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# Highly Reliable Silver Nanowire Transparent Electrode Employing Selectively Patterned Barrier Shaped by Self-Masked Photolithography

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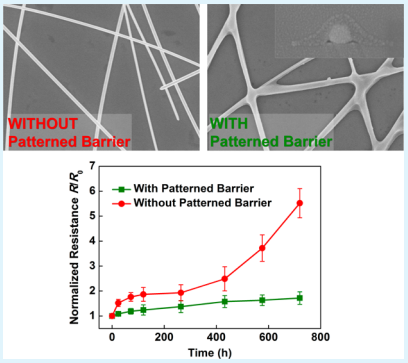
Supporting Information

**ABSTRACT:** The transparent electrode based on silver nanowire (AgNW) networks is one promising alternative of indium tin oxide film in particular for advanced flexible and printable electronics. However, the widespread application of AgNW electrode is hindered by its poor long-term reliability. Although the reliability can be improved by applying traditional overcoating layer or the core−shell structure, the transmittance or conductivity is inevitably undermined. In this paper, a novel patterned barrier of photoresist in situ assembled on the nanowire surface realized the reliability enhancement by simply employing AgNWs themselves as the mask in the photolithography process. The patterned barrier selectively covered the nanowires, while keeping the high transmittance and conductivity unchanged and improving the adhesion of AgNW networks on substrate. After 720 h storage in 85 °C/85% relative humidity (RH) environment, the resistance of electrode with patterned barrier only increased by 0.72 times. This study proposes a new way, i.e., the in situ patterned barrier containing light-sensitive substance, to selectively protect AgNW networks, which can be expanded to various metallic networks including nanowires, nanorods, nanocables, electrospun nanofibers, and so on.




**KEYWORDS:** *silver nanowire, transparent electrode, selective protection, reliability, patterned barrier*

## 1. INTRODUCTION

Flexible and printable electronics has emerged rapidly and attracted much attention in recent years due to its fascinating features and applications.[1−4] The transparent electrode is regarded as one of the essential components in many flexible and printable applications, e.g., solar cells, touch screens, organic light-emitting diodes, and so on.[5−7] Nevertheless, because of the drawbacks of the traditional transparent electrode material, indium tin oxide (ITO), such as the brittleness and high-cost deposition process, several alternatives have been proposed including carbon nanotubes, graphene, conductive polymers, sol−gel metal oxides, and metallic nanowires.[8−10] Among these, the transparent electrode based on silver nanowire (AgNW) networks is able to realize outstanding flexibility, conductivity, and transparency simultaneously compared with other electrode materials, and it also can be fabricated by solution-processed and printable methods for various devices.[11−13] Many previous studies about the AgNW electrode usually focus on three areas: optical, electrical, and mechanical performance improvement,[13−15] process optimization,[16,17] and realizing more applications.[18−20] Several inherent problems, including the high contact resistance between nanowires and poor adhesion on substrates, have been intensively studied.[6,12,21] However, by contrast, there are very limited studies about the long-term reliability of AgNW electrode,[22,23] although the unsatisfactory long-term reliability seriously limits the usage of AgNW electrode and becomes a notable weakness that must urgently be improved for industrial applications.

The long-term reliability of AgNW electrode closely correlates to the degradation behavior of AgNWs.[24,25] Silver nanomaterials often suffer from oxidation and sulfurization under ambient conditions due to the large specific surface area. For example, the size, chemical composition, and surface microstructure of silver nanoparticles (AgNPs) severely change after several weeks due to the reactions, even after only a couple of days in a detrimental environment.[26,27] In contrast with AgNPs featured by the single crystal structure, AgNWs are proposed to be more susceptive to the oxidation and sulfurization due to the defects and dislocations in the multitwinned nanowire structure.[26] During long-time practical usage, the degradation is very likely to be accelerated by some

Received: August 17, 2015
Accepted: September 30, 2015
Published: September 30, 2015




DOI: 10.1021/acsami.5b07619
ACS Appl. Mater. Interfaces 2015, 7, 23297−23304

incentives such as high temperature, high humidity, and light irradiation.[22,26,28,29] Because of the undesired oxidation and sulfurization, the nanowires gradually become coarsened and disconnected along with the generation of silver compounds and the variation of shape and size. These degradation phenomena inevitably sicken the percolating conductive paths and finally increase the sheet resistance of the whole film electrode until its failure.[22] Therefore, it is important to prevent the bare AgNW electrode from the potential deleterious environmental factors including high humidity, excessive light irradiation, oxygen/ozone, and gaseous sulfur-containing compounds like hydrogen sulfide and carbonyl sulfide.[26,30,31]

To employ a barrier layer or an encapsulation layer is a very effective method to realize the protection of metallic nanomaterials.[32,33] For the protection of nanowire networks, various barrier layers have been reported. According to the layer location, these reported layers can be roughly divided into two types: the layers coated on the surface of each individual nanowire to form core/shell structure microscopically[34−36] and the overcoating layers fully coated on the whole nanowire networks macroscopically.[25,37−40] Both types can benefit the reliability of AgNW electrode; however, some indelible drawbacks simultaneously appear when these two types of layers are applied. The first layer type individually encapsulates the nanowires very well but also inevitably increases the contact resistance between wires, introducing impurity leading to poor electrical performance. Although using the second layer type successfully solves the increase of contact resistance, the overcoating layer on the whole networks unfortunately reduces the optical transmittance. It is acknowledged that the nanowires can be applied as the transparent electrode materials because of the mesh structures that allow visible light pass-through. However, the overcoating layer covers all of the areas thoroughly, which inevitably undermines the transparency. Therefore, the protecting layer should selectively cover only on the nanowire surface instead of on the whole substrate, while keeping good wire−wire contacts and low resistivity. To the best of our knowledge, there is still no work that well integrates these two layer types and figures out the way to avoid all of these disadvantages. Although the electroplating and electroless plating are reported as selective coating methods for nanostructures,[24,41,42] it is difficult to achieve a uniform thin layer by both of these methods. The protecting effect of the thin but not uniform plated layer is weakened due to the degradation that begins at the not well-coated positions on the nanowire surface. However, if the coating layer grows thick, the transparency will be greatly influenced because the coated metallic layers are usually not transparent at all.

In this paper, a novel selective barrier layer, i.e., the in situ patterned barrier, has been successfully fabricated with a simple photolithography method using AgNW networks themselves acting as the mask during the process. The in situ photoresist patterned barrier realizes the protection of nanowires by selectively insulating nanowires from the air and shielding light irradiation, while keeping the favorable conductivity and transparency and fairly improving the adhesion between AgNW electrode and substrate. Importantly, the endurance of the electrode under high temperature and high humidity conditions is greatly enhanced. The simple self-masked photolithography method also has great potential to be applied for the in situ protection of metal nanorods, nanocables, and electrospun nanofibers with the barrier containing light-sensitive agents on various transparent substrates.

## 2. EXPERIMENTAL SECTION

**Preparation of AgNW Ink and Transparent Electrode.** The employed AgNWs were synthesized by one-step polyol method at 110 °C, as reported in our previous studies, with average length >40 $\mu$m and average diameter of ca. 90 nm.[15,43] The polyvinylpyrrolidone (PVP) was used as the capping agent in the redox reaction. The as-prepared nanowires were washed in acetone and ethanol using the reported method to reduce organic impurities drastically.[12] The washed AgNWs were immersed in ethanol, and the solution was then stirred for 10−15 min until the nanowires dispersed uniformly in the ink. The concentration of the AgNW ink was 0.5 wt %. Then the AgNW ink was drop-coated on the cleaned glass substrate (S1111, Matsunami Glass Ind., Ltd.) with size of 26 mm × 10 mm and then dried in air at room temperature for 2−3 min until the solvent was evaporated. The ink volume for coating was slightly changed (~5 $\mu$L) every time to achieve different electrode transparencies. The glass substrate was placed on a shaking stage during the drop-coating and drying, so the ink was able to freely flow on the substrate to form a quite uniform coating. Two thin gold strips were deposited on the edge of electrode by an ion sputter (E-1045, Hitachi High Technologies Co., Ltd.) to extract signals for resistance measurement.

**Fabrication of the In Situ Barrier Layer.** The AgNW electrode on glass substrate was thoroughly dried by preheating on a hot plate at 90 °C for 5 min. The positive photoresist (OFPR-800 LB, Tokyo Ohka Kogyo Co., Ltd.) was then spin-coated on AgNW electrode with the speed of 7000 rpm for 40 s. After coating, the AgNW electrode was heated at 90 °C for 5 min once more. The flat glass substrate was turned upside down for light exposure in the markless lithography system (DL-1000, NanoSolutions, Inc.) with a wavelength of 405 nm. After the light exposure, the AgNW electrode was immersed in the photoresist developer, i.e., tetramethylammonium hydroxide (TMAH) solution (NMD-3, Tokyo Ohka Kogyo Co., Ltd.), for 10−15 s to remove the redundant photoresist. Then the electrode was rinsed with pure water and blow-dried at room temperature.

**Characterization and Measurement.** The microstructure was investigated by scanning electron microscopy (SEM, SU8020, Hitachi High-Technologies Co., Ltd.). The sample for cross-sectional microstructure analysis was prepared by perpendicularly cutting the silicon wafer/adhesive/AgNW networks covered by patterned barrier/glass substrate sandwiched structure. All the samples were coated with a platinum thin layer beforehand to improve the conductivity. The electrode resistance was measured using a digital multimeter (2110-120, Keithley Instruments, Inc.). The parallel transmittance ($T_p$) of the AgNW electrode and the absorbance (abs.) of AgNW and the photoresist were measured using a UV−visible/near-infrared spectrophotometer (V670, JASCO Analytical Instruments, Inc.). The AgNWs were dispersed in ethanol and the photoresist was dissolved in acetone to prepare the samples for absorbance measurement. The contact angles were measured with a contact angle analyzer (Drop Master 300, Kyowa Interface Science Co., Ltd.). The 10 wt % PVP/ethanol solution was spin-coated on AgNW electrodes to prepare the PVP-coated samples for contact angle measurement. The degradation of AgNW electrodes at 85 °C/85% relative humidity (RH) was implemented in a temperature and humidity chamber (SH-240, Espec Corp.). 3M Scotch tape with a width of 6 mm was applied in the tape test.

## 3. RESULTS AND DISCUSSION

Figure 1 illustrates the simple fabrication process of the AgNW electrode protected by photoresist patterned barrier on glass substrate. As the figure shows, the AgNW networks formed on a glass slide and the photoresist solution was spin-coated on the nanowire networks to realize a uniform thin film. After this step, the electrode was turned over and exposed to the light. The light beam penetrated the transparent glass substrate and triggered the reaction of photoresist. The applied glass exhibited a transmittance of 91.2% at 405 nm wavelength (see Figure S1), which indicates the effective light exposure


DOI: 10.1021/acsami.5b07619
ACS Appl. Mater. Interfaces 2015, 7, 23297−23304

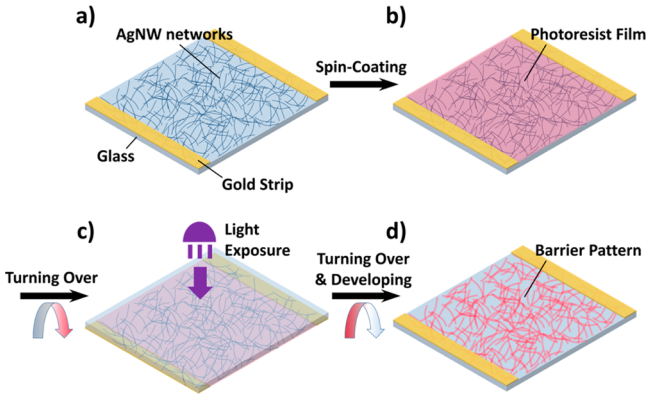



**Figure 1.** Fabrication and structure schematic of the in situ patterned barrier. (a) As-coated AgNW networks on the glass substrates. (b) Spin-coated and dried photoresist film on the glass-based AgNW networks. (c) Electrode turned over and exposed to light. (d) Patterned barrier gained after developing in TMAH solution and rinsing in pure water.

through the glass slide. The AgNW networks acted as the mask themselves due to the insufficient light exposure of the photoresist in the shadow of nanowires. After the light exposure, the electrode was immersed in tetramethylammonium hydroxide (TMAH) solution to remove the reacted photoresist. The photoresist just on the nanowire surface was kept on the electrode, and then the AgNW with patterned barrier emerged as shown in Figure 1d. With this in situ patterned barrier instead of the fully covering barrier layer as shown in Figure 1b, the AgNW networks were selectively encapsulated such as to be expected to avoid the loss of high transmittance. It was otherwise completely different from the core/shell structure, which usually increases the gap between neighboring nanowires and deteriorates the conductivity. The patterned barrier forming after the coating of nanowire networks barely interfered in the contact between neighboring nanowires; thus, the high conductivity was kept as well. The photosensitizer in the photoresist acted as an indispensable role in the formation of selectively coated barrier, which is initially reported to our knowledge. Generally speaking, the photoresist is used to shield certain positions in the photolithography process to fabricate microscopic structures, and finally the photoresist will not be kept on the structure but will just be dissolved in the developer solution. However, in this study, the selectively protecting barrier was still kept covering on nanowire networks, indicating a new application of photoresist. Therefore, the photosensitizer can be mixed with different kinds of resins featured by perfect encapsulation performance to achieve a new kind of photoresist for selective protection.

Figure 2 demonstrates the morphology of the AgNW electrode with or without patterned barrier. It is observed that the pristine nanowires featured by high special surface area were almost directly exposed to the open air. In Figure 2b, the AgNW networks were in situ covered by the photoresist pattern that was well able to isolate the nanowire surface from the ambient atmosphere. Especially, the wire−wire junctions, which are susceptive to degradation,[44] were fully encapsulated by a mass of photoresist as shown in the inset of Figure 2b. The formation of patterned barrier was proven to be closely related to the developing time as shown in Figure S2. With the developing time of 4.0 s, the photoresist layer still completely covered the whole electrode, just presenting very vague

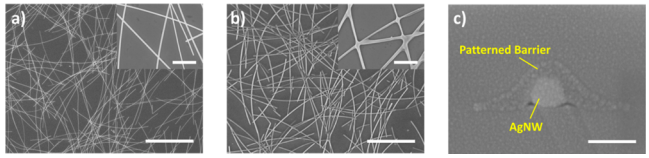



**Figure 2.** (a) Morphology of the pristine AgNWs; scale bar = 20 $\mu$m. Inset: high-resolution image; scale bar = 2 $\mu$m. (b) Morphology of the AgNWs coated with patterned barrier; scale bar = 20 $\mu$m. Inset: high-resolution image; scale bar = 2 $\mu$m. (c) Cross-sectional microstructure of the AgNW coated by patterned barrier; scale bar = 150 nm.

patterns; meanwhile if the time increased to 13.0 s, the patterned barrier was shaped perfectly. Additionally, the diameter of the photoresist-coated AgNWs increased to 140−280 nm, while the average diameter of the pristine AgNWs was ca. 90 nm, which also implied sufficient encapsulation of AgNWs. The cross-sectional microstructure in Figure 2c directly demonstrates the well-encapsulated nanowire and the in situ coated barrier. The photoresist near the nanowire was insufficiently exposed due to the AgNW-induced light intensity loss. Thus, it was accordingly dissolved in TMAH solution insufficiently in the well-controlled developing time and left on the nanowire surface as the in situ patterned barrier.

Figure 3 illustrates the optical transmittance of the pristine AgNW electrode and photoresist-coated AgNW electrode

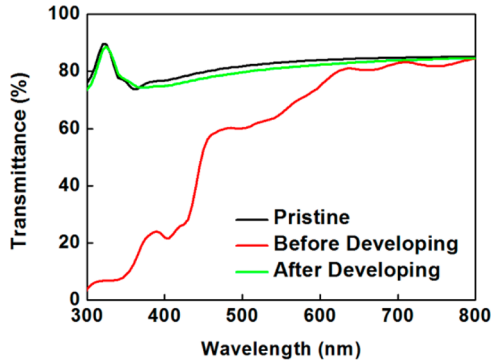



**Figure 3.** Optical transmittance of the pristine AgNW electrode, and photoresist-coated AgNW electrode before developing and after 13 s developing.

before and after developing treatment in TMAH solution. The AgNW electrode before developing showed low transmittance due to the light absorption of photoresist at low wavelengths. However, after developing, the electrode with patterned barrier showed almost the same transmittance as the pristine one, indicates that the photoresist had been fully removed except for those on the surface of AgNWs (shown in Figure 2a). Because of the transparency of the photoresist thin layer, unlike other opaque coatings,[24,36] the increased diameter hardly influenced the transmittance of the electrode. In Figure S3, it can be noticed that the substrate had not been covered by a redundant barrier layer. Therefore, the high transparency is expected to be well-kept with the patterned barrier. It is noted that the transmittance was dependent on the developing time (see Figure S4). It is notable that the initial transmittance largely decreased with the whole photoresist layer. At a wavelength of 550 nm, the transmittance decreased from 83.1% to 65.3%. This declining trend was more remarkable at short wavelengths. From the wavelength of 450 to 430 nm, the


DOI: 10.1021/acsami.5b07619
ACS Appl. Mater. Interfaces 2015, 7, 23297−23304

transmittance of the coated AgNW electrode before developing sharply dropped from 52.6% to 28.3% due to the increasing near-ultraviolet light absorption of photoresist. The transmittance at the wavelength of 550 nm notably recovered from 65.3% to 81.2% due to the removal of photoresist during the developing process. The value of 81.2% was slightly lower than the original one due to the increased diameter as shown in Figure 2a. Except for the optical transmittance, the nanowire contacts were also little influenced by the coated patterned barrier. In Figure S5, the resistances of AgNW electrodes before and after coating the patterned barrier were compared. For all five samples with different transmittances, it shows that the resistance values were stably kept after the coating. Table S1 indicates the detailed resistance values before and after photoresist coating. All five resistances changed for <1.2%. Furthermore, only the average resistance of the first group increased while the other four decreased. Actually, it is also reported that solvent evaporation and polymer shrinkage during the coating and heating process could even improve the wire−wire contact.[25,37,45] In the present work, the nanowires were washed well before coating, and the thick PVP layer adsorbed on the nanowire surface has been drastically removed; thus, the nanowire contact has been already improved in this step. Furthermore, the long nanowires used in this study with average length over 40 $\mu$m are not so sensitive to the wire−wire contact resistance change as the relatively short ones (average length of 10−20 $\mu$m).[15] Meanwhile, although the electrode was heated at 90 °C for 5 min before and after photoresist coating, the temperature was lower and the heating time was much shorter than the typical annealing parameters for AgNW electrodes.[46] Therefore, the conductivity enhancement by the coated photoresist was not so obvious to the AgNW electrodes here. On the other hand, the washing and preheating process improved the nanowire contacts. The coating of patterned barrier hardly broke the contact, and the resistance was maintained accordingly. Therefore, the AgNW electrode with patterned barrier successfully avoided the dilemma of the transparency deterioration or conductivity deterioration associated with the traditional coating methods. Definitely, the transmittance and conductivity are two main performance aspects of transparent electrode; however, for long-term applications, they are not the only issues that should be considered. It is widely known that the unsatisfied adhesion of AgNW networks on the substrate is a non-negligible drawback and inevitably increases the reliability risk during long-term employment.[14,25] Figure 4a shows the AgNW electrodes with or without the patterned barrier after the Scotch tape test with a force ~0.6 N for 10 times. It is observed that the transparency of the electrode without patterned barrier notably increased after tape test, indicating that a mass of AgNWs had been peeled off. In contrast, the transparency of the patterned barrier covered electrode seems to be quite reliable, and much less AgNWs were peeled off. Figure 4b gives the resistance change results of both electrodes. Without the patterned barrier, the resistance of AgNW electrode increased sharply with the number of tape tests and even transformed into insulator after only 3 tape tests. Oppositely, the resistance was really stable after 10 times tape peeling with patterned barrier coated on the AgNW electrode. The $R/R_0$ was only 1.43 after repeating the tape tests 10 times, while the $R/R_0$ became >3.3 × $10^6$ after 3 tape tests. Thus, the patterned barrier effectively improved the adhesion of nanowire networks on the glass substrate, further enabling the AgNW electrode to work reliably in the long term.

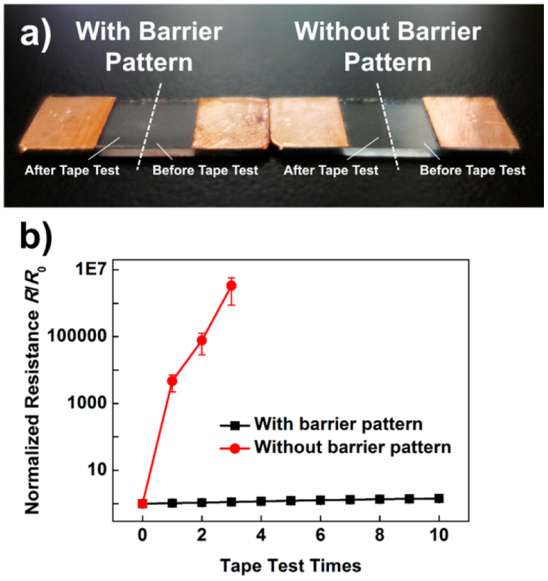



**Figure 4.** (a) AgNW electrodes with or without the patterned barrier after the Scotch tape test for 10 times. The left half of each electrode has experienced the tape test, while the right half has not, for comparison. The transmittance of pristine electrodes was ca. 80%. (b) Resistance changes of both electrodes as a function of number of tape tests.

The temperature and humidity chamber was applied to maintain the high-temperature and high-humidity (85 °C/85% RH) environment for reliability analysis. Figure 5a illustrates the normalized resistance $R/R_0$ of AgNW electrode with or without the patterned barrier after storage in the temperature and humidity chamber for different hours. It is notable that the increase of $R/R_0$ was effectively restrained with the patterned barrier. The $R/R_0$ of the bare AgNW electrode gradually rose up to 5.52 after 720 h storage, while the $R/R_0$ of the patterned barrier coated counterpart only increased to 1.72 under such severe conditions with no sharp variation that occurred during the storage, which indicates the electrode with patterned barrier was more reliable than many other reported ones with overcoating layers.[39,40,47,48] The accelerating test result in this work is compared with other reported results in Figure 5b. The resistance increased faster by applying the Ag@Ni core−shell nanowire structure[24] for 12 h or the AgNWs/rGO (reduced graphene oxide) structure[39] for >144 h. The resistance of the electrode with patterned barrier is relatively stable compared with these two kinds of electrodes, even in the harsher environment (85 °C/85% RH in this work and 80 °C/85% RH and 70 °C/70% RH in the other two works). Although the hierarchical PVA/AgNWs/graphene structure[37] demonstrated better protecting effect in 168 h storage, this result was achieved at a lower temperature of 80 °C and especially much lower humidity of 50% RH. In contrast, the reliability of copper nanowire electrode is much worse even covered with the protecting layer. As shown in Figure 5b, the normalized resistance of the electrode employing Cu@Zn core−shell nanowire structure[36] greatly increased to 12 in only 24 h. Meanwhile, the transmittance of the electrodes notably decreased after coating other protecting layers (24.7% to 3.0%), while the transmittance only changed for <1.9% after coating the patterned barrier as shown in Figure 5c. This novel


DOI: 10.1021/acsami.5b07619
ACS Appl. Mater. Interfaces 2015, 7, 23297−23304

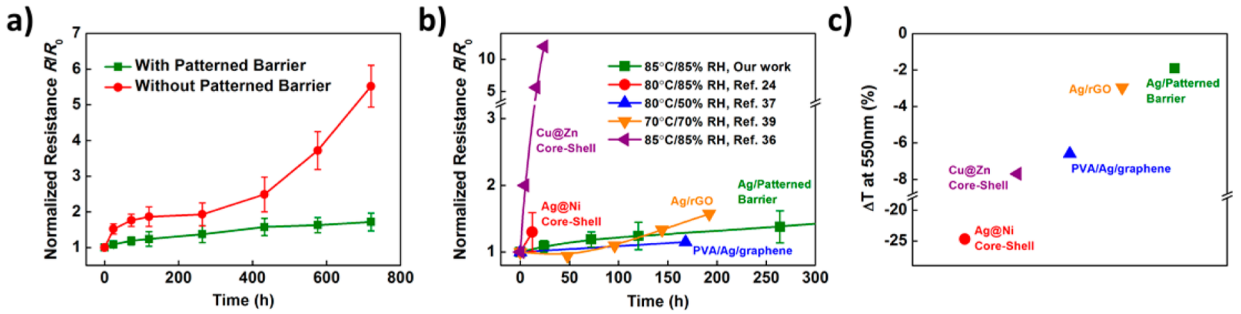



**Figure 5.** (a) Normalized resistance of AgNW electrode with or without the patterned barrier after storage in a temperature and humidity chamber (85 °C/85% RH) for different hours. The transmittance of both electrodes was ca. 80%. (b) Accelerating test result in our work compared with other reported results, including Ag@Ni core−shell nanowire structure,[24] hierarchical PVA/AgNWs/graphene structure,[37] AgNWs/rGO,[39] and Cu@Zn core−shell nanowire structure.[36] (c) Transmittance change $\Delta T$ of the transparent electrodes after coating or covering different protecting layers ($\Delta T = T - T_0$).

patterned protecting layer remarkably enhanced the reliability of AgNW electrode in harsh environment, while successfully keeping the high transmittance. Generally speaking, the electrode degradation in harsh environment is seriously accelerated, and the electrode can be reliably applied in practical environment for much longer time if the accelerating test shows good results. Therefore, it is believed that the electrode with patterned barrier can work effectively in a much longer duration for application.

Figure 6 shows the morphology of the AgNW networks after the 720 h storage in a temperature and humidity chamber (85 °C/85% RH). The AgNW networks coated with patterned barrier did not demonstrate obvious morphological change, indicating the electrode had been well-prevented from the high humidity and other detrimental chemicals in air. However, the bare AgNW networks suffered severe degradation during the long-term storage. Several small dots generated from the nanowire surface and even broke the nanowires. This kind of morphological change gradually undermined the percolating conductive paths and accordingly caused the increase of electrical resistance. The results indicate that the shielding effect of patterned barrier greatly decelerated the environmental degradation of AgNWs and successfully prolonged the long-term reliability of AgNW electrode.

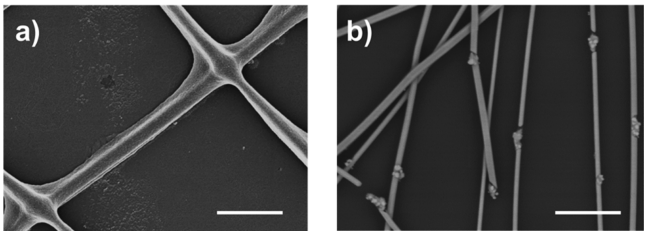



**Figure 6.** Morphology of the AgNW networks (a) with patterned barrier and (b) without patterned barrier, after the 720 h storage in a temperature and humidity chamber (85 °C/85% RH); scale bar = 1 $\mu$m.

However, the simple isolation mechanism is not the only reason for the degradation prevention. The material of the patterned barrier, the photoresist, also exhibited remarkable hydrophobic property. Because the AgNWs were coated by PVP layer after the synthesis using PVP as the capping agent,[12] the wettability of water on photoresist thin film and PVP thin film was investigated. Figure 7 shows the contact angles of water on the two kinds of thin film. The contact angle of water on photoresist thin film was 76.8°, increased by 138.5% compared with the contact angle of 32.2° on the PVP coating. It is notable that the hydrophobic property can be greatly enhanced with the photoresist coating. The applied photoresist is composed of a novolac resin and an organic photosensitizer; both of them are hydrophobic organics and hardly soluble in water.[49−51] The hydrophobic barrier films are often applied to prevent the degradation of metals susceptive to high humidity.[52,53] For AgNWs, the corrosion was accelerated by high humidity,[26] especially cooperated with high temperature.[22] Therefore, the hydrophobic property of AgNW electrode enhanced by the photoresist patterned barrier further benefited the degradation prevention.

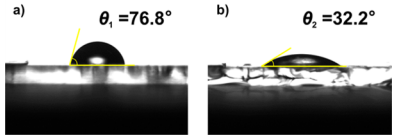



**Figure 7.** Contact angles of water on (a) photoresist thin film and (b) PVP thin film coated on glass substrate.

Except for the mechanical isolation and hydrophobic protection, the photoabsorption of photoresist barrier pattern is another possible factor for preventing AgNW degradation. The light-induced degradation of silver, especially induced by the ultraviolet absorption, has been intensively investigated and believed to be an important influencing factor.[29,31,54] However, the photodegradation phenomenon and prevention of AgNW electrodes have not been fully studied yet. Here the photoresist barrier pattern is provided as a potential antiphotodegradation method for AgNW electrodes. Figure 8 illustrates the UV−vis

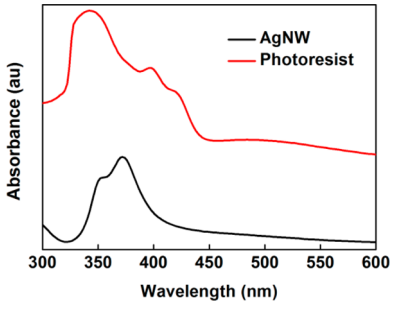



**Figure 8.** UV−vis absorbance of the AgNW and the applied photoresist.


DOI: 10.1021/acsami.5b07619
ACS Appl. Mater. Interfaces 2015, 7, 23297−23304

absorption of AgNW and photoresist at different wavelengths, respectively. The absorbance peak of AgNWs occurred in the wavelength range of 320−420 nm and shows the nanowires' strong absorption of near-ultraviolet and short-wavelength visible light.[55] Fortunately, the photoresist was also sensitive to the light with almost the same wavelength range and showed a notable absorbance peak in 310−450 nm, including the wavelength range in which the absorbance peak of AgNWs existed. Figure S6 shows the morphology of AgNW electrodes with/without patterned barrier after 4-week fluorescent lamp light exposure in the air. It is observed that the pristine nanowires broke seriously and large particles generated due to the degradation accelerated by light illumination, while the AgNW networks covered by photoresist well-kept the original morphology. The resistance changes $R/R_0$ of all the coated samples were <3.0, while the resistance of the pristine AgNW electrode failed to be detected. Therefore, with the photoresist patterned barrier on AgNW networks, the light, especially the near-ultraviolet and short-wavelength visible light, could be largely absorbed by the outer photoresist pattern instead of the nanowires themselves, enabling the AgNWs to be prevented from the photoinduced degradation effectively.

## 4. CONCLUSIONS

The highly reliable silver nanowire transparent electrode was realized with in situ covered patterned barrier in this study. The patterned barrier was skillfully fabricated by photolithography simply employing the coated nanowires themselves as the mask on glass substrate, and this method has potential to be applied on various flexible transparent substrates. High transmittance of the electrode remained perfectly, and harm to the electrical contact of nanowires was successfully avoided. The electrode with patterned barrier performed robustly in high-temperature/high-humidity atmosphere; both the resistance and morphology were found to be reliable during long-term storage. The mechanical encapsulation, hydrophobic property, and photoabsorption of the patterned barrier were believed to benefit the degradation prevention. The applied patterned barrier also greatly enhanced the adhesion of AgNW networks on the substrate, further enabling the AgNW electrode to work stably in the long term. This study initiates the investigation and application of in situ patterned barrier containing light-sensitive material. The patterned barrier demonstrates lots of advantages and is feasible to be generalized as an effective in situ protecting covering of different kinds of susceptive nanowires, nanorods, nanocables, electrospun nanofibers, and so on.

## ■ ASSOCIATED CONTENT

### Supporting Information

The Supporting Information is available free of charge on the ACS Publications website at DOI: 10.1021/acsami.5b07619.

Optical transmittance of the glass substrate, surface topography of the photoresist-coated AgNW electrodes after developing, morphology comparison between the neighboring areas of pristine AgNWs and AgNWs coated with barrier pattern, optical transmittance of the photoresist-coated AgNW electrodes with different developing times, resistances of AgNW electrode samples before and after the photoresist coating, morphology of AgNW electrodes with/without patterned barrier after fluorescent lamp light exposure (PDF)

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### Funding

Showa Denko K. K. Grant-in-Aid for Scientific Research (Kaken S, 24226017) COI Stream Project.


### Notes

The authors declare no competing financial interest.

## ■ ACKNOWLEDGMENTS

This work was supported by Showa Denko K. K., Grant-in-Aid for Scientific Research (Kaken S, 24226017), COI Stream Project, and National Natural Science Foundation of China (NSFC Grant nos. 51275135 and 51474081). The authors express gratitude for Dr. Chulmin Oh's help during the photolithography fabrication. J.W. acknowledges financial support from China Scholarship Council for his Ph.D. research in Osaka University.

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