CARBON NANOTUBES STRAIN SENSORS FOR HUMAN MOTION DETECTION

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Abstract

Carbon nanotubes have great mechanical, electrochemical and piezoresistive properties make the nanotubes an excellent material for construction of sensors. There has been a strong demand for producing highly selective, sensitive, responsive, and cost effective sensors. As a result, research emphasis is on developing new sensing materials and technologies by exploiting nanomaterials to develop next generation of sensors. Devices made from stretchable electronic materials could be incorporated into clothing or attached directly to the body. Here, we report a class of wearable and stretchable devices fabricated from nanomaterials with high durability and fast response. Carbon-nanotubes sensors assembled on stockings, bandages and gloves to fabricate devices that can detect different types of human motion including movement, typing, breathing and speech. The study is tried to explore the strain sensing characteristics of carbon nanotubes, nanowires, nanofibres and nanocomposites to develop various types of sensors. The technological goal is to integrate such sensors onto smart clothes or directly onto the body to monitor human motions in real time. This review aims to act as a reference source for researchers to help them in developing new applications of sensors based on nanotubes and other nanomaterials.

Keywords:

Applications, Carbon nanotubes, Human motion, Nanomaterials, sensors

I. INTRODUCTION

Strain sensors are devices that transform mechanical deformation into electrical signals. The potential scope of flexible strain sensors attracts numerous applications given their high reliability, low maintenance and strain sensing capabilities. Flexible Strain sensors can be used in a variety of industrial, automotive, medical, biomedical, sports, aviation, robotics and consumer electronic applications. Some more advanced application of flexible strain sensors are body integrated electronic systems, which can be attached to the skin or clothing to measure precise strain ranging from pulse rate, heartbeat to bending of joints. When designing a flexible strain sensor, it is necessary to consider the correct fabrication methods and type of materials used to develop a low-cost and sensitive device. A practical strain sensor also requires many specifications including sensitivity, stretchability, flexibility, linearity, durability and response time. In the past, two main categories of strain sensors were developed that are Capacitive and Resistive types, but more recently strain sensors based on piezoelectric materials have been developed.

Stretchable, skin-mountable, and wearable strain sensors are required for several potential applications including personalized health-monitoring, human motion detection, human-machine interfaces, soft robotics, and other applications. Therefore, significant efforts have been invested to develop highly sensitive and stretchable strain sensors, which should be both compliant and sensitive enough to detect the process of body motions and work at high strain to monitor large-scale deformations. Silver nanomaterial was chosen as the sensitive part in the strain sensor because of its excellent performance in both optical and electrical fields. The sensitivity improvement is one of the development directions of the nanomaterials based stretchable sensors. In addition, superb mechanical properties render carbon nanotubes (CNTs) increasingly attractive for various research areas.

All of these types of sensors require substantial amount of power for operation, which often limits their applicability. Piezoelectric flexible strain sensors convert dynamic mechanical deformation into electrical charge due to the piezoelectric properties of the sensing element. During the past decade, there has been a significant interest in developing devices using PVDF(Polyvinyledene floride) materials. PVDF fibers show an outstanding mechanical strength, very low acoustic impedance and exhibit a flat frequency response. Conventional electronic devices, fabricated on rigid but brittle semiconductor wafers, have evolved through a drive towards miniaturization with a view to realizing faster, smaller and more integrated devices. An alternative approach to future electronics is to integrate the attributes of flexibility and stretchability to realize soft and human-friendly devices. Possible applications of this include the detection of human motion, monitoring personal health and therapeutics. Various stretchable devices have been created using this approach.

In such stretchable devices, the functional materials themselves are directly exposed to strain and therefore stretched. This feature offers a unique opportunity to measure the strain-dependent change in device performance to monitor motion, for example of the human body. In this way we realized a novel strain sensor that can have high durability, fast response and low creep. These important features allow the material to be used to precisely monitor large-scale and rapid human motion, as was demonstrated by embedding various strain sensors into clothing worn over the skin then using it to detect movement, typing, breathing and phonation (speech).

As a result of the stretchable device architecture, the skin, bandage and SWCNT(Single wall carbon nanotube) film behave as a single cohesive stretchable object, so deformation of the skin can be monitored directly and precisely using the SWCNT film. When fixed to the chest, respiration could be monitored by the upward and downward slopes of the relative resistance associated with inhalation and exhalation. In contrast, when attached to the throat, the device monitored phonation (speech) by detecting motion of the laryngeal prominence. Such devices might be useful in a breathing monitor for the early detection of sudden infant death syndrome (SIDS) in sleeping infants. To detect large-scale human motion, we seamlessly connected small films to fabricate a large SWCNT strain sensor with extended sensing area. One advantage of using clothing-integrated devices is the option for repeatable and sharable use of the sensor.

Wearable and lightweight pressure sensing devices are of paramount importance for various future applications, such as electronic skin, touch-on flexible displays, soft robotics and energy harvesting. Recently, various nanomaterials, including nanowires, carbon nanotubes, polymer nanofibers, metal nanoparticles and graphene have been used for the design of novel flexible pressure and strain sensors. The majority of these nanomaterials-based pressure sensors are based on capacitance or piezoelectricity. The advantage of resistive pressure sensors lies at simplicity in device fabrication as well as relatively low energy consumption in operation.

Among the various types of sensors, strain gauge is one of the most important smart sensors, which have been widely used in the measurements of strain, acceleration and tension, as well as structural health monitoring. In addition, the combination of conformability and optical transparency will facilitate intelligent electronics and self-powered robot where strain sensors are integrated with optoelectronic devices and direct observation through the devices is necessary. Therefore, stretchability and transparency have to be incorporated into strain gauges for many specific applications.

In the particular case of strain gauges, the realization of stretchability requires not only stretchable conductance but also recoverable and stable, often resistive or capacitive, responses to large strains. Both resistive and capacitive stretchable strain gauges that could detect strains up to 100% have been demonstrated based on carbon nanotubes. However, fabricating stretchable strain gauges with high sensitivity, optical transparency, durability and stability in a simple and large-scale manner still challenges the scientific and engineering communities. So to overcome these difficulties we are introducing various types of sensons with their applications in various fields.

II. Highly Sensitive Strain-Gauge Sensor Using Reversible Interlocking of Nanofibres.

Flexible skin-attachable strain-gauge sensors are an essential component in the development of artificial systems that can mimic the complex characteristics of the human skin. In general, such sensors contain a number of circuits or complex layered matrix arrays. The device is based on two interlocked arrays of high-aspect-ratio Pt-coated polymeric nanofibres [1] that are supported on thin polydimethylsiloxane layers. When different sensing stimuli are applied, the degree of interconnection and the electrical resistance of the sensor changes in a reversible and directional manner with specific, discernible strain-gauge factors. The sensor response is highly repeatable and reproducible up to 10,000 cycles with excellent on/off switching behaviour. We show that the sensor can be used to monitor signals ranging from human heartbeats to the impact of a bouncing water droplet on a superhydrophobic surface.

III. Highly Stretchable and Sensitive Strain Sensor Based on Silver Nanowire–Elastomer Nanocomposite

The demand for flexible and wearable electronic devices is increasing due to their interaction with human body. Stretchable, flexible and wearable sensors can be easily mounted on clothing or directly attached on the body. We include stretchable, flexible and sensitive strain sensors based on nanocomposite of silver nanowire network. Silver nanowire [2] network- elastomer nanocomposite based strain sensor show strong piezoresistivity with guage factor in the ranges of 2 to 14 and a high stretchability up to 70%. Strain sensors respond to mechanical deformations by the change of electrical characteristics such as resistance or capacitance. Recently there have been numerous efforts to develop flexible, stretchable and sensitive strain sensors because of their various potential applications such as for rehabilitation, personal health monitoring and human motion capturing. Previously reported strain sensors have only demonstrated high sensitivity coupled with relatively low stretchable and vice versa. Silver nanowire have been widely used in flexible electronics due to their excellent electrical, optical and mechanical properties.

IV. User-interactive electronic skin for instantaneous pressure visualization.

Electronic skin (e-skin) presents a network of mechanically flexible sensors that can wrap irregular surfaces and spatially map and quantify various stimuli. Previous works on e-skin have focused on the optimization of pressure sensors [3] interfaced with an electronic readout, whereas user interfaces based on a human-readable output were not explored. Here, we report the first user-interactive e-skin that not only spatially maps the applied pressure but also provides an instantaneous visual response through a built-in active-matrix organic light-emitting diode display with red, green and blue pixels. In this system, organic light-emitting diodes (OLEDs) are turned on locally where the surface is touched, and the intensity of the emitted light quantifies the magnitude of the applied pressure. Here three distinct electronic components—thin-film transistor, pressure sensor and OLED arrays—are monolithically integrated over large areas on a single plastic substrate. The reported e-skin may find a wide range of applications in interactive input/control devices, smart wallpapers, robotics and medical/health monitoring devices.

V. Skin-like Pressure and Strain Sensors Based on Transparent Elastic films of Carbon Nanotubes

The essential components of electronic and optoelectronic devices that facilitate human interaction and biofeedback. The availability of conducting thin films with these properties could lead to the development of skin-like sensor that stretch reversibly, sense pressure, bend into hairpin turns, integrate with collapsible, stretchable and mechanically robust displays. We report transparent, conducting spray-deposited films of single-walled carbon nanotubes [4] that can be rendered stretchable by applying strain along each axis, and then releasing this strain. This process produces spring-like structures in the nanotubes that accommodate strains up to 150% and demonstrate conductivities as high as 2,200 S cm^{-1} in the stretched state. We also use the nanotube films as electrodes in arrays of transparent, stretchable capacitors, which behave as pressure and strain sensors.

VI. Highly Stretchable Piezoresistive Graphene–Nanocellulose Nanopaper for Strain Sensors.

Existing commercial products are mainly based on bulky technologies which are cheap but can only detect low strains within a few percent due to the very limited stretchability of metal and semiconductors. Highly stretchable graphene–nanocellulose [5] composite nanopaper is fabricated for strain-sensor applications. Three-dimensional macroporous nanopaper from crumpled graphene and nanocellulose is embedded in elastomer matrix to achieve stretchability up to 100%. The stretchable graphene nanopaper is demonstrated for efficient human-motion detection applications. The stretchable sensor made from solution processable graphene and nanocellulose hold promising applications in emerging human interactive devices. High strain sensors are in demands beyond the existing market such as wearable health monitoring patch robotic sensory skin which require high strain sensing capability that can't be achieved by simple conventional technology. With the ever increasing demand of facile, low cost nano fabrication techniques, development of alternative routs to graphene high strain sensors are of growing interest.

VII. Super-Stretchable, Transparent Carbon Nanotube-Based Capacitive Strain Sensors for Human Motion Detection.

Advanced bio-interactive electronic devices require mechanically compliant sensors with the ability to detect extremely large strain. Here, a new multifunctional carbon nanotube (CNT) based capacitive strain sensor which can detect strains up to 300% with excellent durability even after thousands of cycles. The CNT-based strain gauge devices exhibit deterministic and linear capacitive[6] response throughout the whole strain range with a gauge factor very close to the predicted value, representing the highest sensitivity value. The strain tests reveal the presented strain gauge with excellent dynamic sensing ability without overshoot or relaxation and ultrafast response at sub-second scale. Coupling these superior sensing capabilities to the high transparency, physical robustness and flexibility, we believe the designed stretchable multifunctional CNT-based strain gauge may have various potential applications in human friendly and wearable smart electronics, subsequently demonstrated by our prototypical data glove and respiration monitor.

VIII. Wearable and Highly Sensitive Graphene Strain Sensors for Human Motion Monitoring.

Sensing strain of soft materials in small scale has attracted increasing attention. In this work, graphene [7] woven fabrics (GWFs) are explored for highly sensitive sensing. A flexible and wearable strain sensor is assembled by adhering the GWFs on polymer and medical tape composite film. The sensor exhibits the following features: ultra-light, relatively good sensitivity, high reversibility, superior physical robustness, easy fabrication, easy to follow human skin deformation, and so on. Some weak human motions are chosen to test the notable resistance change, including hand clenching, phonation, expression change, blink, breath, and pulse. Because of the distinctive features of high sensitivity and reversible extensibility, the GWFs based piezoresistive sensors have wide potential applications in fields of the displays, robotics, fatigue detection and body monitoring.

IX. CONCLUSION

The functions of the devices presented here were simple compared to the wearable systems made from commercial devices, we have presented a route to materials and structures, developed through nanotechnology, that can be used to develop human-friendly devices with realistic functions and abilities that would not be feasible by mere extension of conventional technology. Our research suggests devices that can act as part of human skin or clothing, and can therefore be used ubiquitously. Systematic and elaborate strain tests confirmed superior stability, durability and reliability of the devices. A combination of outstanding strain gauging performances, optical transparency, physical robustness and easy fabrication may promise potentially wide applications in bio-interactive and intelligent electronics. We believe that such devices could eventually find a wide range of applications in detection of human motion, recreation, virtual reality, robotics and health care.

We have found that the proposed strain sensors have a good response to the bending and joint angle measurement. Finally, a smart glove made of the stretchable strain sensors assembled in each finger was fabricated and used for the real-time motion detection of fingers. As an application, the proposed strain sensors have been used in posture detection and the control of a robotic hand using our smart glove device. From our research, it is clear that our strain sensor devices will help in developing new areas of study and research into the applications in flexible, stretchable and wearable electronics due to their excellent performances, especially in human motion detection applications where strain should be accommodated by the strain sensor. Therefore, our investigations represent an inspiring achievement in overcoming the drawbacks of conventional sensors and may provide a new way to construct new-generation multifunctional wearable and implantable electronics for plenty of applications.

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