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Research Highlight

A multimodal ion electronic skin for decoupling temperature and strain

Juan Tao [a], Chunfeng Wang [a], Caofeng Pan [a,b,c,*]

[a] College of Physics and Optoelectronic Engineering, Shenzhen University, Shenzhen 518060, China
[b] CAS Center for Excellence in Nanoscience, Beijing Key Laboratory of Micro-nano Energy and Sensor, Beijing Institute of Nanoenergy and Nanosystems, Chinese Academy of Sciences, Beijing 100083, China
[c] School of Nanoscience and Technology, University of Chinese Academy of Sciences, Beijing 100049, China

Human skin possessing abundant thermal and mechanical receptors can distinctively perceive temperature and various mechanical deformations [1]. Mimicking of skin has been emerging with the breakthrough in human–machine interfaces, automation, smart robotics, and Internet of Things, and tactile sensors with onefold sensing capability are gradually inadequate to meet the complex application scenarios. Therefore, multimodal electronic skin (e-skin) mimicking and reproducing the properties of human skin can simultaneously monitor various external stimuli (pressure, temperature, strain, etc.), holding great significance in the next generation of artificial intelligent products [2,3]. Much efforts have been dedicated to the realization of multifunctional sensors by integrating different sensing modules together [4,5], or utilizing a single sensing unit without decoupling [6]. Both of these two methods have their own limitations. First, integrating multimodules into a device would suffer from the structural complexity, low spatial resolution, and complicated technological process. Multi-sensing in a single unit could be a great approach to availably evade aforementioned obstacles, but still encounters inevitable drawbacks including signal interference and accuracy level of measurement. Alternatively, inherent material property independent from variation in dimension can be an access to differentiating temperature sensing from other stimuli evaluated by extrinsic values like resistance or capacitance. Some endeavors have been made to decouple temperature and other mechanical deformation using inherent variables like thermoelectric [7] and pyroelectric [8]. Relied on this concept, simultaneous sensing for temperature and other stimulus without mutual interference in a single unit or one-structure could be a superior option. However, the thermoelectric and pyroelectric effects are mainly resided in some rigid or flexible film materials, thus, the lack of the stretchability within such tactile devices impedes their application scopes, especially in soft robots, wearable devices and stretchable electronics.

Recently, Zhenan Bao and her colleagues [9] have demonstrated a deformable multimodal electronic skin based on ion relaxation dynamics that can distinguish spatial profiles of temperature and strain simultaneously without signal interference in a single unit (Fig. 1a). This soft haptic sensor is composed of an ion conductor (1-ethyl-3-methylimidazoliumbis(trifluoromethylsulfonyl)imide (EMIMTFSI)) sandwiched by top and bottom stretchable electrodes. The Bode plot is utilized to characterize the electrical properties of ionic conductor, dominated by ion migration and polarization at low frequency and high frequency severally. The resistance ($R = d/\sigma A$) and capacitance ($C=\epsilon A/d$) of the ion conductor are approximately equal to the real impedance and the imaginary impedance, where d, A, σ, and ϵ are the thickness, area, ion conductivity, and dielectric constant, respectively. Under external mechanical stretching, the overall impedance plot of the sensor parallelly shifts down with resistance and capacitance going up and down, respectively (Fig. 1b(i)). However, the charge relaxation time ($\tau=\epsilon/\sigma$) depended on the intrinsic variables remains constant because the dimensional parameters can offset each other. When heating the sensor, the resistance reduces and the charge relaxation frequency (τ^{-1}) becomes higher (Fig. 1b(ii)), whereas the normalized capacitance (C/C_0) can eliminate the influence caused by temperature effect of the dielectric constant. Therefore, the relaxation time (τ) can act as a strain-insensitive intrinsic variable for temperature sensing, while the normalized capacitance can serve as a temperature-insensitive extrinsic parameter for strain sensing. Furthermore, under every tensile strain value (ε = 0, 30%, 50%), the temperature-sensitive responsive curves perfectly accord with each other (Fig. 1c(i)). Similarly, the strain-sensitive responsive curves are also consistent under different temperature (T = 20, 30, 40, 50 °C) (Fig. 1c(ii)), experimentally demonstrating a decoupling for temperature and strain sensing in a single unit.

Therefore, this soft tactile sensor can perceive the temperature and strain simultaneously without signal interference. A multimodal tactile sensor array of 10 × 10 is fabricated and adhered to an artificial hand to imitate the perception capability of human skin (Fig. 1d). As displayed in Fig. 1e, when applying a weak and strong unidirectional shear force to the e-skin, the spatial amplitude and location profiles of temperature and strain can be precisely distinguished. Moreover, the strain profile exhibits more prominent in the tensile region when applying a higher shear force, whereas the temperature profile remains almost unchanged in the contact point.

* Corresponding author.
E-mail address: cfpan@binn.cas.cn (C. Pan).

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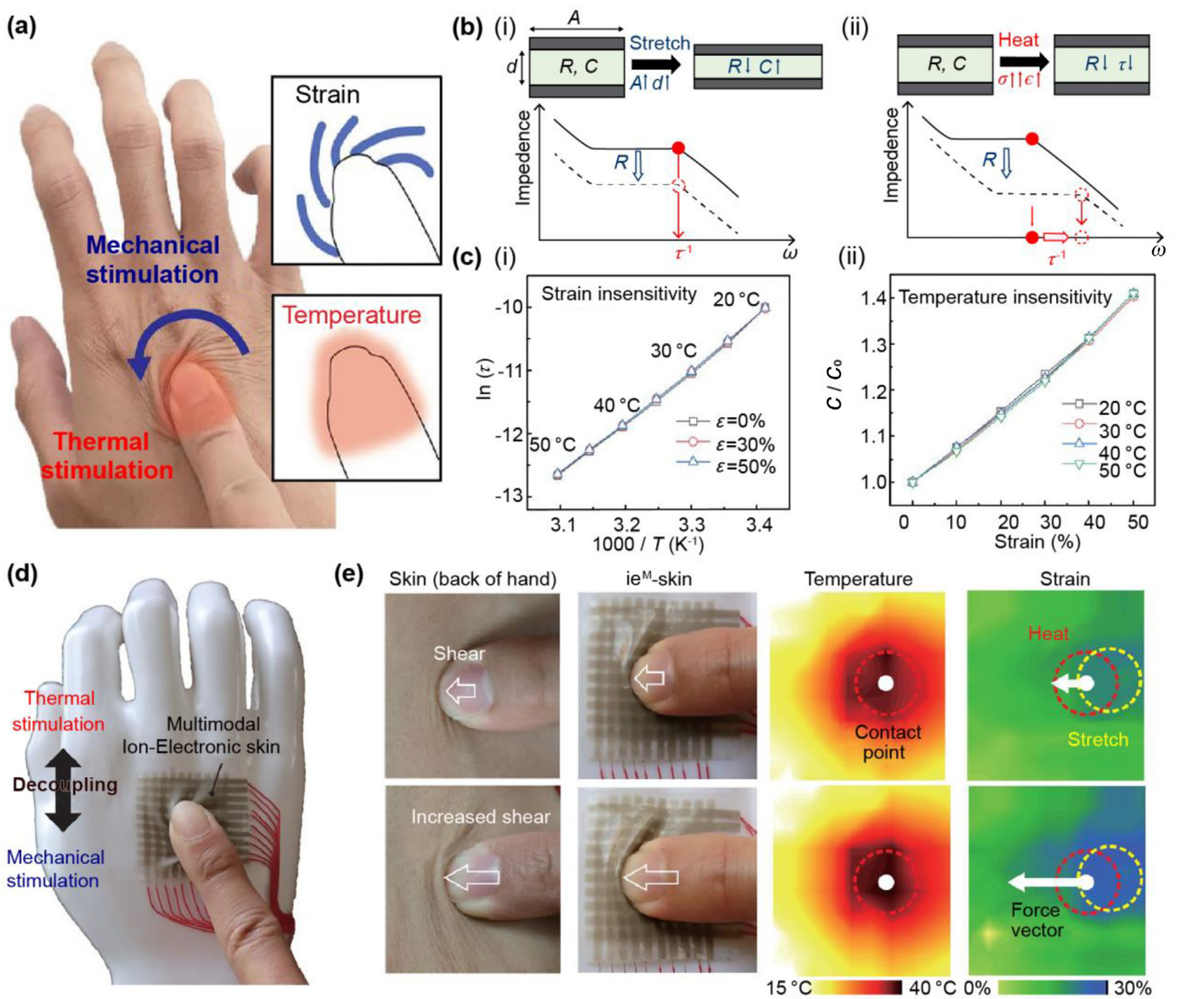

Fig. 1. (Color online) (a) Strain and temperature profiles on real skin when the mechanical and thermal stimuli are applied simultaneously. (b) Schematic Bode plot of ion conductor by stretching (i) and heating (ii). (c) Variations of $\ln\tau$ with respect to T^{-1} at different tensile strains (i) and changes in C/C_0 as a function of stretched strains (ε) at different temperatures (ii). (d) Image of the e-skin with an array of 10 × 10 attached to an artificial hand. (e) Responses (including optical images, temperature and strain profiles) of the multimodal ion e-skin under a weak and strong unidirectional shear. Copyright © 2020, Science.

Additionally, the direction of shear can be deduced from the stretched region to the contact region according to the strain profiles.

However, challenges about the authors' achievements still remain. First of all, employing the normalized capacitance (C/C_0) as strain sensing variable may give rise to a degree of measured deviation. Because the reference capacitance (C_0) is not a definite value, which varies with different measured temperature. Additionally, this work is limitedly emphasized in decoupling only two stimuli: the temperature and stretched strain. Actually, multimodal e-skin should be capable of perceiving and distinguishing manifold stimuli, such as normal pressure, lateral strain, flexion and vibration, so the realization of multifunctional e-skin in one-structure or a single unit without mutual interface is still needed to be further addressed.

In general, this work presents a multimodal ionic e-skin based on ion relaxation dynamics, which can decouple thermal and mechanical stretched strain. This multimodal haptic sensor enables a real-time simultaneous perception for temperature and strain by the intrinsic and extrinsic variables in a single unit without signal interference. This novel approach offers a significant alternative for the design of skin-like e-skin for multifunctional tactile sensing.

Conflict of interest

The authors declare that they have no conflict of interest.

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Juan Tao received her Ph.D. degree (2020) at Beijing Institute of Nanoenergy and Nanosystems, Chinese Academy of Sciences. She has started her postdoctoral research in Shenzhen University since 2020. Her research is mainly focused on flexible tactile sensors and their applications in various intelligent systems.

Caofeng Pan received his B.S. (2005) and Ph.D. (2010) degrees in Materials Science and Engineering from Tsinghua University, China. Subsequently, he joined the group of Prof. Zhong Lin Wang at the Georgia Institute of Technology as a postdoctoral fellow. He has been a professor and a group leader at Beijing Institute of Nanoenergy and Nanosystems, Chinese Academy of Sciences since 2013. His research interest mainly focuses on the fields of piezotronics/piezophototronics for fabricating new electronic and optoelectronic devices, nano-power source, hybrid nanogenerators, and self-powered nanosystems.