Self-Powered Stretchable Mechanoluminescent Optical Fiber Strain Sensor

Haohua Liang, Yongcheng He, Meihua Chen, Licheng Jiang, Zhishen Zhang, Xiaobo Heng, Lin Yang, Yanpeng Hao, Xiaoming Wei, Jiulin Gan,* and Zhongmin Yang*

Strain sensors that can work sustainably and continuously without any external power supply are highly desirable for future wearable and implantable devices. Herein, a self-powered stretchable strain sensor based on the integration of mechanoluminescent phosphors with an elastomer optical fiber is proposed and developed. This mechanoluminescent optical fiber is capable of emitting light just driven by external strain, without the need of an external light source or electric power. The strain-induced emitted light can be collected and guided along the mechanoluminescent optical fiber. The sensor exhibits linear strain response up to 50% and high-accuracy strain measurement (±1%). Moreover, this optical fiber strain sensor displays consistent signals over 10 000 stretch–release motion cycles, which demonstrates the good durability of the sensor. Due to the excellent light confinement of the elastomer optical fiber, this strain sensor is demonstrated in both bright- and dark-field measurements, wearable gloves, and an implantable sensing device, thereby demonstrating potential as a promising technology for future self-powered optical sensor systems.

1. Introduction

Highly flexible and stretchable strain sensors have attracted considerable attention due to their wide usage in wearable and implantable devices for numerous applications, such as health monitoring,[1,2] human motion detection,[3–5] and human–machine interaction.[6,7] Generally, real-time detection of strains in these applications requires strain sensors to be mechanically compatible and durable enough to withstand large and repeated deformations.[8] Moreover, the next generation of strain sensors will need to be self-powered, which will enable the accurate and continuous detection of physiological signals without the need of an external power supply.[9] Driven by these demands, continuous efforts have been made to develop flexible and stretchable electronic strain sensors by exploiting different kinds of materials and structures (e.g., carbon nanotubes, metal nanowires, or graphene combined with polymer substrates), which benefit from simple signal collection and readout mechanisms combined with low power consumption or even ability to self-power.[10–13] However, these strain sensors often require complex manufacturing processes and suffer from electrical safety issues such as current leakage, in addition to which they are susceptible to electromagnetic interference (EMI), all of which restrict their practical applications in many important fields.[14]

Compared to their electronic counterparts, optical strain sensors, which commonly transform deformation into changes of optical parameters such as light intensity, phase, or wavelength have intrinsic advantages, including ease of fabrication, inherent electrical safety, and freedom from the influence of humidity. As well as the aforementioned advantages, optical fiber strain sensors are compact with a simple core-cladding morphology and are immune to EMI.[15–17] Thus, optical fiber strain sensors have become one of the most attractive alternatives to electronic strain sensors for quantitative strain detection. However, conventional glass or plastic optical fiber strain sensors are rigid and limited to measuring small deformations.[18,19] For example, the maximum strain silica-based fibers can tolerate is less than 1%. Therefore, soft, flexible, stretchable, and biocompatible materials were used to fabricate new types of strain sensors; particularly hydrogels and elastomers have been extensively used.[20–24] To date,
hydrgel-based optical fiber strain sensors that survive repetitive tensile strains up to 700% have been reported. Guo et al. have accomplished large strain sensing based on absorption spectroscopy using a dye-doped hydrogel optical fiber. However, conventional hydrogel-based sensors are not stable due to the evaporation of water in dry conditions and fail to work at temperature below 0°C. To avoid these problems, many groups have developed optical fiber strain sensors from elastomers, such as polydimethylsiloxane (PDMS), methylnethysiloxane, and polystyrene-based elastomers. Both hydrogel-based and elastomer-based optical fiber strain sensors mostly rely on the changes of transmitted light intensity as the fiber is deformed by stretching. However, this kind of a sensing scheme is easily affected by external disturbances such as vibration and temperature variation, resulting in poor stability and accuracy. Moreover, such an attenuation-based sensor scheme needs a sustainable and stable external light source, which induces extra power consumption and complicates the implementation of the sensor. For these reasons, a self-powered optical fiber strain sensor with excellent flexible and stretchable properties is highly appealing and desirable in wearable/implantable devices for real-time quantitative measurement of strain.

Effects such as the piezoelectric, triboelectric, thermoelectric, and photovoltaic effects have been widely investigated for application in self-powered sensing systems. Mechanoluminescent (ML) materials are capable of converting mechanical stimuli into visible light emission. ML materials based on the piezophotonic effect have recently been reported. In particular, elasto-ML materials, such as the metal-ion-doped zinc sulfides ZnS:Cu and ZnS:Sn, possess highly linear mechano-optical conversion properties and display repetitive ML light emission without the need for any pre- or postirradiation. These materials have turned out to be promising functional materials for various applications such as display or lighting systems, multiphysical coupling devices, wearable devices, and particularly strain/stress-sensing devices. However, in the strain/stress-sensing application, ML materials have been simply integrated into an elastic matrix and prepared as thin films or fibers and directly attached to the target objects, so the fluorescence detection requires a darkened environment using high-sensitivity-imaging charge coupled devices (CCDs) or photomultiplier tubes (PMTs) in close proximity to the emitting films or fibers. As the sensing and emitting components are spatially separated, the result is poor integration. In conclusion, the requirement of a darkened environment for fluorescence detection and poor integration of the entire sensing devices severely limit their practical applications.

In this article, we describe the design and fabrication of a self-powered, flexible, and stretchable optical fiber strain sensor, which is based on the integration of ML ZnS:Cu phosphors with an elastomer optical fiber. We take advantage of the silicone-based elastomer optical fibers with high core-cladding refractive index difference and use a two-step process to fabricate them, after which we coat a sensing layer of ZnS:Cu and PDMS over a designated region of the fiber cladding. We show that the detected and guided ML emission intensity responds linearly to applied axial strain over a range of 10–50%, and could work in both in dark field and bright field, which has not been accomplished in previous works. To elucidate the potential of this ML optical fiber as a self-powered wearable and implantable strain sensor, we successfully integrate it onto a glove for continuous finger movement tracking, and implant it into a piece of pig tissue for muscle movement monitoring.

2. Results and Discussion

2.1. Sensor Design and Fabrication

Schematic illustration of the self-powered stretchable optical fiber strain sensor is shown in Figure 1a. When the sensing section of the fiber was stretched, without the need of an external light source for any pre- or postirradiation, this optical fiber was capable of converting the mechanical stimuli into visible light emission, and the strain-induced ML light signal could be collected and guided along the optical fiber for measurements. Here, the ML ZnS:Cu phosphor incorporated in the sensing layer of the optical fiber was utilized as the energy source for the self-powering ability. Upon loading and unloading mechanical stimulation, a piezoelectric potential was produced by the piezoelectric polarization charges that were induced within the wurtzite-structure ZnS, which tilted the bands of the ZnS. Therefore, the trapped electrons became much more easily detrapped into the conduction band of ZnS, and nonradiative recombination between detrapped electrons and holes occurred. The released energy excited the Cu2⁺ dopant ions, followed by light emission when the excited ions returned to the ground state.

This highly flexible and stretchable optical fiber was fabricated from a transparent silicone elastomer optical encapsulant (OE) and PDMS (see the Experimental Section for details) as the core and cladding materials, respectively. These materials also have excellent chemical stability and biocompatibility. The mixing ratio of the PDMS base and curing agent were optimized to ensure well-matched optical and mechanical properties between the OE core and PDMS cladding of the optical fiber. The transmittance, refractive index, and elongation at break of the OE and PDMS materials were investigated as shown in Figure S2–S4, Supporting Information, respectively. We fabricated 1 mm thick flat sheets of the materials, using the steps shown in Figure S1, Supporting Information, and described in the Experimental Section. After curing, these sheets were demolded and cut into 2 cm × 2 cm squares for testing. As shown in Figure S2, Supporting Information, the 1 mm thickness PDMS samples with base material to curing agent mixing ratio of 5:1, 10:1, and 20:1 all possessed good transmittance (>90%) in the wavelength range of 300–800 nm, although the OE sheet had a lower transmittance (>85%) due to light scattering caused by the rough surface produced during the curing process. To achieve high light collecting and guiding efficiency of an optical fiber structure, the refractive index (RI) of the cladding should be much lower than that of the core. Figure S3, Supporting Information, shows the measured RI of OE and PDMS sheets, for PDMS fabricated with different mixing ratios. At a wavelength of 517 nm, the measured RI values n2 were 1.4153 (5:1), 1.4147 (10:1), and 1.4138 (20:1), each of which is much lower than n1 = 1.5626 measured for the OE sheet, so the numerical aperture (NA) of the designed optical fiber could reach up to...
The mechanical properties are also crucial for the stretchability and repeatability of this optical fiber strain sensor. The elongation at break, or fracture strain, of OE fibers and PDMS fibers were measured to be 85%, 178% (5:1), 200% (10:1), and 190% (20:1), respectively (Figure S4, Supporting Information), values that ensure suitability for most wearable applications.

As shown in Figure 1b, a three-step approach has been developed to fabricate the self-powered optical fiber. First of all, after stirring and degassing, the OE precursor solution (1:1 mixing ratio) was sucked up by syringe into a Teflon tube serving as the mold with an inner diameter of 620 μm. Then a section of 1 cm length 400/440 μm silica optical fiber was inserted into the tube as a pigtail. After thermal curing at 90 °C for 2 h, the fiber core was obtained by manually stripping off the tube using scissors and tweezers. Subsequently, the prepared fiber core was dipped into the PDMS precursor solution (10:1 mixing ratio) and pulled out. Next, the PDMS-coated core was spun horizontally using a rotating motor at 3000 rpm for 1 min to form a homogeneous cladding layer. Then a core-cladding structure optical fiber was obtained after curing at 80 °C for 40 min. Finally, the PDMS þ ZnS:Cu mixture was prepared as follows: PDMS precursor with 10:1 base to curing agent weight ratio and ZnS:Cu powder with size of 18 ± 5 μm (Figure S5a, Supporting Information) was mixed in a weight ratio of 3:7, and poured into a Petri dish with a hole slightly larger than that of the prepared core-cladding fiber. The fiber was pulled vertically at constant speed through the hole in the Petri dish while keeping the fiber concentric with the hole. In this way, a uniform sensing layer was deposited onto the fiber cladding surface after curing at 80 °C for 40 min. The fabricated self-powered optical fiber strain sensor with a 3 cm length sensing area is shown in Figure 1c–e, where the diameters of the core, cladding, and sensing layer are 620, 710, and 1330 μm, respectively.
2.2. Mechanical and Optical Properties

We examined the mechanical and optical properties of this self-powered ML optical fiber using tensile testing, propagation loss measurement, and spectroscopic analysis.

The strain–stress curves of the bare core fiber (620 μm), core–cladding structured optical fiber (620/710 μm), and self-powered ML optical fiber with a core–cladding–sensing layer structure (620/710/1330 μm) are shown in Figure 2a. The strain–stress curve of the core–cladding fiber (red curve) exhibited two fracture points “A” and “B”, point A being the failure of the core at elongation of 85% and point B being the complete fracture of the whole fiber. Meanwhile, the self-powered ML optical fiber showed complete failure at 76% elongation due to the addition of 70 wt% ZnS:Cu powders to PDMS as the sensing layer, thereby reducing the rubber-like properties of PDMS. The Young’s modulus (E) of 1.85 MPa of the self-powered ML optical fiber, based on the linear region of the strain–stress curve, is suitable for application in wearable and implantable devices. To further investigate the mechanical properties, a self-powered ML optical fiber was repeatedly stretched and released from 0% to 55% strain over 500 cycles, as shown in Figure 2b. During this cycling, the peak stress in the fiber decreased within the first 200 cycles from 2.26 to 1.68 MPa, and gradually stabilized at 1.54 MPa, which was attributed to a combination of the Mullins effect⁴⁵ and the Payne effect.⁴⁶ The Mullins effect describes stress softening and hysteresis that appear in elastomeric materials, including PDMS.⁴¹ The Payne effect can be observed in the filled elastomers under strain due to the breakdown of weak bonds between elastomer molecules and filler particles. To ameliorate the detrimental effects, each fiber used for sensing was preconditioned by cycling from 0% to 50% strain over 200 cycles. In practice, preconditioning can always be performed at a higher maximum strain than the sensor will encounter in use.

To characterize the light-guiding efficiency of the optical fiber, light from a frequency-doubled yttrium aluminum garnet (YAG) laser at 532 nm was coupled into the fiber to measure the propagation loss using the cutback method. Optical attenuation in decibels as a function of length, as shown in Figure 2c, increases linearly with fiber length (Figure 2c). For the optical fiber with core–cladding structure, the attenuation coefficient was measured to be 0.21 dB cm⁻¹ in air, which is much lower than the 0.66 dB cm⁻¹ measured for the core-only optical fiber. The optical fiber with the protection of a PDMS cladding layer is more stable to the surrounding medium compared to the OE core-only

![Figure 2](image_url)

Figure 2. Mechanical and optical properties of the fibers. a) Stress–strain curves of bare core, core–cladding, and self-powered ML optical fibers. b) Dynamic tensile test of a self-powered ML optical fiber being stretched over 500 cycles over the strain range 0–55%. c) Propagation loss of OE fiber core with and without PDMS cladding, measured in air by cutback method. d) ML spectra of self-powered ML optical fiber with increasing strain from 10% to 60%. The upper inset shows the relationship between the ML peak intensity and the applied tensile strain, and the bottom inset shows the ML emission picture under stretching at 30%.
optical fiber. Thus, for the fabricated self-powered ML optical fiber, the axially collected fluorescence light emitted from the sensing layer not only can be guided effectively by the guiding mechanism, but is also less affected by the external environment.

To investigate the strain response characteristics of the self-powered ML optical fiber, we measured the ML spectra under different tensile strain conditions. As shown in Figure 2d, we observe an obvious broad ML emission peak at 517 nm from the sensing layer consisting of ZnS:Cu phosphors and PDMS. The ML emission required no external light or electric excitation. The green ML emission was strong enough to be seen by the naked eye in a darkened room. More specifically, as shown in the upper insert of Figure 2d, under the same stretching velocity, the peak intensity of the ML spectra increased with the increasing strain and tended to saturate for strain above 40%. In conclusion, the peak intensity of the ML emission spectra was found to be strain-dependent, and the ML emission changing with strain could be stably collected and guided along the optical fiber and then the applied strain could be quantitatively demodulated, which provided the basis for this self-powered stretchable ML optical fiber strain sensor.

2.3. Sensing Properties

Figure 3a shows a schematic diagram of the strain-sensing performance test setup based on the self-powered ML optical fiber. The fabricated fiber was clamped to the tensile strain tester controlled by a laptop, and the port with a silica fiber pigtail of the fiber was connected to a PMT with an internal 517 nm ± 5 nm bandpass filter. The ML emission was detected in real time and converted into voltage signal by the PMT.

To explore the quantitative strain-sensing characteristics of this self-powered ML optical fiber, the fiber was subjected to repeated stretching and releasing cycles with different peak strains applied to the fiber at a constant moving rate of 1000 mm min⁻¹. Figure 3b shows how the ML light signal change with time over a single stretching and releasing cycle at a fixed moving rate, with the peak tensile strain ranging from 10% to 50%. The green ML pulse signals were emitted twice within one cycle, corresponding to stretching and releasing of the optical fiber, respectively. Compared with the strain-induced ML spectra shown in Figure 2b, the time-domain ML emission signal had better synchronization with the motion events; also it had better ability to resolve the motion event details in the time domain. Here, the integral intensity is defined as the integral of the area of the ML light emission produced during stretching or releasing, which can be expressed by

\[ I = \int_{t_1}^{t_2} f(t) \, dt \]  

where \( I \) is the time-integrated intensity, \( t_1 \) and \( t_2 \) are the 5% height width of each ML emission pulse, and \( f(t) \) is the time-intensity signal.

With increasing peak tensile strain, the time-integrated intensity of stretching and releasing increased correspondingly. Here, to be consistent with the practical application, the relationship between the time-integrated intensity and applied strain during stretching and releasing was explored. As shown in Figure 3c, the time-integrated intensity produced during stretching and releasing could be described as a linear fitting equation of strain, respectively

\[ I_S = 0.0064e - 0.0385 \]  
\[ I_R = 0.0051e - 0.0488 \]  

where \( I_S \) and \( I_R \) are the integral intensity of stretching and releasing, respectively, and \( e \) is the corresponding applied peak strain. Two slopes of the fitting lines were defined as the sensitivity of the self-powered ML optical fiber strain sensor corresponding to stretching and releasing states, and both exhibited an obvious linearly increasing trend for peak strains ranging from 10% to 50%. It can be clearly distinguished that the time-integrated intensity of stretching was higher than that of releasing because the interaction between ZnS:Cu phosphors and PDMS was stronger and the interaction time was longer during stretching, and thus more ML was emitted when stretched. Even though the time-domain ML emission signal had better event-resolving ability, it was still difficult to identify the action of stretching or releasing just based on observing a single ML emission pulse signal. Some assistant parameters such as the optical fiber propagation loss, could be referred to for solving the stretch/release action identification problem.

Moreover, the threshold strain was 10%, which is mainly attributed to the threshold pressure of the ZnS:Cu phosphor[44,47] which seemed to be less sensitive for some small motion monitoring applications. This strain-sensing threshold could be adjusted using a stiffer base material for optical fiber fabrication, such as using polymethyl methacrylate (PMMA) instead of PDMS for a larger pressure transfer coefficient, but the strain-sensing range would be compromised to a great extent. So, according to the application requirements, the strain-sensing range and sensitivity could be optimized by choosing a suitable base material. To precisely determine the magnitude of strain applied to the sensor, we repeated the measurements ten times to obtain the standard deviation of the integrated intensity from the sensor, as shown by the vertical error bars in Figure 3c. The standard deviations of the sensor under stretching and releasing were calculated to be 0.0091 and 0.0106, respectively, which indicate satisfactory repeatability and high accuracy (±1%).

To further investigate the stability and repeatability of this self-powered ML optical fiber strain sensor, periodic stretching–releasing (S–R) motion for more than 10,000 cycles was applied to the sensor with fixed 50% applied peak strain (Figure 3d). Generally, the ML intensity was stable during the entire test, except for the slight decrease for the initial 2000 cycles that may be attributed to the decay of the ZnS:Cu phosphor and stress softening of the sensing layer.[38,48] A detailed plot of the area outlined in red is shown in Figure 3e, where two ML pulses appeared during each cycle, as already described.

For previously reported ML material–based films or fibers that have been investigated for strain/stress sensing, the fluorescence detection was observed and quantified in dark environments, a limitation that severely restricted their practical applications.[38–44] Here, we demonstrate the strain-sensing property of the self-powered ML optical fibers in a well-lit environment.
Figure 3. a) Schematic diagram of the strain-sensing system based on the self-powered ML optical fiber. b) Time-dependent ML emission intensity of self-powered ML optical fiber under peak strain range of 10–50% over one cycle of stretching and releasing. c) Integrated ML intensity as a function of the applied strain during stretching (black line) and releasing (red line). Data for ten repeated measurements are shown. d) Time-dependent ML emission intensity produced from self-powered ML optical fiber during periodic stretch and release over 10 000 cycles with 50% applied peak strain. e) Magnified plot of the area outlined in red in (d). f) Time-dependent ML intensity of the self-powered optical fiber in dark and bright field (150 lux) with a maximum 30% applied strain under one stretching–releasing cycle. g) Photographs of strain detection in bright (upper photo) and dark field (lower photo) corresponding to the signal of (e).
Figure 3f shows the time-dependent ML intensity of the self-powered ML optical fiber performed in the dark and in bright (150 lux) environments that corresponds to outdoors on an overcast day, respectively, with 30% applied strain. Even though the ML emission could not be seen by the naked eye due to the high brightness of the surrounding light, the ML intensity still could be detected in the bright field as in the dark field, and the ML intensity curve obtained in the bright field was the same as the dark one, except for the raised baseline attributed to the ambient light, which could be easily subtracted by signal processing. Therefore, compared to the ML-based films or fibers used for strain sensing in the former research, the fabricated self-powered ML optical fibers are more appealing and promising for integrative, remote, and real-time quantitative strain detection.

2.4. Application as Wearable and Implantable Devices

We present two types of devices to demonstrate the application of the self-powered ML optical fiber strain sensor for human motion detection, where strain is expected to be lower than 50%. These proposed devices are wearable and implantable strain sensors, and the working principle of both is based on monitoring of the ML emission generated from human motion. For practical applications, the ML detection and processing can be performed in a compact circuit board and the demodulated signal can be wirelessly transmitted through Bluetooth or Wi-Fi.

The wearable strain sensor was demonstrated by a glove that integrated a self-powered ML optical fiber on the index finger to monitor the finger joint movement (Figure 4a). To firmly integrate the glove with the self-powered ML optical fiber, a PDMS precursor with good adhesion was used as the glue. The self-powered ML optical fiber fixed atop the glove was stretched when the finger was bent, and the ML emission pulse was emitted twice in response to the flexion and extension of the finger (as shown in Figure 4b). Moreover, the integrated ML intensity emitted from the optical fiber increased with the increasing bending angle, maintaining relatively stable voltage signal output during several bending and relaxation cycles of the finger movement. The results indicated that the glove integrated with the ML emitting optical fiber allowed us to monitor and visualize the finger movement without power supply, making it promising for real time and quantitative monitoring of human motion to aid in rehabilitation without using a battery.

![Figure 4](image).

**Figure 4.** a) A glove integrated with the self-powered ML optical fiber strain sensor for detecting joint movement of the index finger. b) Time-dependent ML intensity under different angles of finger joint bending and relaxation. The fiber was stretched when the finger was bent, and ML pulses appeared twice corresponding to the finger bending and relaxing process. c) Images of a self-powered ML optical fiber being implanted into a piece of pork tissue for monitoring the strain generated by tissue motion. d) The sensor response to different tissue motions; the ML intensity in response to the different bending angles could be obviously distinguished.
To demonstrate the strain-sensing ability in muscle, the self-powered ML optical fiber was implanted into a slice of pig muscle tissue (Figure 4c). The implanted optical fiber was stretched when the pork tissue was bent, and its ML emission was similar to that observed from the glove described before: Two ML pulses were emitted during bending and relaxing of the tissue, respectively. The integrated ML light intensity changed under different bending angles of 30°, 90°, and 180°, as shown in Figure 4d, where the integrated ML intensity increased as the bending angle increased. For the development of implantable devices, an indispensable factor is a sustainable electrical power unit, which has emerged as another important issue. In this demonstration, the optical fiber strain sensor was powered by tissue motion instead of external electric power. The ML light produced from the optical fiber could be collected and guided by the sensing fiber itself with propagation loss of 0.21 dB cm⁻¹, so the implanted depth would be extended to the submeter scale. These results confirmed that this novel self-powered stretchable ML optical fiber strain sensor is promising for implantable applications.

3. Conclusion

In summary, we have demonstrated a self-powered optical fiber strain sensor based on ZnS:Cu ML phosphors and silicone elastomers, which is able to emit light under tensile loading and unloading. The ML emission light can be collected and guided along the optical fiber with 0.21 dB cm⁻¹ propagation loss, and real-time sensing measurements show a highly linear response to strain in the range 10–50%, making it feasible for quantitative strain detection. More than 10 000 stretch-release motion cycles have been executed to confirm the stable ML signal and reliable sensing. Compared with ML phosphor-based fibers and films used for strain sensing, which only work in a dark field, this self-powered ML optical fiber with excellent light confinement can effectively work in both dark and bright fields. To demonstrate the utility of the optical fiber sensor for wearable and implantable applications, we presented a novel glove integrated with this self-powered optical fiber, enabling tracking finger movement, and we also implanted this self-powered optical fiber into pork tissue, enabling monitoring of muscle movement. We believe this self-powered ML optical fiber strain sensor is appealing and promising for wearable and implantable device applications.

4. Experimental Section

Materials: The ZnS:Cu (LP6845) phosphor was purchased from Lonco Company Limited. PDMS (Sylgard 184 two-part silicone elastomer) and the OE (OE 6550 two-part silicone elastomer made of methylphenyl siloxane) were obtained from Dow Corning Corporation (Shanghai, China). All the materials were used without any further purification.

Characterization: The scanning electron microscope (SEM) image was taken by a Zeiss Merlin field emission SEM. The UV–vis spectra of PDMS and OE sheets were obtained using a PerkinElmer Lambda 900 UV/Vis spectrophotometer. The refractive indexes of PDMS and OE sheets were acquired using a Metricon 2010/M prism coupler. The attenuation was measured with a Thorlabs PM100D optical power meter. The tensile testing was performed using a tensile stress machine ZHIQU ZQ-980B 10 N load cell. The emission spectra were obtained by a fiber optic spectrometer (QE Pro, Ocean Optics). The time-domain waveform was acquired using a PMT (Hamamatsu H10722-01) to convert the ML emission into a voltage signal, and displayed on an oscilloscope (Keysight DSOX3014T).

Fabrication of OE and PDMS Sheets: The OE precursor was prepared with a constant base to curing agent ratio of 1:1 (w/w). The PDMS precursor was obtained with different base to curing agent ratios of 5:1, 10:1, and 20:1 (w/w). All the precursors were stirred uniformly ahead of vacuum degassing, and then poured onto a homemade glass plate and extended to thin slices through blade coating. After curing at 90 °C for 2 h and 80 °C for 40 min, successively, the OE and PDMS sheets were demolded and cut to a size of 2 cm × 2 cm × 1 mm.

Fabrication of OE and PDMS Fibers: First, the OE precursor with a base to curing agent ratio of 1:1 (w/w) and the PDMS precursor with a base to curing agent mixing ratio of 5:1, 10:1, and 20:1 (w/w) were prepared. After stirring and degassing, these precursors were sucked up by a syringe into a Teflon tube with an inner diameter of 620 μm and cured at 90 °C for 2 h and 80 °C for 40 min, respectively. Finally, the OE and PDMS fibers were obtained by stripping the Teflon tubes.

The experiments involving human subject have been performed with the full, informed consent of the volunteer. The pork tissue samples were obtained from a grocery store.

Supporting Information

Supporting Information is available from the Wiley Online Library or from the author.

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Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

H.H.L. and J.L.G. conceived the idea. H.H.L., Y.C.H., M.H.C., and L.C.J. performed the experiments. H.H.L. and J.L.G. analyzed the data. H.H.L. and J.L.G. wrote the manuscript. All the authors commented on the manuscript. J.L.G. and Z.M.Y. supervised the project.

Data Availability Statement

The data that supports the findings of this study are available from the corresponding author upon reasonable request.

Keywords

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