ethylenedioxy content in the polymer molecule is altered, leading to an almost four-fold increase in the thermopower of the thin film polymer and achieving a maximum thermopower of around 26 μV·K-

1. Although poly[bi(3,4-ethylenedioxy)-alt-thienyl] shows a significant increase in thermopower compared to poly[bi(3,4-ethylenedioxy)], the thin film conductivity exhibits a nearly imperceptible decreasing trend due to its highly ordered microstructure. This work highlights the potential to control the aggregation state of polymer molecules and achieve an approximate decoupling between the conductivity and thermopower of thermoelectric materials by rationally designing polymer molecules.

Keywords: Aggregation regulation, precursor structure modification, polythiophenyl derivatives, organic thermoelectric material

21. Reduced graphene oxide reinforced PDA-Gly-PVA composite hydrogel as strain sensors for monitoring human motion

Research Article Full-Text PDF RIS

Copy here to cite this article: Ke X, Mu X, Chen S, Zhang Z, Zhou J, Chen Y, Gao J, Liu J, Wang X, Ma C, Miao L. Reduced graphene oxide reinforced PDA-Gly-PVA composite hydrogel as strain sensors for monitoring human motion. *Soft Sci* 2023;3:21. http://dx.doi.org/10.20517/ss.2023.14

Abstract

Hydrogels with soft, skin-friendly properties and high biocompatibility are promising alternatives to traditional sensors. However, balancing electrical conductivity and sensitivity remains a significant challenge. The sensitivity-improved strain sensor was designed by reduced graphene oxide (rGO) reinforced polydopamine (PDA)-glycerol (Gly)-polyvinyl alcohol composite hydrogels (PGPHs). The hydrogels exhibited excellent sensing sensitivity with a gauge factor of 2.78, conductivity of 2.2 S/m, tensile deformation of 200%, fast response time of 370 ms, and recovery time of 260 ms, surpassing those of most previously reported hydrogel-based strain sensors. This improvement can be attributed to the high electrical conductivity and uniform distribution of the rGO associated with Gly and PDA. PGPHs also exhibited an attractive monitoring effect for hand movements and precise detection feedback for the slight dynamics of the pharynx. Hydrogel-based strain sensors have been demonstrated as a potentially sustainable solution for dynamic detection and communication.

Keywords: Composite hydrogels, reduced graphene oxide, strain sensors, dynamic detection

22. Hair-compatible sponge electrodes integrated on VR headset for electroencephalography

Research Article Full-Text PDF RIS

Copy here to cite this article: Li H, Shin H, Zhang M, Yu A, Huh H, Kwon G, Riveira N, Kim S, Gangopadahyay S, Peng J, Li Z, Rao Y, Sentis L, Millán JR, Lu N. Hair-compatible sponge electrodes integrated on VR headset for electroencephalography. *Soft Sci* 2023;3:22. http://dx.doi.org/10.20517/ss.2023.11

Abstract

Virtual reality (VR) technology has emerged as a promising tool for brain-computer interaction and neuroscience research due to its ability to provide immersive and interactive experiences for its users. As a powerful tool to noninvasively monitor the cortex, electroencephalography (EEG) combined with VR represents an exciting opportunity for the measurement of brain activity during these experiences, providing

insight into cognitive and neural processes. However, traditional gel-based EEG sensors are not compatible with VR headsets, and most emerging VR-EEG headsets utilizing rigid comb electrodes are uncomfortable after prolonged wear. To address this limitation, we created soft, porous, and hair-compatible sponge electrodes based on conductive poly(3,4-ethylenedioxythiophene) polystyrene sulfonate/melamine (PMA) and integrated them onto a VR headset through a customized, flexible circuit for multichannel EEG during VR task performing. Our PMA sponge electrodes can deform to make contact with the scalp skin through hairs under the pressure naturally applied by the strap of the VR headset. The specific contact impedance was consistently below 80 kΩ·cm2, even at hairy sites. We demonstrated the capability of our VR-EEG headset by recording alpha rhythms during eye closure at both hairless and hairy sites. In another demonstration, we developed a VR task to evoke the contingent negative variation potential and achieved a classification accuracy of 0.66 ± 0.07, represented by the cross-validated area under the receiver operating characteristic curve. Our sponge-electrode-integrated VR headset is user-friendly and easy to set up, marking a step toward future reliable, comfortable, and reusable VR-EEG technology.

Keywords: PEDOT:PSS, soft electrode, electroencephalography, virtual reality, brain-computer interface

23. Wireless batteryless soft sensors for ambulatory cardiovascular health monitoring

Review Full-Text PDF RIS

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Abstract

Seismocardiography (SCG) is the measure of local vibrations in the chest due to heartbeats. Typically, SCG signals are measured using rigid integrated circuit (IC) accelerometers and bulky electronics. However, as alternatives, recent studies of emerging flexible sensors show promise. Here, we introduce the development of wireless soft capacitive sensors that require no battery or rigid IC components for measuring SCG signals for cardiovascular health monitoring. Both the capacitive and inductive components of the circuit are patterned with laser micromachining of a polyimide-coated copper and are encapsulated with an elastomer. The wearable soft sensor can detect small strain changes on the skin, which is wirelessly measured by examining the power reflected from the antenna at a stimulating frequency. The performance of the device is verified by comparing the fiducial points to SCG measured by a commercial accelerometer and electromyograms from a commercial electrode. Overall, the human subject study demonstrates that the fiducial points are consistent with data from commercial devices, showing the potential of the ultrathin soft sensors for ambulatory cardiovascular monitoring without bulky electronics and rigid components.

Keywords: Soft sensor, capacitive strain sensor, passive wireless, laser micromachining, LC resonance sensor, ambulatory monitoring, cardiovascular health

24. Prospects of soft biopotential interfaces for wearable human-machine interactive devices and applications

Review Full-Text PDF RIS

Copy here to cite this article: Nagwade P, Parandeh S, Lee S. Prospects of soft biopotential interfaces for wearable human-machine interactive devices and applications. *Soft Sci* 2023;3:24. http://dx.doi.org/10.20517/ss.2023.12

Abstract

Human interaction with machines can be made easy, comfortable, and accessible by introducing user-friendly interfaces. In the case of wearable devices, their sensors and other interfacing elements are very well within the proximity of users. Since biopotential signals can be accessed from the surface of the human skin, users can have seamless interaction with wearable human-computer interactive devices. Rigid interfaces can hinder the user experience, and therefore, the need for soft biopotential interfaces is important. Imperceptible and unobtrusive soft biopotential interfaces will drastically enhance many aspects of human-computer interaction. This paper reviews the use of soft, flexible, and stretchable biopotential interfaces in wearable human-machine interactive devices. Additionally, attention is brought to the scope of other possible applications of soft biopotential interfaces in wearable devices.

Keywords: Biopotential, soft interface, wearable, interface, human-machine interface (HMI), human-computer interaction (HCI)

25. Electronic skins with multimodal sensing and perception

Perspective Full-Text PDF RIS

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Abstract

Multiple types of sensory information are detected and integrated to improve perceptual accuracy and sensitivity in biological cognition. However, current studies on electronic skin (e-skin) systems have mainly focused on the optimization of the modality-specific data acquisition and processing. Endowing e-skins with the abilities of multimodal sensing and even perception that can achieve high-level perception behaviors has been insufficiently explored. Moreover, the perception progress of multisensory e-skin systems is faced with challenges at both device and software levels. Here, we provide a perspective on the multisensory fusion of e-skins. The recent progress in e-skins realizing multimodal sensing is reviewed, followed by bottom-up and top-down multimodal perception. With the deepening understanding of neuroscience and the rapid advance of novel algorithms and devices, multimodal perception function becomes possible and will promote the development of highly intelligent e-skin systems.

Keywords: Electronic skins, multimodal sensing, perception fusion

26. Self-powered wearable IoT sensors as human-machine interfaces

Review Full-Text PDF RIS

Copy here to cite this article: Xi Y, Tan P, Li Z, Fan Y. Self-powered wearable IoT sensors as human-machine interfaces. *Soft Sci* 2023;3:26. http://dx.doi.org/10.20517/ss.2023.13

Abstract

Self-powered wearable Internet of Things (IoT) sensors have made a significant impact on human life and health in recent years. These sensors are known for their convenience, durability, affordability, and longevity, leading to substantial improvements in people's lives. This review summarizes the development of self-powered wearable IoT sensors in recent years. Materials for self-powered wearable sensors are summarized and evaluated, including nanomaterials, flexible materials, and degradable materials. The working mode of self-powered wearable IoT sensors is analyzed, and the different principles of its physical sensing and chemical sensing are explained. Several common technologies for self-powered wearable IoT sensors are presented, such as triboelectric technology, piezoelectric technology, and machine learning. The applications of self-powered IoT wearable sensors in human-machine interfaces are reviewed. Its current shortcomings and prospects for its future development are also discussed. To conduct this review, a comprehensive literature search was performed using several electronic databases, resulting in the inclusion of 225 articles. The gathered data was extracted, synthesized, and analyzed using a thematic analysis approach. This review provides a comprehensive analysis and summary of its working mode, technologies, and applications and provides references and inspiration for related research in this field. Furthermore, this review also identifies the key directions and challenges for future research.

Keywords: Self-powered sensor, internet of things, human-machine interfaces

27. Soft conductive nanocomposites for recording biosignals on skin

Review Full-Text PDF RIS

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Abstract

Soft conductive nanocomposites have introduced significant breakthroughs in bio-integrated electronics by mitigating the mechanical mismatch between the body and the device. Compared with conventional wearable sensors based on rigid electronic materials, the wearable sensors based on soft nanocomposites are advantageous to long-term and high-quality biosignal recordings. Materials used for the synthesis of the nanocomposites, especially nanofillers, are critical for determining the quality of

recorded biosignals and the performance of the nanocomposites. In this review, we focus on recent advances in soft conductive nanocomposites, mainly on their electrical and mechanical properties according to the types of nanofillers, and present their applications to wearable biosignal recording devices. We have classified the nanofillers into four categories: carbon-based nanomaterials, conducting polymers, metal-based nanomaterials, and liquid metals. We then introduce the applications of nanocomposites as wearable sensors that record various biosignals, including electrophysiological, strain, pressure, and biochemical information. In conclusion, a brief outlook on the remaining challenges for future nanomaterial-based bioelectronics is provided.

Keywords: Nanocomposites, nanomaterials, soft materials, wearable sensors, bio-integrated electronics

28. Development of soft dry electrodes: from materials to structure design

Perspective Full-Text PDF RIS

Copy here to cite this article: Liu H, Chen X, Wang Z, Liu Y, Liang C, Zhu M, Qi D. Development of soft dry electrodes: from materials to structure design. *Soft Sci* 2023;3:27. http://dx.doi.org/10.20517/ss.2023.16

Abstract

Bioelectric signals reflect our daily physiological activities, which can be recorded in the form of electroencephalography, electrocardiography, electromyography, etc. The traditional Ag/AgCl wet electrode is the gold standard for clinical monitoring of bioelectrical signals at present, while complicated preparation and gel evaporation limit its long-term application. Therefore, it is meaningful to research dry electrodes without conductive paste or additional adhesives. Unfortunately, the high interface impedance between electrodes and skin is a fatal defect of dry electrodes, which leads to excessive noise levels and poor signal quality. Consequently, more efforts are required to achieve conformal contact between dry electrodes and skin to reduce the contact impedance. From this perspective, we review the recent progress in capacitive electrodes, invasive microneedle electrodes, and common-contact dry electrodes. Material selection and structural design to obtain conformal contact are highlighted. Finally, we propose the future development direction of dry electrodes.

Keywords: Dry electrode, conformal contact, electrode-skin impedance, bioelectric signal

29. Advances in printing techniques for thermoelectric materials and devices

Review Full-Text PDF RIS

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Abstract

Thermoelectric materials and devices have garnered significant attention in recent years

due to their potential for converting waste heat into usable electricity, opening new avenues for sustainable energy harvesting. As research in the field of thermoelectric materials and devices continues to grow, so does the need for efficient and scalable fabrication methods. Among various fabrication techniques, printing methods have emerged as promising approaches to producing thermoelectric materials and devices, offering advantages such as low cost, high throughput, and design flexibility. Here, we overview the recent advances in printing methods for the fabrication of thermoelectric materials and devices. We discuss the key principles, challenges, and opportunities associated with various printing techniques, including screen printing, inkjet printing, and 3D printing, with a focus on their applications in thermoelectric materials and devices. Furthermore, we highlight the progress made in optimizing the printing parameters, ink formulations, and post-processing methods to enhance the thermoelectric performance of printed materials and devices. Finally, we provide insights into the prospects and potential research directions in the field of printing methods for thermoelectric materials and devices. This review aims to provide a comprehensive overview of the state-of-the-art printing techniques for thermoelectric materials and devices and to serve as a reference for researchers and practitioners working in this rapidly growing field.

Keywords: Flexible thermoelectric generators, large-scale fabrication, printing technology, transport of charge carriers, phonon scatterings

30. Flexible pressure and temperature sensors towards e-skin: material, mechanism, structure and fabrication

Review Full-Text PDF RIS

Copy here to cite this article: Tian S, Wang Y, Deng H, Wang Y, Zhang X. Flexible pressure and temperature sensors towards e-skin: material, mechanism, structure and fabrication. *Soft Sci* 2023;3:30. http://dx.doi.org/10.20517/ss.2023.21

Abstract

Electronic skin (E-skin) has gained significant attention due to its potential applications in the Internet of Things (IoT), artificial intelligence (AI), and flexible multi-sensing systems. Mimicking human skin, e-skin sensing devices can be employed in various scenarios. Among the most important sensing elements for tactile e-skin sensors are pressure and temperature sensors, which have increasingly garnered research interest over the past few decades. However, the design and fabrication of advanced pressure and temperature sensors can be challenging owing to complications such as signal interference, complex mechanism integration, and structural design issues. This review provides an overview of flexible pressure and temperature sensors used in e-skin, covering four main perspectives: material selection, mechanism integration, structural design, and manufacturing methods. The materials of different elements in the entire sensing system are comprehensively discussed, along with single and compound mechanisms of pressure and temperature sensing. Pressure and temperature sensors are

divided into two types based on their electric output signals, which are exemplified in detail. The manufacturing methods used to fabricate these sensors, including printing methods, are outlined. Lastly, a summary of the future challenges faced by flexible pressure and temperature sensors used in e-skin is presented.

Keywords: Flexible electronics, electronic skin, printed sensors, MEMS, human-machine interaction

31. Bioreceptor-inspired soft sensor arrays: recent progress towards advancing digital healthcare

Review Full-Text PDF RIS

Copy here to cite this article: Arab Hassani F. Bioreceptor-inspired soft sensor arrays: recent progress towards advancing digital healthcare. *Soft Sci* 2023;3:31. http://dx.doi.org/10.20517/ss.2023.23

Abstract

Recent advances in soft sensor technology have pushed digital healthcare toward life-changing solutions. Data reliability and robustness can be realised by building sensor arrays that collect comprehensive biological parameter data from several points on the underlying organs simultaneously, a principle that is inspired by bioreceptors. The rapid growth of soft lithography and printing, three-dimensional (3D) printing, and weaving/knitting technologies has facilitated the low-cost development of soft sensors in the array format. Advances in data acquisition, processing, and visualisation techniques have helped with the collection of meaningful data using arrays and their presentation to users on personal devices through wireless communication interfaces. Local- or cloud-based data storage helps with the collection of adequate data from sensor arrays over time to facilitate reliable prognoses based on historical data. Emerging energy harvesting technologies have led to the development of techniques to power sensor arrays sustainably. This review presents developmental building blocks in wearable and artificial organ-based soft sensor arrays, including bioreceptor-inspired sensing mechanisms, fabrication methods, digital data-acquisition techniques, methods to present the results to users, power systems, and target diseases/conditions for treatment or monitoring. Finally, we summarise the challenges associated with the development of single and multimodal array sensors for advanced digital healthcare and suggest possible solutions to overcome them.

Keywords: Bioreceptor-inspired, soft sensor arrays, multimodal, senses of vision, hearing, taste, smell, spatial perception

32. Flexible tactile sensor with an embedded-hair-in-elastomer structure for normal and shear stress sensing

Research Article Full-Text PDF RIS

Copy here to cite this article: Cao Y, Li J, Dong Z, Sheng T, Zhang D, Cai J, Jiang Y. Flexible tactile sensor with an embedded-hair-in-elastomer structure for normal and

shear stress sensing. *Soft Sci* 2023;3:32. http://dx.doi.org/10.20517/ss.2023.22

Abstract

Endowing robots with multi-directional tactile sensing capabilities has long been a challenging task in the field of flexible electronics and intelligent robots. This paper reports a highly sensitive, flexible tactile sensor with an embedded-hair-in-elastomer structure, which is capable of decoupling normal stress and shear stress. The flexible tactile sensor is fabricated on a thin polyimide substrate and consists of four self-bending piezoresistive cantilevers in a cross-shaped configuration, which are embedded in an elastomer. The sensor can decouple the tactile information into a normal stress and a shear stress with simple summation and differencing algorithms, and the measurement error is kept within 3%. Moreover, the sensitivity and detection threshold of the sensor can be adjusted by simply changing the elastic material. As a demonstration, the flexible tactile sensor is integrated into a robotic manipulator to precisely estimate the weight of the grasped objects, which shows great potential for application in robotic systems.

Keywords: Tactile sensor, piezoresistive cantilever, flexible sensor, intelligent robot

33. A stretchable all-nanofiber iontronic pressure sensor

Research Article Full-Text PDF RIS

Copy here to cite this article: Wu Y, Dong S, Li X, Wen L, Shen H, Li M, Liu X, Zhang Y, Zeng G, Zheng J, Wu D. A stretchable all-nanofiber iontronic pressure sensor. *Soft Sci* 2023;3:33. http://dx.doi.org/10.20517/ss.2023.24

Abstract

Flexible pressure sensors with high stretchability, sensitivity, and stability are undoubtedly urgently required for potential applications in intelligent soft robots, human-machine interaction, health monitoring, and other fields. However, most current flexible pressure sensors are unable to endure large deformation and are prone to performance degradation or even failure during frequent operation due to their multilayered structures. Here, we propose a stretchable all-nanofiber iontronic pressure sensor that is composed of ionic nanofiber membranes used as dielectric layers and liquid metal used as electrodes. This sensor exhibits a high sensitivity of 1.08 kPa-1 over a wide range of 0-300 kPa, with a fast response-relaxation time of about 18/22 ms and excellent stability. The high sensitivity comes from the electric double layer formed at the ionic film/electrode interface, while high stretchability and stability are enabled by in-situ encapsulated all-nanofiber structures. As a proof of concept, a prototype sensor array is integrated into a soft pneumatic gripper, demonstrating its capability of pressure perception and object recognition during the grasping process. Thus, the scheme provides another excellent strategy to fabricate stretchable pressure sensors with superb performance in terms of high stretchability, sensitivity, and stability.

Keywords: Electrospinning, all-nanofiber structures, stretchable iontronic pressure sensor, soft pneumatic gripper

34. Vacuum filtration method towards flexible thermoelectric films

Review Full-Text PDF RIS

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Abstract

Thermoelectric (TE) conversion technology can directly exploit the temperature difference of several Kelvin between the human body and the environment to generate electricity, which provides a self-powered solution for wearable electronics. Flexible TE materials are increasingly being developed through various methods, among which the vacuum filtration method stands out for its unique advantages, attracting the favor of researchers. It has been proven to construct flexible TE thin films with excellent performance effectively. This paper presents a comprehensive overview and survey of the advances of the vacuum filtration method in producing flexible TE thin films. The materials covered in this study include conducting polymer-based materials, carbon nanoparticle-based materials, inorganic materials, two-dimensional materials, and ternary composites. Finally, we explore potential research outlooks and the significance of flexible films, which are at the forefront of research in TE materials science.

Keywords: Thermoelectric, vacuum filtration, flexible film

35. Liquid metal-based strain-sensing glove for human-machine interaction

Research Article Full-Text PDF RIS

Copy here to cite this article: Wu P, Yiu CK, Huang X, Li J, Xu G, Gao Y, Yao K, Chow L, Zhao G, Yang Y, Jiao Y, Yu X. Liquid metal-based strain-sensing glove for human-machine interaction. *Soft Sci* 2023;3:35. http://dx.doi.org/10.20517/ss.2023.26

Abstract

Soft and stretchable strain sensors have aroused great interest in research and engineering fields due to their promising application potential in many areas, including human-machine interface and healthcare monitoring. However, developing stable, strain-sensitive, and fatigue-resistant wearable strain sensors remains challenging. Herein, we report a low-cost strain-sensing glove based on a commercial nitrile glove and liquid metal as both sensing units and circuit/interconnects, with excellent response to strains and great stability in long-term use. The liquid metal sensing circuit is prepared by scraping the liquid metal slurry in situ on glove fingers, followed by soft silicone encapsulation. The whole process does not involve toxic chemicals, so no strict requirements on the operating environment are necessary. The strain-sensing glove is capable of real-time monitoring of finger gestures in a very sensitive and accurate way, which exhibits great application potential as a soft controller in manipulating the machine hand to achieve related human-machine interaction.

Keywords: Liquid metal, strain sensor, human-machine interaction, flexible electronics

36. A highly stretchable and sintering-free liquid metal composite conductor enabled by ferrofluid

Research Article Full-Text PDF RIS

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Abstract

Stretchable and highly conductive elastomers with intrinsically deformable liquid metal (LM) fillers exhibit promising potential in soft electronics, wearables, human-machine interfaces, and soft robotics. However, conventional LM-elastomer (LME) conductors require a high loading ratio of LM and the post-sintering to rupture LM particles to achieve electric conductivity, which results in high LM consumption and process complexity. In this work, we presented a straightforward and post-sintering-free method that utilizes magnetic aggregation to fabricate stretchable LME conductors. This was achieved by dispersing LM ferrofluid into the elastomer precursor, followed by applying the magnetic field to induce the aggregation and interconnection of the LM ferrofluid particles to form conductive pathways. This method not only simplifies the preparation of initially conductive LME but also reduces the LM loading ratio. The resulting conductive LME composites show high stretchability (up to 650% strain), high conductance stability, and magnetic responsiveness. The stretchable LME conductors were demonstrated in various applications, including the creation of flexible microcircuits, a magnetically controlled soft switch, and a soft hydrogel actuator for grasping tasks. We believe the stretchable LME conductors may find wide applications in electronic skins, soft sensors, and soft machines.

Keywords: Liquid metal, sintering-free, conductor, ferrofluid

37. Recent advancements in liquid metal enabled flexible and wearable biosensors

Review Full-Text PDF RIS

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Abstract

Wearable biosensors have demonstrated enormous potential in revolutionizing healthcare by providing real-time fitness tracking, enabling remote patient monitoring, and facilitating early detection of health issues. To better sense vital life signals, researchers are increasingly favoring wearable biosensors with flexible properties that can be seamlessly integrated with human tissues, achieved through the utilization of soft materials. Gallium (Ga)-based liquid metals (LMs) possess desirable properties, such as fluidity, high conductivity, and negligible toxicity, which make them inherently soft and well-suited for the fabrication of flexible and wearable biosensors. In this article, we present a comprehensive overview of the recent advancements in the nascent

realm of flexible and wearable biosensors employing LMs as key components. This paper provides a detailed exposition of the unique characteristics of Ga-based LM materials, which set them apart from traditional materials. Moreover, the state-of-the-art applications of Ga-based LMs in flexible and wearable biosensors that expounded from six aspects are reviewed, including wearable interconnects, pressure sensors, strain sensors, temperature sensors, and implantable bioelectrodes. Furthermore, perspectives on the key challenges and future developing directions of LM-enabled wearable and flexible biosensors are also discussed.

Keywords: Liquid metal, flexible electronics, biosensors, wearable electronics

38. Morphing matter: from mechanical principles to robotic applications

Review Full-Text PDF RIS

Copy here to cite this article: Yang X, Zhou Y, Zhao H, Huang W, Wang Y, Hsia KJ, Liu M. Morphing matter: from mechanical principles to robotic applications. *Soft Sci* 2023;3:38. http://dx.doi.org/10.20517/ss.2023.42

Abstract

The adaptability of natural organisms in altering body shapes in response to the environment has inspired the development of artificial morphing matter. These materials encode the ability to transform their geometrical configurations in response to specific stimuli and have diverse applications in soft robotics, wearable electronics, and biomedical devices. However, achieving the morphing of intricate three-dimensional shapes from a two-dimensional flat state is challenging, as it requires manipulations of surface curvature in a controlled manner. In this review, we first summarize the mechanical principles extensively explored for realizing morphing matter, both at the material and structural levels. We then highlight its applications in the soft robotics field. Moreover, we offer insights into the open challenges and opportunities that this rapidly growing field faces. This review aims to inspire researchers to uncover innovative working principles and create multifunctional morphing matter for various engineering fields.

Keywords: Shape-morphing, mechanical principles, strain-mismatch, elastic instability, origami/kirigami, discrete element, morphogenesis-inspiring, robotic application

39. Soft devices empowered by mechanoluminescent materials

Perspective Full-Text PDF RIS

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Abstract

Mechanoluminescence is the phenomenon in which certain materials emit light when subjected to mechanical stimuli, such as bending, stretching, or compression. Soft devices containing embedded mechanoluminescent materials are capable of responding

to mechanical deformation by emitting light, which can be utilized for various applications, including sensing, display, communication, and visual feedback. In this Perspective, we discuss recent advancements and emerging applications of mechanoluminescent materials for soft devices, with a focus on the remaining challenges in mechanoluminescent materials, such as performance, mechanism, synthesis, and device fabrication, that need to be addressed for developing advanced soft devices, and propose the potential solutions.

Keywords: Mechanoluminescence, mechano-to-light conversion, soft devices, wearable electronics, internet of things

40. Liquid metals nanotransformer for healthcare biosensors

Review Full-Text PDF RIS

Copy here to cite this article: Bai Y, Zhang J, Lu C, Rao W. Liquid metals nanotransformer for healthcare biosensors. *Soft Sci* 2023;3:40. http://dx.doi.org/10.20517/ss.2023.38

Abstract

Featuring low cost, low melting points, excellent biocompatibility, outstanding electrical conductivity, and mechanical properties, gallium-based liquid metals (LMs) have become a promising class of materials to fabricate flexible healthcare sensors. However, the extremely high surface tension hinders their manipulation and cooperation with substrates. To address this problem, the inspiration of nanomaterials has been adopted to mold LMs into LM nanoparticles (LMNPs) with expanded advantages. The transformability of LMNPs endows them with functionalities for sensors in multiple dimensions, such as intelligent response to specific molecules or strains, various morphologies, integration into high-resolution circuits, and conductive elastomers. This review aims to summarize the superior properties of LMs, transformability of LMNPs, and correlated advantages for sensor performance. Multidimensional functional sensing forms consisting of LMNPs and corresponding applications as healthcare sensors will be presented. In the end, the existing challenges and prospects in the processing and application of LMNPs will also be discussed.

Keywords: Liquid metal, nanoparticles, transformability, healthcare biosensors, flexible electronics