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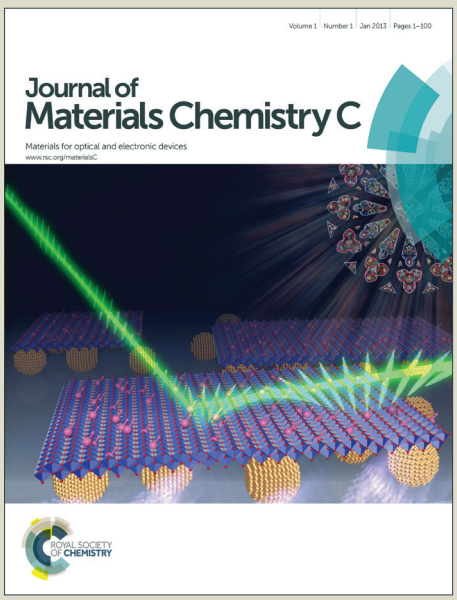

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ARTICLE

High-Performance Stretchable Transparent Electrodes based on Silver Nanowires Synthesized *via* an Eco-Friendly Halogen-Free Method

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Silver nanowires (AgNWs) with high aspect ratio are usually prepared *via* complicated multi-step procedures or by a relatively tedious polyol method with the assistance of X^{a-}/O_2 (X^{a-} represents halide ion or sulfion) etching. In this paper, silver nanowires with both high aspect ratio of 800~1600 and high purity were prepared *via* a simple, cost-effective, high-yield and eco-friendly method without the introduction of external halides or sulfides. Embedding the as-prepared silver nanowires beneath the surface of the poly(dimethylsiloxane) (PDMS) substrate, novel stretchable AgNWs/PDMS electrodes with superior comprehensive performances were fabricated. The resulting AgNWs/PDMS electrodes show high optoelectronic performance. Without annealing, transparent conductive films with both high conductivity and transmittance, R_s = 14 Ω/□, T = 90% and R_s = 9 Ω/□, T = 81% were fabricated, respectively. To our knowledge, they are among the best AgNWs/PDMS electrodes in terms of transparency and electrical conductivity. The transparent electrodes also possess excellent electromechanical performance and stretchability (no obvious changes in sheet resistance with strain up to 20%). What is more, the conductive layer of the as-prepared electrodes shows strong adhesion to the substrates, demonstrating their superior durability. They also perform high flexibility, good chemical stability and high uniformity.

1. Introduction

The recent dramatic progress in the mechanically unconventional electronics presents a new direction for future electronics. It mainly studies electronics that is based on elastic substrates and thus can be foldable, twisted, compressed, stretched or deformed into arbitrary shapes while maintaining a high level of electrical performance, reliability, and integration ability. Examples include stretchable organic light-emitting diodes,[1] stretchable solar cells,[2] dielectric elastomer actuators,[3,4] supercapacitor,[5,6] skin sensors,[7,8] artificial muscles[9] and electronic eye cameras.[10] Stretchability is the key for future durable and wearable electronics, especially for conformal bio-inspired devices.

Thin-film electrodes are the basic components of electronics; their properties have great influence on the performances of electronic devices. Indium tin oxide (ITO) is the most widely used transparent electrode material due to its excellent optoelectronic performance, but its brittle nature and high cost largely hamper its utility in the emerging stretchable electronics. Exploring alternative electrode materials including carbon nanotubes (CNTs),[11,12] graphene,[13-18] silver nanowire meshes,[19-21] copper nanowires (CuNWs),[22,23] and conductive polymers such as PEDOT:PSS,[24,25] has thus recently attracted considerable research interest. Poly(dimethylsiloxane) (PDMS) is the most popular substrate material for stretchable transparent electrodes due to its high elasticity and transparency. The inherently stretchable carbon nanomaterials (carbon nanotubes, graphene) dominate the research field of stretchable thin-film electrodes. However, these materials have a rather high sheet resistance of 100~1000 Ω/□ at 80% optical transmittance, about ten times higher than that of ITO.[11-13] Silver nanowires (AgNWs) stand out for their excellent optoelectronic performances comparable to ITO, along with better electromechanical flexibility and chemical stability. They are considered to be very promising candidates for stretchable electronics for replacing ITO.

The aspect ratio of silver nanowires is a crucial factor for their applications in transparent electrodes; AgNWs with high aspect ratio tend to have better optoelectronic performance. However, most metal NWs synthesized by wet chemistry methods are limited to 1-20 μm in length.[26] Silver nanowires with high aspect ratio are often fabricated with complicated multi-step procedures or with the assistance of the X^{a-}/O_2 (X^{a-} represents halide ion or sulfion) etching.[19,27] As to the preparation of the stretchable AgNWs/PDMS electrodes, previous research mainly focused on finding compromise between stretchability and conductivity. So far, AgNWs/PDMS electrodes with good stretchability, conductivity and transparency have rarely been reported. Xu[21] and Wang[28] have fabricated stretchable AgNWs/PDMS electrodes previously; neither of them reported transparency. Although stretchable and transparent AgNWs/Ecoflex electrodes with T = 90%~96% and R_s = 9~70 Ω/□ were fabricated by Lee[19] *via* vacuum filtration and transfer processes, the durability of the electrodes remains a problem, in that the conductive silver nanowires were directly deposited on the surface of the substrates and can be easily delaminated or damaged by external friction or adhesion.

In this contribution, silver nanowires with both high aspect ratio of 800~1600 (average length 40~50 μm, some as high as 80 μm, average diameter ~50 nm) and high purity were prepared *via* a very

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simple, cost-effective, high-yield and eco-friendly method. Embedding the as-prepared silver nanowires beneath the surface of the poly(dimethylsiloxane) (PDMS) substrate, novel stretchable AgNWs/PDMS electrodes with superior comprehensive performances were fabricated. The resulting AgNWs/PDMS electrodes show excellent optoelectronic performance. Without annealing, transparent conductive films with both high conductivity and transmittance, R_s = 14 Ω/□, T = 90% and R_s = 9 Ω/□, T = 81%, were fabricated, respectively. To the best of our knowledge, they are the best AgNWs/PDMS transparent electrodes fabricated *via* embedding AgNWs beneath the surface of PDMS in terms of transparency and electrical conductivity. The transparent electrodes also possess excellent electromechanical performance and stretchability (no obvious changes in the sheet resistance with strain up to 20%). Moreover, the conductive layer of the as-prepared electrodes shows strong adhesion to the substrates, demonstrating their superior durability. They also possess high flexibility, good chemical stability and high uniformity.

2. Experimental

2.1. Preparation of silver nanowires

Silver nanowires were prepared *via* a novel polyol method. Ethylene glycol (EG) solution of poly(vinyl pyrrolidone) (PVP, K30) (0.3995~0.402 g PVP dissolved in 10 mL EG) were heated in an oil bath at 170°C for 1 h with vigorous stirring. Then 10 mL ethylene glycol solution of silver nitrate (0.1~0.102 g $AgNO_3$ dissolved in 10 mL EG) was added to the above-mentioned solution in two steps. Firstly, 1 mL $AgNO_3$ solution to produce crystal seeds was added dropwise into PVP solution within 3~5 min. After 4~5 min, the remaining 9 mL $AgNO_3$ solution was added 1 mL by 1 mL using a syringe within 9~12 min. The interval between each 1 mL is about 20~30 s. After 15~20 min, the solution turned into a grey emulsion. Then the emulsion continued to react for about 30 min. The final emulsion was left alone for about one day, until silver nanowires fully deposited to the bottom. The supernatant that contained tiny silver nanoparticles was poured out and reserved for other use. The products at the bottom were simply centrifuged and silver nanowires with high quality were obtained.

2.2. Fabrication of patterned transparent conductive films

Different patterns were designed by adhering clear plastic taps to the pre-cleaned glass substrates into expected shapes. Disperse the silver nanowires in methanol and dilute to a concentration of 0.1 mg mL^{-1}. The resulting solution was drop-cast onto the patterned area on the substrates. Before drop-casting, the dispersion should be sonicated about 2 min to minimize the agglomeration of nanowires. The clear plastic taps were torn off from the glass substrates after the AgNWs were fully dried, forming a uniform conductive layer with specific patterns. The liquid PDMS (Sylgard 184 Dow Corning, prepared by mixing the "base" and the "curing agent" at a ratio of 10:1) was coated on the top of the AgNW layer and was flattened evenly using a glass rod, followed by evacuation to remove the air bubbles and curing at 100°C for 0.5 h in a drying oven. Finally, the AgNWs/PDMS film was peeled off from the glass substrate.

3. Results and discussion

A simple, cost-effective, and eco-friendly method was developed for the preparation of silver nanowires. Only common and inexpensive raw materials, including poly(vinyl pyrrolidone) (PVP) (K30), ethylene glycol (EG) and silver nitrate ($AgNO_3$), were used during the process. The process mainly included the simple drop-casting of the $AgNO_3$ solution by a syringe without the complicated multi-step reactions and the assistance of X^{a-}/O_2 etching.[19,27]

Typically, each silver nanowire evolved from a multiply twinned crystal seed.[29] The multiply twinned nanoparticles (with a decahedral shape) have a five-fold symmetry configuration, with their surfaces bounded by ten (111) facets. A set of five twin boundaries are required to generate the decahedral particle because it is impossible to fill the space of an object of 5-fold symmetry with only a single-crystalline lattice. A twin boundary represents the highest-energy site on the surface of a multiply twinned particles, it helps to attract silver atoms to diffuse toward its vicinity from the solution to form nanowires. The side surface of each silver nanowire is composed of (100) facets. These (100) facets are easier to be capped by the surfactant PVP than (111) facets of the nanoparticles, leading to the continuous growth of the nanowires along (111) facets, as illustrated in Fig. S1.

Thus, the amount of crystal seeds had a strong influence on the aspect ratio and the purity of the silver nanowires. Proper volume of silver nitrate solution should be added to form the crystal seeds. Fig. S2 shows the scanning electron microscopic (SEM) images of the silver nanowires prepared with different amount of crystal seeds. The volume of the silver nitrate solution to produce crystal seeds in Fig. S2a and b was 2 mL and 0.5 mL, respectively. Fig. S2c is the SEM of the silver nanowires prepared with 1 mL silver nitrate solution to produce crystal seeds. Fig. S2d is the amplifying image of Fig. S2c. It can be found that silver nanowires with high aspect ratio (length about 30 μm, average diameter about 50~100 nm) and high purity were obtained when the volume was about 1 mL. When the volume was 2 mL, short silver nanowires containing some nanoparticles were obtained. Although long silver nanowires were formed, a large number of nanoparticles were also found when the volume decreased to 0.5 mL.

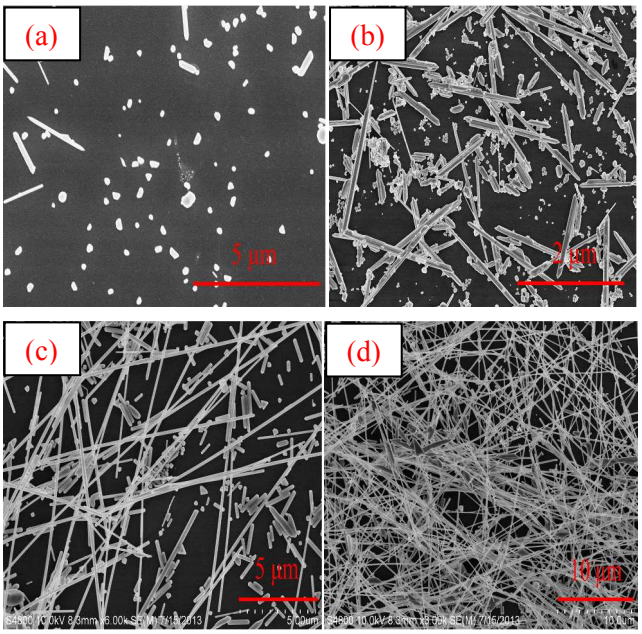

Fig. 1 SEM images of the silver nanowires prepared with different subsequent reaction time (The time was caculated from the solution turned into a grey emulsion). (a) 0 min; (b) 5 min; (c) 20 min and (d) 30 min.

The subsequent silver nitrate solution was successively added into the reaction system within 9~12 min. Shorter or longer time led to the formation of a large number of silver nanoparticles. SEM

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images were taken to detect the morphology changes of the silver nanowires with increasing the growth time in order to optimize the reaction conditions. When the silver nitrate solution was completely added, the reaction liquid turned into a grey emulsion in 15~20 min, indicating that silver ions translated into silver nanoparticles, as illustrated in Fig. 1a. After ~25 min, short silver nanorod formed, as shown in Fig. 1b. A large number of long silver nanowires generated after ~40 min as can be seen in Fig. 1c. After ~50 min, almost all the nanoparticles grew into long silver nanowires, as illustrated in Fig. 1d. Thus, the optimum subsequent reaction time was ~50 min. Furthermore, the optimum reaction temperature and the optimum molar ratio of the precursor $AgNO_3$ to PVP were also investigated. It was found that the optimum temperature and the molar ratio were 170°C and 6:1, as shown in Fig. S3 and Fig. S4.

With the optimized conditions, silver nanowires with high aspect ratio of ~500 (length ~30 μm, average diameter 60 nm) were obtained, as illustrated in the Fig. 2a and b. It was found that the aspect ratio of the silver nanowires could be further increased *via* changing the adding procedure of the subsequent silver nitrate solution. If it was not successively added, but added 1 mL by 1 mL (the interval was about 20~30 s) into the reaction liquid, the aspect ratio of the silver nanowires further increased to 800~1000 (average length 40~50 μm, average diameter ~50 nm), as shown in Fig. 2c and d. It deserves to be mentioned that the length of some of the resulting AgNWs was as high as 80 μm, while retaining a diameter ~ 50 nm, indicating their very high aspect ratio of 1600, as illustrated in Fig. S5a and b.

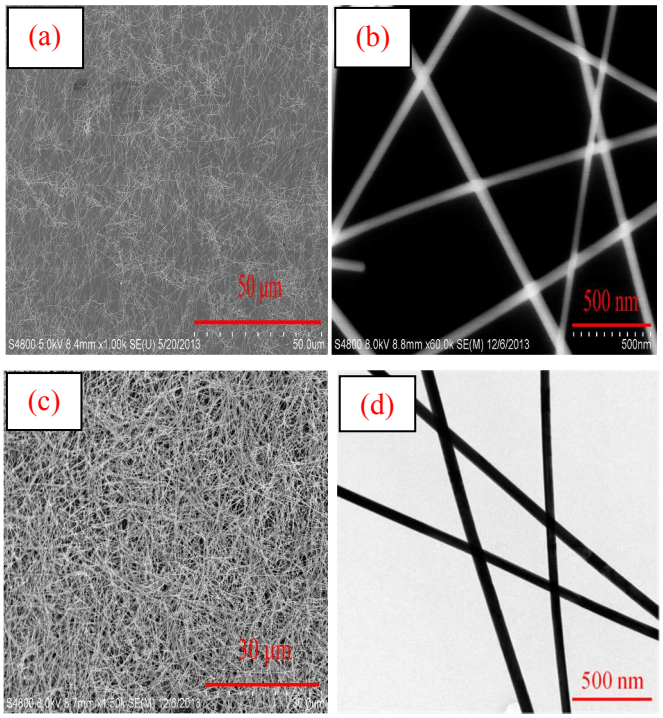

Fig. 2 Images of silver nanowires prepared with different adding procedure of the subsequent silver nitrate solution: (a) and (b) SEM of the AgNWs prepared *via* successive adding; (c) and (d) SEM and TEM of the AgNWs prepared *via* adding step by step.

Under the optimum reaction conditions, the resulting silver nanowires not only have high aspect ratio, but also possess high purity, indicating that most of the silver nanoparticles grew into long silver nanowires. This not only enhanced the purity but also resulted in high yield of silver nanowires (> ~90%). For example, 0.102 g $AgNO_3$ was used as the starting material, the resulting AgNWs of > ~0.058 g was isolated. The residual tiny silver nanoparticles can be easily separated from the silver nanoiwires *via* spontaneous decantation when the final emulsion was left alone for one day. The supernatant containing the tiny silver nanoparticles was poured out. The products at the bottom were simply centrifuged and highly pure silver nanowires were obtained.

Fig. 3a is the UV-vis spectrum of the as-synthesized silver nanowires. Two typical absorption peaks were observed at wavelength of 350 nm and 390 nm. The 350 nm peak is due to the out-of-plane quadrupole resonance, while the 390 nm peak is ascribed to the transverse plasmon resonance. The absence of the 410 nm peak, which is normally ascribed to nanoparticles,[30] confirming the high purity of the as-synthesized silver nanowires. Fig. 3b depicts the X-Ray diffraction spectrum of the resulting AgNWs. The four typical peaks at $2\theta \approx 38.2°$, 44.5°, 64.5°, 77.4° correspond to the crystalline plane of (111), (200), (220) and (311), respectively. The result is consistent with the standard diffraction spectrum of single crystal silver, indicating the face-centred cubic structure and the high crystallinity of the as-prepared AgNWs. The peak for (111) crystal plane has the strongest intensity and is sharper than that of the other three crystal planes. It demonstrates that significant anisotropic growth along (111) direction dominated in the AgNWs growth process, leading to their long length. Furthermore, the fact that no other peaks appear in the X-Ray diffraction spectrum also further verifies that the as-synthesized silver nanowires possessed high purity.

The developed synthetic method not only produced silver nanowires with high aspect ratio and purity, but also is environmentally friendly. No halides (such as $PtCl_2$ or $CuCl_2$) or sulfides (such as Na_2S) were used and the silver ions were completely transformed into nano-silver without waste. Such simple, cost-effective, high-yield and environmentally friendly nature of this method would thus greatly contribute to the large-scale mass production and commercialization of high quality silver nanowires.

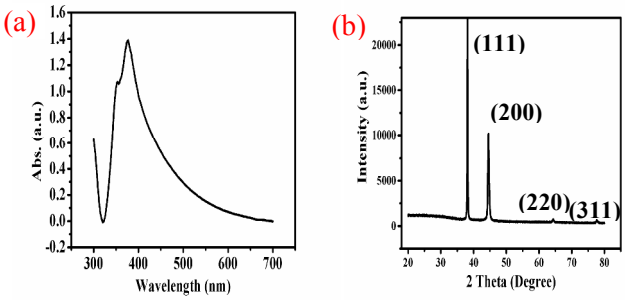

Fig. 3 (a) UV-vis spectrum and (b) X-Ray diffraction spectrum of the as-prepared silver nanowires.

Using the resulting silver nanowires, stretchable AgNWs/ PDMS electrodes were fabricated. The fabrication process is illustrated in Fig. 4.

The glass substrates were precleaned and treated with oxygen plasma. The cleaning process can remove impurities adsorbed on the substrate surface and the oxygen plasma treatment can enhance the surface hydrophilicity, both of which are propitious to decreasing the agglomeration of AgNWs and forming a highly conductive and uniform inter-connected network. Without complicated and costly photolithography, various patterns were designed on the glass substrate by adhering clear plastic taps to the substrates into expected shapes, which is simple and cost-effective. Silver nanowires dispersed in methanol without the addition of film-

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forming materials were drop-cast to the patterned area. Before drop-casting, the AgNWs solution was diluted to a suitable concentration (0.1 mg mL^{-1}) and then sonicated for 2 min. All of these treatments contributed to the diffusion of AgNWs solution on the substrate and enhancing the film uniformity. It is worth mentioning that clear taps are not only used to design patterns, but also to restrict the flow of silver nanowires solution within a specific region; namely, the flow gets bounced back by the tape edges. This back-flow also has the beneficial result of minimizing the coffee-rings effect, thus contributing to forming a smooth film. The clear plastic taps were torn off from the glass substrate after the silver nanowires were fully dried, leaving behind a uniform AgNWs conductive layer with the pre-designed patterns. The PDMS liquid (base/crosslinker~10:1) was coated on the AgNWs conductive layer and was further flattened by a glass rod, followed by evacuation to remove the air bubbles and curing at 100°C for 0.5 h.

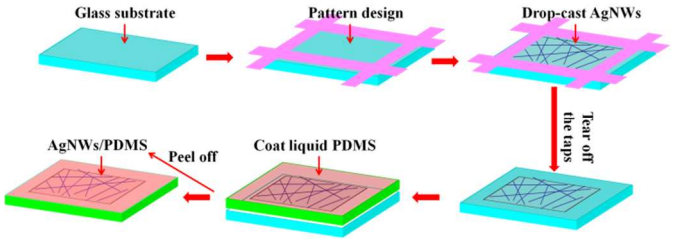

Fig. 4 The fabrication process of AgNWs/PDMS transparent electrodes.

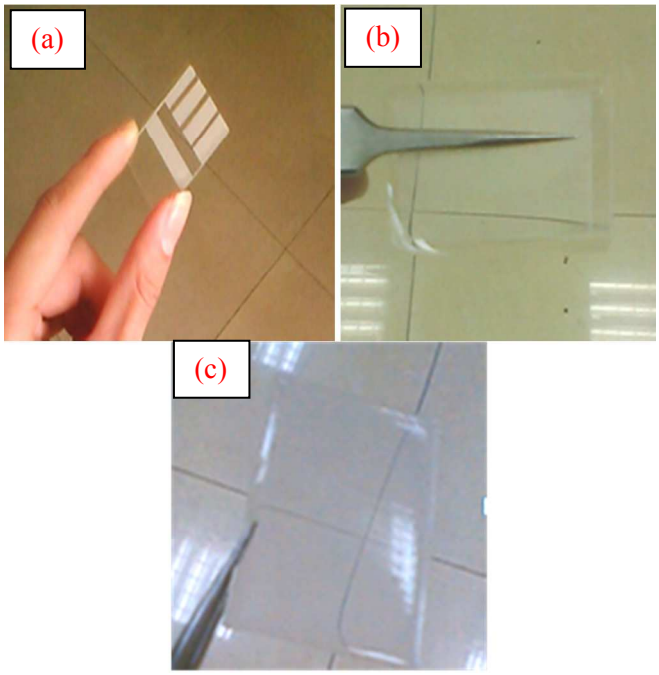

Fig. 5 Transparent electrodes with different patterns, sheet resistance and transmittance: (a) R_s = 2 Ω/□, T = 62%; (b) R_s = 9 Ω/□, T = 81%; and (c) R_s = 14 Ω/□, T = 90%.

The volatilization of the bubbles contributed to the permeation of PDMS into the space among silver nanowires. When heated, PDMS was cross-linked among the silver nanowires, leading to strong physical bonding between them. This cross-linking effect consolidated not only the contact between nanowires and PDMS but also between single nanowires, and therefore enhanced the conductivity as well as the durability of the AgNWs/PDMS electrodes. Although the physical bonding between AgNWs and PDMS is strong, the bonding between PDMS and the glass substrate is weak adsorption force. Furthermore, the PDMS (with thickness of about 500 μm) is highly elastic and durable. Thus, the AgNWs/PDMS film can be easily peeled off from the glass substrate without damage. The as-prepared stretchable AgNWs/PDMS transparent conductive films with different patterns are shown in Fig. 5 and Fig. S6. The preparation process of the transparent conductive AgNWs/PDMS film is facile without inert gases protection or complicated post-treatments.

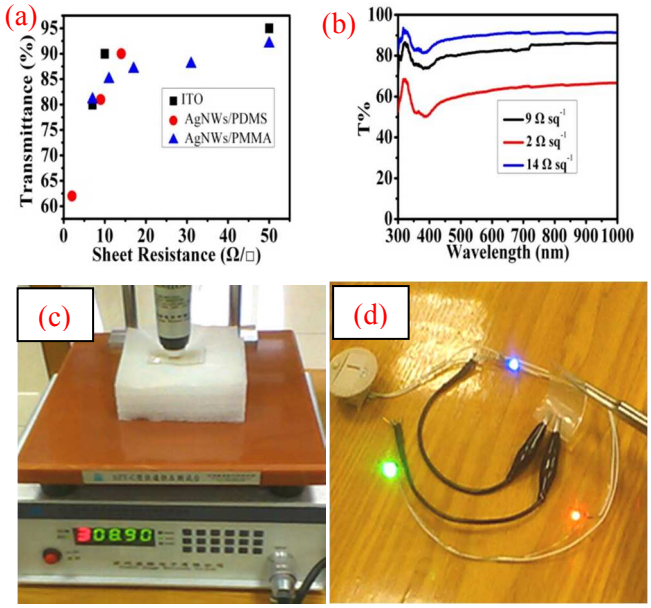

Fig. 6 (a) T% versus sheet resistance of the as-prepared AgNWs/PDMS electrodes and the previously reported comparison data; (b) wavelength versus transmittance graph of AgNWs/PDMS transparent electrodes with different sheet resistance; (c) sheet resistance of the transparent electrodes (T = 81%) measured by four-point probe instrument; (d) flexible transparent conductive film (T = 90%) in an electrical circuit powering three LEDs.

The geometry (length and diameter) and the purity of the silver nanowires are vital to the improvement of the optoelectronic performance. In order to enhance the conductivity of the electrodes, a good inter-connected network is expected. According to the percolation theory, silver nanowires density must surpass the percolation threshold of the network, i.e., $Nc \geq (4.326/l)^2/\pi$; Nc is the critical density and l is the length of the silver nanowires. It is obvious that the longer the NWs, the lower the density to form perfectly connected network and the higher the transmittance. Furthermore, the diameter of AgNWs has a great influence on the film transmittance. If the AgNWs diameter is much smaller than the wavelength of the visible light, the light scattering from the metallic silver surface is reduced significantly in comparison with the AgNWs with larger diameter, resulting in high transmittance and low haze. Thus, silver nanowires with high aspect ratio and purity synthesized in this work would be largely beneficial to the improvement of the optoelectronic performance. Highly conductive and transparent electrodes with sheet resistance as low as 9 Ω/□, transmittance 81% and sheet resistance 14 Ω/□, transmittance 90% were fabricated, respectively. To the best of our knowledge, these figure-of-merits surpass those of previously reported stretchable AgNWs/PDMS film fabricated *via* embedding AgNWs beneath the surface of the cross-linked PDMS. They are comparable to that of traditional ITO or previously reported stretchable AgNWs/PMMA

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electrodes,[20] as illustrated in Fig. 6a. Fig. 6b is the wavelength versus transmittance graph of the resulting AgNWs/PDMS films. It can be seen that the transmittance decreased with the decline of sheet resistance. The sheet resistance was measured by the four-point probe instrument (selecting the transparent electrode with T = 81% as an example) and was shown in Fig. 6c. In Fig. 6d, the as-fabricated transparent electrode (R_s = 14 Ω/□, T = 90%) can complete the circuit and enable light-emitting of all LEDs with different colours, demonstrating its high conductivity.

The surface of the AgNWs/PDMS is very smooth and uniform. Fig. 7a is the SEM image of the surface morphology of the AgNWs/PDMS (Rs = 9 Ω/□). The silver nanowires are embedded beneath the surface of PDMS substrate and distributed evenly without accumulation, resulting in the formation of well interconnected and uniform conductive AgNWs network. This was further confirmed by measuring R_s of the film at different positions. The R_s value of this film is in the range of 7.4 Ω/□ to 14.2 Ω/□ measured at different positions, with most around 9 Ω/□, without large deviation as shown in Fig. 7b.

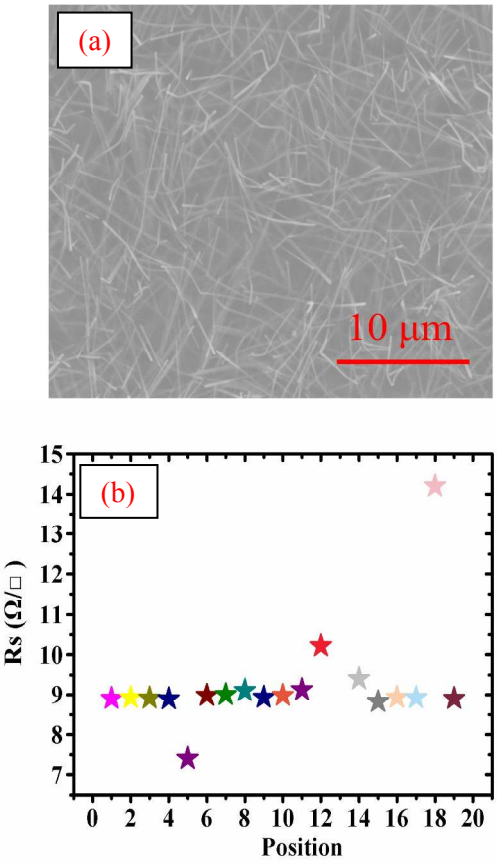

Fig. 7 (a) SEM image of the AgNWs/PDMS surface morphology; (b) Sheet resistance measured at randomly selected positions.

In order to enhance the durability of the electrodes, the conductive layer is expected to have strong adhesion to the substrate. If AgNWs were directly deposited on the substrate such as glass, PET or PDMS, the conductive layer could be easily removed or damaged by external force, such as friction or adhesion. Embedding silver nanowires beneath the surface of the PDMS could largely enhance the adhesion of the conductive layer to the substrates. The 3 M scotch test was performed to monitor the adhesion of the conductive layer to the substrate. As illustrated in Fig. 8, the sheet resistance showed a relatively large change only at the first time, from the original 2.39 Ω/□ to 4.57 Ω/□, but no obvious changes in the subsequent process. The inset of Fig. 8 is the plot of the relative variation of the sheet resistance versus adhesion times. It is obvious that the $\Delta R_s/R_s$ value is in the range of 0.8~1.2, which is low, demonstrating no obvious changes in the sheet resistance upon adhesion. The image in the inset is the photograph of a thin-film electrode fabricated *via* directly depositing the AgNWs onto the glass substrate. It can be seen that the conductive layer was obviously damaged after friction. However, the conductive layer of AgNWs/PDMS was almost undamaged after strong adhesion by the tap, as illustrated in Fig S7. The strong adhesion of the resulting AgNWs/PDMS electrode is mainly due to the cross-linking of the PDMS among silver nanowires when it was cured at 100 °C.

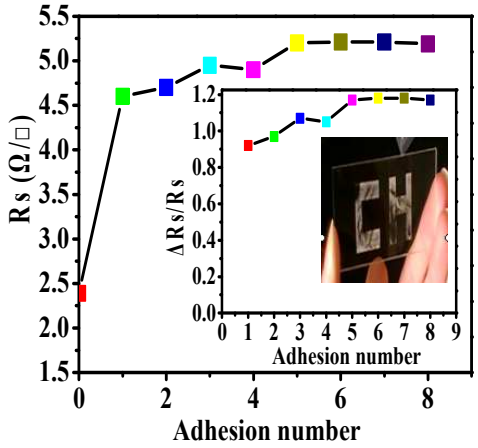

Fig. 8 Sheet resistance of AgNWs/PDMS transparent electrodes versus adhesion times. The inset is the graph of the relative variation of the sheet resistance versus adhesion times of the resulting AgNWs/PDMS electrode. The image in the inset is the photograph of a transparent electrode prepared by depositing AgNWs to glass substrate directly. After friction, the conductive layer was removed and damaged obviously.

The flexibility of the AgNWs/PDMS transparent electrodes was also investigated. The results showed that its sheet resistance maintained no obvious changes when bent to a small curvature (as shown in the inset of Fig. 9b) under tensile or compression strain more than 100 times, respectively. The bent transparent electrodes can still complete the circuit, also demonstrating their high electromechanical flexibility, as illustrated in Fig. 6d.

The AgNWs/PDMS transparent electrode not only showed high flexibility, but also possessed superior stretchability, as shown in Fig. 9a. The sheet resistance initially increased slowly from 2.64 Ω/□ to 6.25 Ω/□ until the strain was up to 25 %, then the growth amplitude got larger (14.23 Ω/□ at 35% strain), meaning contact among some of the silver nanowires got loose. Upon release of the strain, the sheet resistance partially recovered and declined to about 5.34 Ω/□ when the film recovered to its original length. Intriguingly, when the strain was increased to 35% again, the sheet resistance remained nearly constant at about 5.34 Ω/□ up to 20% strain. Beyond 20%, the sheet resistance again increased with the strain, following almost the same path as the first stretching. More stretching and releasing cycles in the range of 0-20% were performed. The sheet resistance still remained nearly constant at 5.34 Ω/□ in each stretching cycle. Fig. 9b shows the sheet resistance in the tenth and fiftieth stretching cycles, and it can be seen that the resistance remained almost unchanged at ~5.34 Ω/□. The

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reversibility of the sheet resistance demonstrated the superior stretchability of the AgNWs/PDMS electrodes.

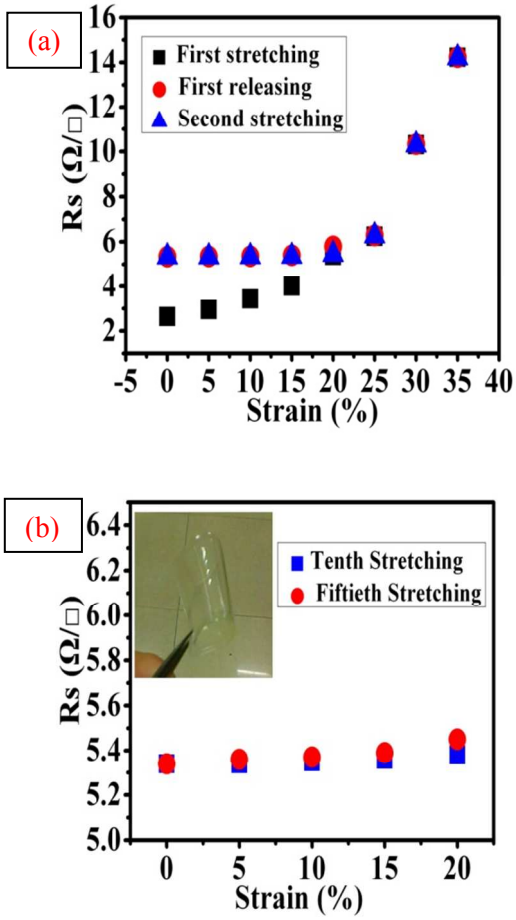

Fig. 9 (a) Sheet resistance of AgNWs/PDMS as a function of strain. (b) Resistances as a function of tensile strains (0-20%) for the stretchable AgNWs/PDMS electrode in the tenth and fiftieth stretching cycles. The inset is the photograph of AgNWs/PDMS film bent to a small curvature.

ITO exhibits low resistance to acid or alkaline. In contrast, the AgNWs/PDMS electrodes showed high stability in the alkaline solution. It was proved by a simple experiment, i.e., its sheet resistance remained constant when immersed in sodium hydroxide solution (5 M) for more than 1 h. Moreover, the AgNWs/PDMS electrodes were highly resistant to oxidation. Three AgNWs/PDMS films with different sheet resistances (3.3 Ω/□, 8.9 Ω/□ and 14.2 Ω/□) were kept in ambient environment for a month and their sheet resistances were periodically measured. Fig. 10 is the plot of the sheet resistances versus time for the three AgNWs/PDMS electrodes. It can be seen that the sheet resistances of the three electrodes showed only slight increases with time from one to ~twenty days. After ~twenty days, their resistances remained nearly unchanged (Probably, Ag_2O formed on the surface of the film and prevented further oxidation). Moreover, it was found that the lower the sheet resistance, the higher the antioxidation capability of the film which can be demonstrated by the increase magnitude of the sheet resistance. The conductive film with lower sheet resistance usually has a thicker conductive layer which attributes to preventing oxidation.

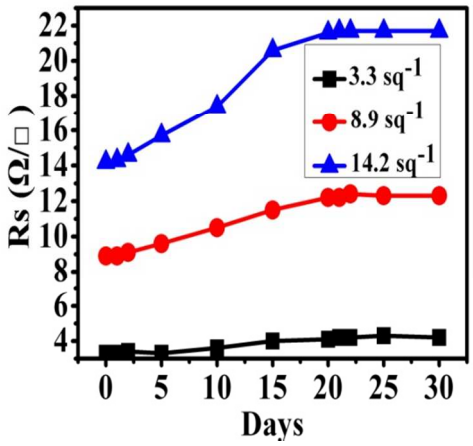

Fig. 10 Oxidation resistant test. The plot of the sheet resistances versus time for the three AgNWs/PDMS electrodes with different sheet resistances.

4. Conclusions

In summary, silver nanowires with high aspect ratio of 800~1600 and high purity were prepared *via* a simple, cost-effective, high-yield and eco-friendly polyol method. The simple, cost-effective, high-yield and eco-friendly nature of this method would thus promise future large-scale production and commercialization of the silver nanowires with high quality. The high aspect ratio and purity of the as-prepared silver nanowires largely contribute to enhancing the photoelectric performances of the electrodes. Embedding these long and pure silver nanowires beneath the surface of the cross-linked PDMS, transparent conductive AgNWs/PDMS films with various patterns and superior comprehensive performance were successfully fabricated, which showed brilliant optoelectronic performance with good stretchability, high flexibility, excellent chemical stability, durability and high uniformity, etc. It should be noted that the high figure-of-merits, i.e., R_s = 14 Ω/□, T = 90% and R_s = 9 Ω/□, T = 81%, surpassed most of previously reported AgNWs/PDMS electrodes. The simple and eco-friendly synthetic procedures and superior optoelectronic and mechanical compliance characteristics of the transparent conductive AgNWs/PDMS electrodes reported herein hold great potential for optoelectronic applications, especially for stretchable optoelectronic devices, such as foldable displays and stretchable solar cells. Further study in this direction is in progress.

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Notes and references

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† Electronic Supplementary Information (ESI) available: Additional SEM and TEM images of the as-prepared silver nanowires, conductive networks formed through coating silver nanowires, other examples of stretchable transparent AgNW/PDMS electrodes. This material is available free of charge *via* the Internet at http:// www.rsc.org. See DOI: 10.1039/b000000x/

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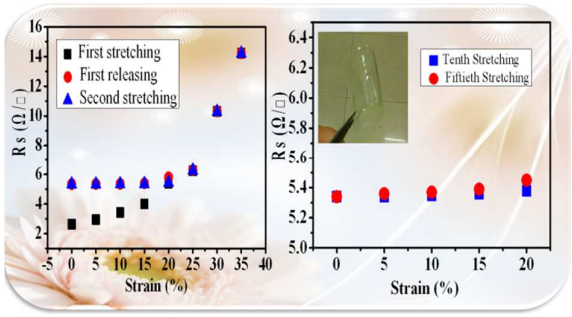

Stretchable transparent electrodes with superior comprehensive performances were prepared using high aspect ratio AgNWs synthesized *via* a facile eco-friendly method.

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