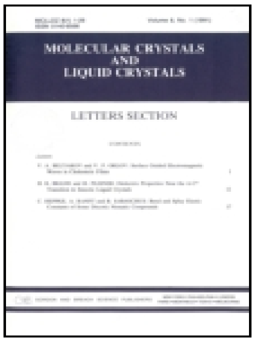

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Fabrication of ZnO/Ag Nanowire/ZnO Thin Films for Optoelectronic Applications

SSLIMSEAROM YOU, YONG SEO PARK, HYUNG WOOK CHOI, AND KYUNG HWAN KIM*

Department of Electrical Engineering, Gachon University, Gyeonggi, Korea

In order to improve the electrical properties of ZnO thin films to a level comparable with ITO transparent electrodes, silver nanowires (AgNWs) were coated between two ZnO layers as an inter-layer to produce a multilayer transparent conductive thin film. To achieve this, a uniform and stable AgNW layer was first formed by spin coating, onto which ZnO layers were deposited by facing target sputtering to protect against damage and oxidation. This structure was found to negate the drawbacks of each material layer, with a sheet resistance of 34.5 ohm/sq. and a transmittance of 84.5% being achieved.

Keywords silver nanowire; zinc oxide; facing target sputtering; multilayer; transparent electrode

Introduction

Modern technology makes it possible to quickly and easily access a diverse range of information through devices such as computers, notebooks, tablets and smartphones, all of which rely on a screen panel that typically contains some form of transparent electrode. Transparent electrodes are also used in solar cells, OLEDs and various other optoelectronic devices, with indium tin oxide (ITO) currently being the most widely used material. As with other metal oxide-based transparent electrodes, this can provide both a high electrical conductivity and optical transmittance through oxygen vacancies or impurity dopants[1,2]; however, this comes at a high financial cost due to the scarcity of indium and the need for high-temperature annealing.[3] Various alternative materials have therefore been proposed, such as carbon nanotubes[4,5], graphene[6,7], metal nanowires[8,9], metal oxides and hybrids thereof.[5,8] Among these, one of the more promising materials is based on a combination of silver nanowires (AgNWs) and zinc oxide (ZnO).[10,11] Unlike indium, zinc resources are quite plentiful[12] and its oxide film does not require additional annealing[3,12], but unfortunately also has quite poor electrical and optical properties relative to ITO thin films. In this study, we explore the feasibility of sandwiching AgNWs between two ZnO thin-film layers to create a multilayer film with improved electrical properties. Silver is already well-known for its high electrical conductivity, and the use of a well-formed network of nanowires

*Address correspondence to Prof. Kim Kyung Hwan, Department of Electrical Engineering, Gachon University, 1342 Seongnamdaero, Sujeong-gu, Gyeonggi 461-701, Korea (ROK). E-mail: khkim@gachon.ac.kr

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Table 1. Sputtering conditions

Deposition Parameter	Sputtering Conditions	
Targets	ZnO (5N)	
Substrate	Glass (15×15×1(mm))	
Base Pressure	4.67×10^{-4} Pa	
Working Pressure	0.26 Pa	
Gas Flow	Ar (10 sccm)	
Current	0.05 (A)	
Input Voltage	320 (V)	
Temperature	Room Temperature	
	Bottom Layer	**Top Layer**
Thickness	50, 100, 150 nm	50, 100, 150, 200 nm

allows this conductivity to be maintained over a wide area with minimal film thickness. There is a trade-off, however, in that increasing the overlap of nanowires improves the electrical conductivity at the expense of optical transmittance, thus making the length and diameter of the nanowires an important consideration.[13] These two dimensions are inherently linked by the limitations of the anisotropic growth of the nanofibers, and for this reason we opted to use spin-coating to ensure a uniform film thickness. The electrical, optical and structural properties of the resulting multilayer thin film were subsequently and are herein discussed.

Experimental

Before production to the sample, the substrate was undergone to cleaning process separately, wherein a 15×15 mm glass substrate cleaned by ultrasonic cleaner with acetone, ethyl alcohol, and deionized water, and then dried with a jet of nitrogen gas. The samples used in this study were produced by a three-stage process. Two 4 inch ZnO ceramic targets were then used to first deposit 50–150 nm-thick ZnO films through facing targets sputtering (FTS) under an Ar atmosphere (see Table 1 for details of the sputtering conditions used). The second step entailed ultraviolet-ozone (UV-O) treatment of the hydrophilic ZnO surface

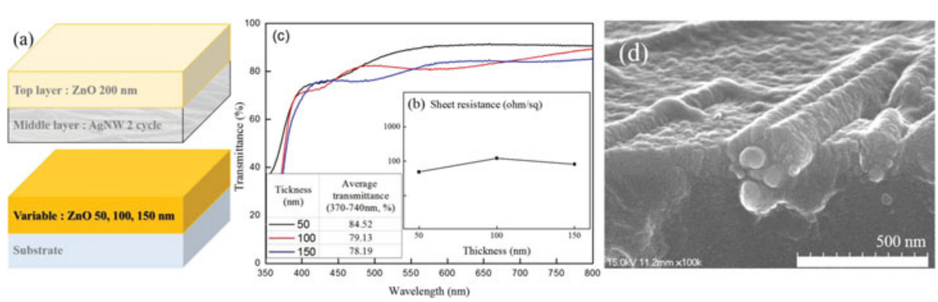

Figure 1. Properties of multilayer that fabricated by function in the bottom-layer thickness at 50 to 100 nm, (a) the structure of the measured samples, in this structure, the sheet resistance (b) and the transmittance (c), (d) the FE-SEM cross sectional image taken from 45 ° a tilted sample stage.

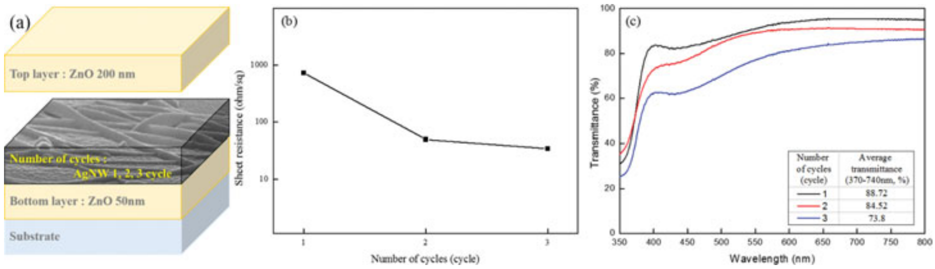

Figure 2. Properties of multilayer that fabricated by function in the number of the AgNW spin-coating, (a) the structure of the measured samples, in this structure, the sheet resistance (b) and the transmittance (c).

at 1000 rpm for 10 s, then 2000 rpm for a further 15 s, which was followed by spin coating of a 0.5% isopropanol suspension of AgNWs 60 nm in diameter and 10 μm in length. After drying in a conventional furnace at 150°C for 90 sec, this process was repeated by cycle (3times). The final step was the FTS deposition of the second ZnO layer using the same conditions and method as the first. It should be noted here that the FTS system used differed slightly from usual in that instead of facing the target and substrate[14,15] it was facing the two targets. This meant that the substrate was separated from the plasma generated, thereby minimizing the damage caused to the thin film by the collision of high-energy particles.[15] This arrangement also made it possible to adjust the distance between the targets and to the substrate, thus allowing the discharge voltage and the mean free path of the sputtered particles to be controlled mechanically.[16] Optical measurements of the resulting multilayer thin films were performed in the 300–800 nm spectral range using UV/visible spectrometry (Hewlett-Packard HP8453). Their sheet resistance was also measured using a 4-point-probe system (AIT Co, Ltd, CMT-SR1000N), after which the adhesion of the AgNWs to the ZnO layer was tested by the attachment and removal of Kapton tape.

Results and Discussion

In order to further optimize the multilayer film, the individual contributions of the bottom explored in relation to their respective thickness. As shown in Figure 1, varying the thickness of the bottom-layer from 50 to 150 nm had no significant effect on the total transmittance or sheet resistance, indicating that this layer's sole purpose is simply to prevent contact

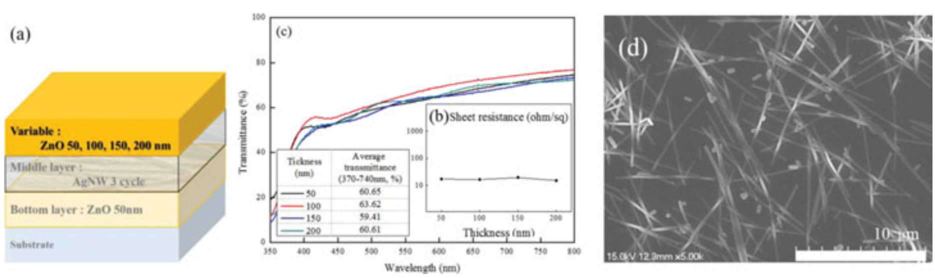

Figure 3. Properties of multilayer that fabricated by function in the top-layer thickness at 50 to 200 nm, (a) the structure of the measured samples, in this structure, the sheet resistance (b) and the transmittance (c), (d) the FE-SEM plane image.

(a)

Adhesion test	AgNW monolayer
Before	28.6 ohm/sq
After	Can not measured

(b)

Adhesion test	Multilayer
Before	20.6 ohm/sq
After	21.8 ohm/sq

Figure 4. Photographic image of the sample after the adhesion test, (a) AgNW monolayer, (b) ZnO / AgNW / ZnO multilayer.

between the substrate and the AgNWs. Figure 1(d) is can be found that the ZnO, without the empty spaces, between the substrate and the AgNWs. The inter-layer were produced from function of the number of cycle coated the AgNW (Fig. 2(a)). A significant change in sheet resistance was observed with an initial increase in the number of cycle (Fig. 2(b)). The transmittance progressively decreased with increasing the number of cycle (Fig. 2(c)), which confirms that the nanowire network indeed have significant effect on the sheet resistance and transmittance. Finally, much like the bottom-layer, the top-layer (Fig. 3(a)) was found to have no real significant effect on the sheet resistance (Fig. 3(b)) or transmittance (Fig. 3(c)). This is not the result that was expected, as this top-layer represents the last stop of electron movement; in other words, a thicker (and therefore smoother) film should, in theory, reduce the sheet resistance and increase the transmittance. It is therefore considered that the network of AgNWs must be sufficiently dense for this effect to be rendered negligible (Fig. 3(d)). The AgNW monolayer created for the multilayer film is very vulnerable to physical damage (i.e., scratches), and so adhesion tests were performed to test its durability. As shown in Figure 4,

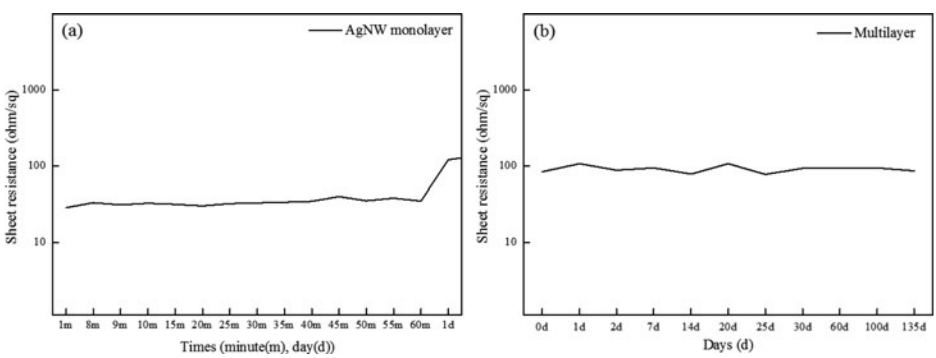

Figure 5. The sheet resistance of a AgNW monolayer (a) and the multilayer (b) film when they are exposed to atmospheric oxygen.

this revealed that although an uncoated AgNW network is readily removed by Kapton tape, it is unaffected when covered by a ZnO top-layer. It can be found as the sheet resistance measure before and after removal of the AgNWs by the Kapton tape. Figure 5 shows the variation in sheet resistance of the multilayer film and an AgNW monolayer when they are exposed to atmospheric oxygen. This reveals a clear increase in the sheet resistance of the AgNW monolayer after just 1 day (Fig. 5(a)), whereas even after 150 days, no change is observed in the multilayer (Fig. 5(b)). This clearly demonstrates the effectiveness of the ZnO thin film in preventing oxidation of the AgNWs, as also evidenced by the SEM image in Figure 1(c).

Conclusions

A multilayer transparent conductive thin film has been successfully created based on an electrospun network of AgNWs that can provide good electrical conductivity, yet still remain thin enough to also allow suitable optical transmission. This AgNW is sandwiched between two ZnO layers that are deposited by FTS, and which insulate the AgNWs from the underlying substrate and exposure to atmospheric oxygen. In this way, the two film types effectively cancel out each other’s major drawbacks, resulting in a sheet resistance of 34.5 ohm/sq and a transmittance of 84.5%.

Acknowledgments

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