Responsive materials have been investigated for a lot of applications such as smart devices and sensors, which change shape, color, transparency, or functionality when stimulated by external stimuli. However, the practical applications of responsive materials have been largely hampered by their irreversible transitions under limited stimuli such as temperature, pH, and chemical. As a result, a lot of research has been paid to improve the reversibility of chromatism and deformation. In this review, the recent research of responsive materials based on aligned carbon nanotubes is described, with the focus on the responsive materials in response to light and electricity.

1. Introduction

Light and electrically responsive materials have been studied over several decades [1–10]. It is well known that multi-responsive materials usually change their physical or chemical properties in response to various external stimuli, such as light, electro-magnetic fields, temperature, moisture and pH [10–19]. The light and electrically responsive materials show great potential in applications for smart devices. In this review, we aim to highlight recent important and intriguing results on functionalized aligned carbon nanotubes (ACNTs) which are responsive to light and electricity. Due to the highly aligned and porous structure, ACNTs can be incorporated with a number of polymers to prepare composite materials while preserving alignment structure. The resulting composites exhibit significantly enhanced physical properties than traditional randomly dispersed CNTs [20–25]. In addition, the synergetic interaction between ACNTs and sensitive polymers can create new responsive behaviors. In this review, we first introduce the synthesis of ACNT materials and then discuss the polymer/ACNT composites and their chromatic and deformable properties. The challenges and application of ACNTs-based responsive materials are summarized at last.
2. Synthesis of aligned carbon nanotube materials

Many methods have been reported to synthesize ACNT materials including thermal chemical vapor deposition (CVD), plasma-enhanced hot filament CVD, fluidized bed catalytic CVD etc. [26–29]. Amongst them, thermal CVD method is widely appreciated because the morphology and structure of the resulting ACNT array can be controlled by catalyst, growth temperature, reaction time, flow rate, carbon sources and partial pressure [30,31].

The synthesis process of ACNT arrays is illustrated in Fig. 1. In a typical procedure, a catalyst is first prepared by sequentially depositing a buffer layer of Al₂O₃ and layer of Fe catalyst on a silicon wafer by electron-beam evaporation. Then the ACNTs are grown in a tube furnace filled with a constant flow of reaction gas including the carbon source, such as ethylene, carried by argon and hydrogen mixture. The temperature of furnace is increased to reacting temperature of 740 °C in 15 min. During this process, the catalyst layer is cracked into individual nanoparticles and uniformly dispersed on the substrate. When temperature reaches 740 °C, hydrocarbon is decomposed into carbonaceous clusters and dissolved in catalytic nanoparticles. Subsequently, the carbonaceous species are saturated and ejected to nucleate at the surface of the catalytic nanoparticles and the ACNTs grow continuously. The growth is stopped when the carbon source is cut off. Cooling the tube furnace or deactivating the catalyst can also stop the growth. Due to the strong van der Waals interaction among the neighboring carbon nanotubes, the resulting ACNTs are inclined to vertically align on the substrate to form array by crowding effect (Fig. 1a) [32].

By designing the catalyst (Fig. 2a) and controlling the synthesis conditions, the resultant ACNT can be spinnable, i.e., ACNT sheets and fibers can be prepared through a simple dry-drawing technique. The strong interaction and dense arrangement of ACNTs are advantageous to the spinnability of ACNTs array. [33,34]. SEM images of the side view of ACNT arrays showed a highly aligned structure (Fig. 2b–d). For an appropriate interaction and interconnection, the height from 100 μm to 1.5 mm is can be obtained for spinnable ACNT arrays [31,34]. The alignment and density of ACNTs, determined by uniform size distribution of catalytic particles are also important for the spinnability [35]. For instance, when the diameter of CNT is ~10 nm, ACNT array with a high area density of ~10¹¹ cm⁻² is spinnable, while the arrays with area density of less than 10¹⁰ cm⁻² are unspinnable [36]. The continuous ACNT materials including sheets and fibers were prepared from ACNT arrays by dry-drawing process (Fig. 1b and c) [37]. These sheets show light weight, tunable thickness and density while keeping highly aligned (Fig. 2e–i). The volumetric density of the ACNTs sheet is measured to be ~0.0015 g/cm³ [38]. The unique structures endow the ACNTs materials high conductivity, strength, thermal stability and flexibility [31,34].

---

![Fig. 1](image_url) **Fig. 1.** Schematic illustration to the synthesis of ACNT materials. (a) The synthesis of ACNT arrays through CVD process, EBE is an abbreviation of electron-beam evaporation. (b and c) The synthesis of ACNT sheets and fibers from ACNT array by dry-spinning [32].
3. Light-responsive aligned carbon nanotube composite materials

3.1. Light induced deformation

Stimuli-responsive polymer has persisted over many decades. These materials are able to select and execute specific functions sensitively in response to environmental stimuli. Among various environmental stimuli, light is an unlimited, free and sustainable source of energy. Light responsive polymers can change their properties in response to light with appropriate wavelength. This unique responsive behavior promises many possible applications such as reversible optical information storage, photomechanical transduction and actuation, tissue engineering, and drug delivery [39]. Among light responsive polymers, liquid crystalline polymers (LCPs) which combine the merits of liquid crystals and polymers attract increasing interest. LCPs are usually tightly cross-linked networks which contain rigid shape-anisotropic ‘mesogenic’ units incorporated into the flexible, isotropic polymer chains. In this cross-linked network, the orientation of mesogens have a significant effect on the conformation of the polymer chains, hence the alignment of the mesogens that induced by light can alter the macroscopic deformations. In most cases, the macroscopic deformation is reversible because the “memory effect” of LCPs [40]. By this kind of photo-deformation, light energy can be converted to mechanical power directly. It should be simple to utilize LCPs for micro- and nano-applications, such as light-driven devices, optically controlled switches, micro-machines and soft robots.

Photo-sensitive moieties like azobenzene are often incorporated into the LCPs to realize light induced deformation. The inducible deformation of LCPs containing azobenzene is derived from reversible photo-isomerization of mesogens triggered by light, i.e. cis–trans isomerization (Fig. 3) [41]. A photochemical phase transition in LCPs doped with low-molecular-weight azobenzene has been first reported by Ikeda et al. They illustrated that the trans–cis isomerization induced by UV light gave rise to the reversible nematic–isotropic phase transition of LCPs (Fig. 3) [42,43]. In these works, the trans–cis isomerization of azobenzene in LCPs not only depends on the intensity of the illumination, but also relies on the orientation of mesogens. For instance, a homogeneously oriented LCPs film bent toward the light source along the oriented direction of mesogens. On the contrary, a home tropically oriented film bent away from the light source [44]. Thus, the orientation of LC mesogens is important for their applications. Many methods have been done to facilitate the orientation of LC mesogens. Typically, an aligned polyimide (PI) layer with parallel grooves is prepared by mechanical rubbing along one direction. The grooves are then used to induce the orientation of the LC molecules [45]. However, some problems are still remained, such as the broken debris and structural damage during fabrication and the charge accumulation on the surface during use, which have largely limited the application of the LCPs.

ACNTs have attracted keen attention as promising candidates for oriented LC mesogens owing to their unique and versatile properties. The anisotropic shape of ACNTs along the nanotube axis often brought strong anisotropy properties.

![Fig. 2. Photographs and SEM images of ACNT materials. (a) Iron nanoparticles catalyst on Si substrate, (b–e) ACNT array, (f) ACNT sheets and (g–i) ACNT fibers at different magnifications, respectively [36].](image-url)
Sun and co-workers suggested ACNTs arrays and sheets with unique anisotropic structure can induce the orientation of polymer chains by mutual interaction and achieve the anisotropic actuation with higher degree [21]. So how to control the ACNTs orientation is of great importance for the application of ACNTs in LCPs.

The method to disperse and assemble CNTs in lyotropic liquid crystals had been reported, and the results indicated that CNTs aligned along the direction of the liquid crystalline supramolecular ordered structure. However the realistic application of ACNTs adding in LCPs materials has been limited because of the difficulties in aligning them in the required directions. To obtain better photodeformable behavior, excellent alignment of nematic phase mesogens is required, and well-arrayed ACNTs in LCPs are highly desired too.

A LCPs containing azobenzene exhibited excellent photodeformable behavior, which used ACNTs as a template to induce the LCPs alignment nanocomposites [46,47]. The LCPs/ACNTs composite film was prepared by injecting the molten mixtures of the liquid crystalline monomer, initiator and crosslinker into the ACNTs sheet. After a photopolymerization process, the freestanding LCPs film was obtained at the liquid crystalline phase and the LCPs mesogens were effectively oriented along the ACNTs length (Fig. 4). The resulting composite film underwent a rapid and reversible light induced deformation by alternate irradiations of ultraviolet and visible lights. This light induced deformation can be cycled repeatedly more than 100 times without obvious fatigue. It is worthy of note that the LCPs film curled along the aligned direction of ACNTs, indicating mesogens oriented parallel to the align direction of ACNTs. When the LCP film was fabricated by a solution process, the monomer, initiator and crosslinker were all dissolved in the solvent and doped onto the ACNTs strip. The resulting LCPs/ACNTs composite films showed a unique photomechanical behavior, which bent against the incident direction of UV light and reversed by opposite irradiation. Moreover, solely UV light can also induce the reversible deformation. The LCPs/ACNTs composite film bending away from the light source also indicated that mesogens would be oriented perpendicular to the alignment direction of ACNTs. Although the mechanisms of alignment of mesogens induced by ACNTs still need further discussion, the high mechanical properties and electrical conductivity have been attained by the incorporation of ACNTs in LCPs composite film.

3.2. Photo-thermo actuation

Thermal stimuli is conveniently used driving stimulus in actuation systems, and various actuators based on different types of thermal-actuating materials have been explored in recent years. Among these thermal-actuating materials, liquid–crystalline polymers (LCPs) with three-dimensional networks are able to undergo controlled and reversible deformation in response to thermal stimulus. LCPs provide many opportunities for creating new thermal actuated devices owning these unique responsive behaviors. But there are some intrinsic limitations to impede their further development. For example, most of the LCPs are chemically cross-linked within three-dimensional networks, in which the movement of the aligned mesogens are limited, meaning that large deformation always need strong actuation force. Furthermore,
the thermal conductivity, response speed, and fatigue resistance of LCPS are all expected to improve. When CNTs are incorporated in thermal responsive LCPS, they could enhance the mechanical performances of the pristine LCPS [21]. Once the LCPS is heated above or cooled down below its nematic-isotropic transition temperature, the alignment of mesogens is changed, and the spontaneous uniaxial contraction/restoration of the LCPS along the axis results in spontaneous elongation or contraction of the whole network along the nematic direction. After the nematic-isotropic phase transition, the LCPS revert to their original state and make the polymer material contract along the director axis [49]. In many cases, function-alized CNTs are also used as nanoscale heaters and thermal conductors to induce the thermal phase transitions of LCPS.

However, the used thermal stimulus is not an ideal option for actuation, because the responsiveness is usually limited by the slow heat transport into/out of the thermal responsive materials. Furthermore, it is difficult to create a localized thermal stimulus that can be remotely applied and precisely controlled. To overcome these problems, light induced photo-thermal transduction can be embedded in a polymer matrix to induce thermal actuation. The mechanism of photo-thermal transduction is still not fully understood, but compared to other actuators, light induced thermal actuation, which provides an alternative way to actuator structures, and brings distinctive advantages such as wireless actuation, remote control, low noise, and high level integrity. Photo-thermal actuation will pave a new way for combining different properties of material systems to develop new stimuli responsive actuation.

Recent studies show that ACNTs have a novel character of absorbing of light from visible to near infrared region and converting light energy into thermal. This photo-thermal conversion can offer ACNTs a superior opportunity in actuation applications. So many researchers select ACNTs as the photo-absorbing material to induce the thermal response of LCPS via their strong ability to capture photons and convert into local heat, thus triggering the required phase changes in the LCPS [50,51]. Camargo and co-workers prepared a LCPS/ACNTs composite film with blister-like monodomain region. The film displays a reversible shape change behavior in response to red light. A cantilever made of LCPS composites embedded ACNTs exhibited a bending motion on local heating with a laser diode at 660 nm. According to previous reports, certain obstacles are still ahead, and few studies focused on ACNTs/LCPS. Because the range of actuation strains and stresses found in ACNTs/LCPS composites is small and the alignment of ACNTs in the matrix is very difficult. Many researchers make efforts to overcome these challenges. For instance, ACNT/epoxy composite arrays with ACNT ends exposed exhibited a thermal conductivity of 0.65 W m$^{-1}$ K$^{-1}$, appropriately 280% higher than the composite materials in which ACNTs were dispersed randomly [52]. Chen and co-workers have demonstrated a temperature responsive polymer films composed of poly(N-isopropylacrylamide) and the vertically ACNT forest. By infiltrating the poly(N-isopropylacrylamide) polymer gel into the vertically ACNT forest, they developed a novel temperature responsive composite film [53]. Though these composite materials were not directly used as photo-thermo actuator, the available approaches to A CNTs in polymer matrix to form thermal responsive system have been proved. Due to the functional and structural properties of ACNTs embedded within LCPS, there are tremendous opportunities in the development of photo-thermo actuator.

4. Electrically responsive aligned carbon nanotube composite materials

4.1. Electrochromism

Chromatic materials based on ACNT have been extensively explored as responsive devices. Inorganic materials and polymer materials such as tungsten oxide [54], liquid crystal molecules [55], polydiacetylene (PDA) [56–58], poly[1-phenyl-2-(p-trimethylsilyl)phenylacetylene](PTP), polyurethane (PU), polyaniline (PANI), polypyrrole (PPy) and polydimethylsiloxane (PDMS) can be combined with ACNT to obtain performance of change color in response to electricity.

The typical inorganic material of tungsten oxide can be combined with ACNT to obtain an electrochromic composite [54]. The coaxial WO$_3$/ACNT sheets exhibit a color change from yellowish to blue under cathodic polarization. Fig. 5 demonstrates the chromatic transitions with chronoamperometry under 1.0 V to trace the progress of electrochromism. The coaxial WO$_3$ and ACNT cable can function as both the electrochromic component and electrode. The original state of WO$_3$/ACNT appear yellow (Fig. 5a). When the work voltage is at 1.0 V for 5 s, the sheet shows two different colors. The upper part of the sheet turns into deep-blue, while the color of the lower part is unchanged (Fig. 5b). With the work voltage time prolonged to 15 s, the deep-blue band travelled down to the end of the ACNT sheet (Fig. 5c). Finally, the WO$_3$/ACNT sheet turned completely deep-blue (Fig. 5d). Such gradient electrochromism indicates the directional and orderly electron motion in WO$_3$/ACNT sheets. Electrons are injected from the upper part to the lower part in WO$_3$/ACNT sheets, which captured by WO$_3$ nanoparticles from top to bottom in an orderly manner.

PDA can typically change color from blue to red under various external stimuli. Most of chromatic phenomena of PDA are irreversible [59,60], which limited its practical applications. Therefore, scientists are trying to improve the reversibility and sensitivity, and expand the scope of stimuli. However, due to the low conductivity of bare PDA, their electrochromatism is difficultly to realize. Fortunately, ACNT fibers have high conductivity and electron transport speed, which are promising candidates to combine with PDA to realize the desired electrochromatism. PDA/ACNTs composite fibers are prepared by coating bare ACNT fibers with a solution of diacetylene monomers followed by polymerization under UV light [56]. ACNTs remain high-orientating and PDA is also uniformly distributed in the resulting PDA/ACNTs composite fiber. Fig. 6a demonstrates experimental set-up and chromatic transitions. The minimum direct current for chromatic transitions is 10 mA at room temperature. Colorimetric reversibility
Fig. 5. Chromatic transition of crystalline WO₃/CNT sheets under cathodic polarization. (a) Original color appearing yellow; colored states after applying 1.0 V for (b) 5 s, (c) 15 s and (d) 30 s. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

Fig. 6. (a) Color change of a PDA/ACNT composite fiber in response to an electric current [61]. (b) Fluorescent micrographs of an ACNT/PTP composite fiber upon application of increasing direct currents [62]. (c) Chromatic transitions during the charge–discharge process. An electrochromic fiber-shaped supercapacitor at 0 V, the positive, electrode at 1, 0.5, −0.5, and −1 V, respectively [63,64]. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)
of ACNT/PDA fibers is controlled by varying the absolute value of the current. And the blue-to-red transition is reversible (Fig. 6a) when current is lower than 30 mA. Furthermore, the color change can respond to current with a speed of 2 s; that is, blue fibers became red in 2 s when current is passed through and red fibers also switched back to blue in 2 s after the removal of the current. A reversible color change can continue for cycles. When an electric current pass through the PDA/ACNTs composite fiber, the side chain of PDA are easily response to electric fields, then further induces the structure change of PDA backbones, and finally leads to color change. The PDA/ACNTs composite fiber could be useful for non-destructive detection and structure monitoring in a broad scope from aircraft to small electronic facilities.

PTP, another kind of polymer material, can also be combined with ACNT to realize electrochromatism [62]. However, PTP has a higher thermal stability than PDA due to a rigid “jacket”, which is formed by the intra- and interchain molecular interaction of benzene and silicon moieties, the conjugated PTP backbone from the thermal attack exhibits a reversible change in fluorescent [65,66]. The PTP/ACNT composite fibers rapidly change in fluorescent intensity as well as color with electric current changing from 5 mA to 40 mA (Fig. 6b). The color change can be repeated more than a thousand cycles without any damage in structure and sensitivity. After combining with ACNTs, the PTP/ACNTs composites have a thermal decomposition of higher than 500 °C, electrical conductivity of ~370 S cm⁻¹, respectively. PTP/ACNTs composite film is also prepared by coating the PTP solution on ACNT sheets [62]. The composite film could show a reversible fluorescent quenching and color change when current is in a broader range of 20–240 mA. Color of composite film change from yellowish green to dark green (Fig. 6b), color changing process rapidly finished in a second with current on and off. ACNTs act as a continuous pathway for electron transport, and polymer chains structure are reconstructed under electric field, which lead to rapid color change.

PANI can exhibit different colors at different redox states [67]. The intrinsic color of the polyaniline is green, if PANI is in the oxidized state, its color is blue, and if PANI is in reduced state, its color is yellowish. So PANI can be combined with ACNT by electrochemical deposition to fabricate a smart electrode. Preparation method is as follows: a layer of ACNTs sheet is first drew onto an elastic fiber or an elastic sheet; and then PANI is deposited through electropolymerization of aniline; Finally, the two PANI/ACNTs composite fibers or sheets are used as both electrodes to fabricate electrochromatic display [68]. In this devices, ACNTs have a high conductivity to transfer and accumulate charge, while PANI has a chromatic behavior for response to different redox states of the device [63,64]. Such as, the two PANI/ACNTs composite fibers coated with electrolyte prepared into a fiber-shaped supercapacitor. The fiber-shaped supercapacitor will display yellowish, green and blue when voltage charged from −1 to 1 V, as shown in Fig. 6c. Moreover, the unique properties of ACNTs and the special fabrication process lead the fiber-shaped electrode to high stretchability and flexibility. In conclusion, when chromatic polymers satisfy requirements of energy storage devices, charge state can be monitored by displaying different colors, it may be developed novel smart devices.

Optical switchable windows have attracted great interest in daily life. Their practical applications range from electrical shutters, smart auto windows to projection screen and band-pass filters. The PU/ACNT composite film can realize rapidly changed from opacity to transparency in a few seconds under current on, but slowly reversed after current off. This composite film is prepared by a layer of ACNT sheet sandwiched between two PU films by a simple solution process to obtain PU/ACNT composite films (Fig. 7a) [69]. The heat generated from current induce phase transition of the soft segments in PU, which lead to opaque-to-transparent transition (Fig. 7b). In this composite materials, a layer of ACNT sheet provides a pathway to electrically conductive, but this sheet also has a relatively high resistance. Moreover, a large number of small and uniform spherules along the aligned direction are formed by the spatial confinement and interaction between ACNTs and PU induce, this is the reason of a decreased melting point of soft segments from 52 to 47 °C and faster transition. The PU/ACNT composite film can be electrically conductive, flexible, and switchable from opaque to transparent under various environments. Because of the easy synthesis and sufficiently low power consumption to maintain the transparency.

### 4.2. Electrically induced deformation

In general, amorphous polymers are difficulty to realize an anisotropic deformation, because their structure arrangements are disordered, there have many small deformations in amorphous polymers [70]. The orientation of polymer chains need to introduce other aligned materials to contribute an anisotropic behavior in deformation. ACNT have an anisotropic structure and excellent physical and chemical properties, which is a candidate to induce orientation of polymer chains. So the introduction of ACNTs helps to obtain anisotropic structure with higher degree.

**Fig. 7.** (a) The structure diagram of a PU/ACNT composite film. (b) The reversible change of transmittance for a PU/ACNT composite film under an electric current off and on. [69].
Electrically responsive ionic polymers are attractive transduction materials, their large deformation, high mechanical strength can be generated under low voltage. Ionic polymers can be directly integrated into microelectronic controlling circuits to obtain complex actuations, which exhibit excellent characteristics of electro-deformations [71,72]. Generally, the uptake of counter ions is happened during electrochemical redox processes, and the durability is destroyed by stress relaxation because of introduction of the conducting polymers. So the electromechanical response become more and more slowly because of deterioration of the electrical conductivity. In order to solve above problems, ACNTs have been introduced into the ionic electrically responsive polymer, because ACNTs as second component possess a high conductivity and mechanical strength to enhance their electromechanical response. A sulfonated tetrafluoroethylene based fluoropolymer–copolymer (Nafion) is a typical ionic electro-active polymer with high ionic conductivity and excellent physical properties [73,74]. The actuation of conductive polymer is generally accomplished in electrolyte solutions. But Nafion can absorb ionic liquids as electrolytes, so it can be actuated in air. The electromechanical performance of Nafion is the result of the ion transport in materials under a certain voltage. ACNT have high volume fraction, conductivity and modulus, which are applied to improve the electromechanical performance of Nafion. The responding rate, strain and actuation efficiency of composite films depend on the concentration and mobility of ions and the modulus of materials.

A sulfonated tetrafluoroethylene based fluoropolymer–copolymer (Nafion) is another ionic electro-active polymer, which has a high ionic conductivity and excellent physical properties [75]. The actuation of conductive polymer is generally accomplished in electrolyte solutions. But Nafion can absorb ionic liquids as electrolytes, so it can be actuated in air. The electromechanical performance of Nafion is the result of the ion transport in materials under a certain voltage. ACNTs have high volume fraction, conductivity and modulus, which are an excellent candidate to incorporate and improve the electromechanical performance of Nafion. The responding rate, strain and actuation efficiency composite films depend on the concentration and mobility of ions and the modulus of materials.

The composite film with sandwich structure can be made from two Nafion/ACNTs composite films as electrodes, and an Nafion ionomer as separated layer which absorb imidazolium ionic liquids as electrolytes (Fig. 8a) [72]. When actuator

![Fig. 8. The electro-deformation based on polymer/ACNTs composites. (a) Schematic drawing of a Nafion/ACNTs composite materials with current off and on; (b) Optical image of the bending Nafion/ACNTs composite film under a voltage of 4 V [72]. (c) Schematic illustration of electrothermal actuation mechanism for a PDMS/ACNT actuator and (d) the bending behavior of a PDMS/ACNT actuator [74].](image-url)
combined with a certain voltage, the ions will accumulate to one Nafion/ACNTs composite electrode while depleted from the other one. The ion transfer will induce an opposite volume strain, in other words, one electrode of the actuator is expanded whilst the other is contracted. The composite film finally shows a bending behavior actuated under a certain voltage (Fig. 8b). The excellent physical properties of ACNTs contribute to the actuation performance of the composite film. High surface area of composite film provides abundant space to accumulate ions, which results in a high ion concentration and large strain. High electrical conductivity contributes to the effective path for rapid ion transport, and ensures rapid response. Because of anisotropy of mechanical properties, ACNTs contribute to the actuation amplitude. These composite shows over 8% of strain actuated by a 4 V pulse voltage with 0.5 Hz in frequency. This actuation will remain more than 10 min.

A electro-thermal actuator is made of U-shaped PDMS/ACNTs composite film, which is prepared by embedding ACNT sheets into the PDMS surface (Fig. 8c and d) [74,76]. The thermal expansion of PDMS is restricted by the large interfaces between ACNTs and PDMS. Therefore, the longitudinal thermal expansion coefficient of the ACNTs-rich PDMS layers two orders of magnitude is lower than that of bare PDMS. Conductive ACNT sheets inside PDMS can convert electrical energy to thermal energy. The ACNT direction is perpendicular to the length direction of the horizontally cut electrode (Fig. 8d). The prepared actuators have two layers, one is the ACNT layer and the other is the PDMS layer. The two electrothermal actuators bent to the ACNT sides along the length direction of the U-shaped electrodes, and the deformation of the horizontally cut actuator is large. The parts which generated more heat would show obvious bending in the two electrothermal actuators. When the double-layer composite film is electrically heated, the fast temperature increase will cause thermal expansion.

Apart from electrochemical actuation, electro-thermal actuation is also a very important part in responsive behavior, which is in response to electric heat. The actuation is benefited from the thermal properties mismatch like thermal conductivity or coefficients of thermal expansion. As a consequence, an electro-thermal actuator can be made from assembling materials with different thermal properties. ACNTs have not only high electrical conductivity but also high thermal conductivity with different thermal expansion coefficient from polymer, so it can be used for electro-thermal actuator by compositing with flexible polymers [77].

5. Conclusions

In this review, we summarized the recent research literature on several sensitive polymer/ACNTs composites with new chromatic and deformable properties. The intrinsic mechanism of the interaction between ACNTs and polymers are widely studied. The alignment of CNT determines the orientation and crystallization of polymer, and polymer/ACNTs composites are in responsive to external light and electro-stimuli. At the same time, the sensitivity and stability of these composite must be further improved to meet the practical applications. The polymer/ACNTs composites will realize deformation and chromatism simultaneously by choosing proper responsive polymers. The chromatism and deformation of responsive polymer/ACNTs composites are also promising for application in smart energy devices, such as showing the work state of devices by color change and producing portable devices.

Acknowledgements

This work was supported by Introducing High level Talent Research Start Fund of Central South University of Forestry and Technology (No. 1040281) and Key Laboratory of Hexi Corridor Resources Utilization of Gansu (No. ZX1206).

References
