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Application of Silver Nanowire for Transparent Electrode of OLED Device

Akihiko Tadamasa, Taisuke Matsui and Akira Tsujimoto

Panasonic Corporation.
Nishi-kadoma District, R&D Division, PC
1006 Kadoma, Kadoma City, Osaka 571-8501, Japan
Phone: +81-50-3587-2278 E-mail: tadamasa.akihiko@jp.panasonic.com

Abstract

A smooth transparent electrode structure was produced by covering conductive polymer on the silver nanowire film before removing binder resin which prevents aggregation of silver nanowires. And the composite electrode without peaking structures was produced by reducing micro sized organic aggregates in silver nanowire film. The OLED device using this composite electrode decreased the electric contact failure between the anode and the cathode (Short Failure), and reduced Current Leakage to 1/10. As a result, the performance of the white OLED device with silver nanowire was equivalent to that with ITO, and high efficiency of 100 lm/W device was developed.

1. Introduction

Recently, electrical device markets, such as electronic paper, a solar cell, organic electroluminescence, have grown rapidly. ITO (indium tin oxide) is generally used as the transparent layer material with electric conduction. However, indium price is predicted to rise sharply for exhaustion based on ITO is rare metal. And demands of flexible devices are expected to be widely expanded. Therefore, substitution of ITO for transparent electric conduction film equipped with lightweight properties or flexibility is energetically developed [1-3]. As the one candidate, silver nanowire (AgNW) film advantageous to the reduction in resistance is listed. The silver nanowire which bears an electric conduction function has arranged on a substrate, and conductivity is realized by each wire contacts. The length and the diameter of silver nanowire are designing 20 μm and 40 nm, respectively for compatibility of conductivity and transmittance. Therefore, the thickness difference of 120 nm causes the silver nanowire film from the intersection point of wires to the area without a wire (Fig 1).

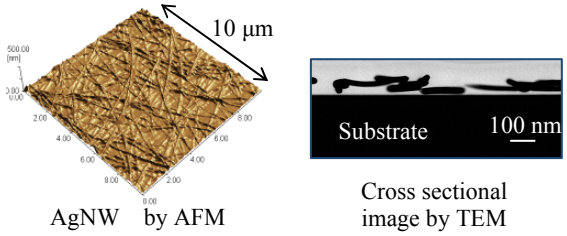

Fig. 1 AgNW image by AFM and TEM

At stacking process on nanowire film by directivity stacking method such as vapor deposition and spattering, stacking thickness becomes thin at the slope which is caused by roughness. Especially the OLED device which stacked organic layers on the silver nanowire electrode, such as emitting layer tends to cause Short Failure and Current Leakage. Because the film thickness of an organic layer is tens of nano-meter and is thin as compared with thickness difference of the silver nanowire. Therefore, for decreasing surface roughness, the silver nanowire layer is coated to cover by conductive polymer. If the film thickness of the conductive polymer is thick, surface roughness will decrease, but there is a trade-off relation between optical absorption and surface roughness. In this paper, in order to break off the trade-off relation, the transparent electrode film using silver nanowire was produced by developing the silver nanowire ink refining process and the conductive polymer stacking process on the silver nanowire layer. And silver nanowire electrode adapted for OLED device.

2. Experimental

Silver nanowires were made by Polyol method. Synthesized silver nanowire solution included impurities such as silver nanoparticles and excess dispersing agent. The lighter and larger impurities than the nanowire were eliminated by decantation and filtration respectively. After that, the silver nanowire ink was prepared by adding binder resin to prevent aggregation of silver nanowires. The silver nanowire ink was coated on substrate as silver nanowire layer. The transparent composite electrode is consisted of silver nanowire and p-type conductive polymer which was coated on the silver nanowire layer. The surface of the silver nanowire layer was treated as pre-treatment before coating conductive polymer. Two kinds of pre-treatment were tested (Table I).

Table I Pre-treatment to silver nanowire Layer

Pre-treatment to AgNW Layer		UV-O_3	Ar Plasma
Electrode	Thickness of AgNW [nm]	80	8
	Roughness; Ra [nm]	12	6
OLED device	Provability of Short Failure [%]	100	0

One is UV-O_3 treatment under atmosphere and the other is Ar plasma treatment under vacuum condition. The thickness of the silver nanowire layer was measured by contacting method, and the thickness decreased 90% by Ar plasma treatment in contract with the thickness didn't change by UV-O_3 treatment. It is considered that the substances which constitute silver nanowire layer were decreasing by Ar plasma treatment, compared to the surface of the silver nanowire layer was only modified by UV-O_3 treatment. The binder resin which was mostly consisted of silver nanowire layer could be removed selectively by Ar plasma, because sheet resistance of silver nanowire layer is not decreased. Furthermore, the roughness of the electrode treated by Ar plasma decrease to 50%. It is considered that removal of the binder resin could eliminate distribution of wettability originated by silver nanowires or binder resin, and improve the coverage of the conductive polymer on the silver nanowire layer.

The OLED device was made by evaporation method to stack hole transport layer, some of emission layers, electron transport layer, electron injection layer and cathode on the silver nanowire/conductive polymer anode, and by encapsulated under nitrogen atmosphere. The device with the anode treated by Ar plasma shows less short-circuit defect. However, this device didn't decrease the leakage current.

In other to investigate Current Leakage, the infrared emission was observed by applying small voltage less than diode threshold for driving the device, and found some of leakage points in the emissive area. At these points, single-micron sized aggregates were observed by SEM, and it specified that the aggregates were consisted of organic materials by EDX analysis. These organic aggregates were generated in synthesizing silver nanowires because they exist in silver nanowire ink but don't exist in the binder resin. The organic aggregates cannot be separated by decantation and filtration from silver nanowire. Because, in filtration, most single-micron sized aggregates were penetrated together with silver nanowires through filter of tens of micrometer pore size, or silver nanowires were caught by the filter of single-micron pore size. Therefore, as the additional silver nanowire ink refining method after filtration, single-sized organic aggregates were separated by centrifugal separation process which using the differences of sedimentation velocity in ink. And it clarified that, because of its over hundreds of aspect ratio, the silver nanowire sediments more slowly than the single-micron sized organic aggregation even which lighter than the silver nanowire. Rheology of silver nanowire ink was designed pseudoplasticity for larger sedimentation velocity difference. The silver nanowire layer was coated with this centrifugal separated ink, and the number of over 0.5 micrometers of aggregates was counted. By centrifugal separation, the number of aggregates can reduce 95 % and it indicats that the organic aggregates had been removed. Using the silver nanowire layer which reduced the organic aggregates, the OLED device was produced and the performance of device was evaluated. Fig. 2 shows that for reducing organic aggregates, the leakage current of the OLED device decreases to 10^{-4} mA/cm^2 at 4V, and becomes equivalent as compared with the device using ITO as a transparent electrode. As a result, it proves that the white OLED device with transparent electrode of the silver nanowire equivalent to the OLED device using ITO at high efficiency over 100 lm/W (Table II).

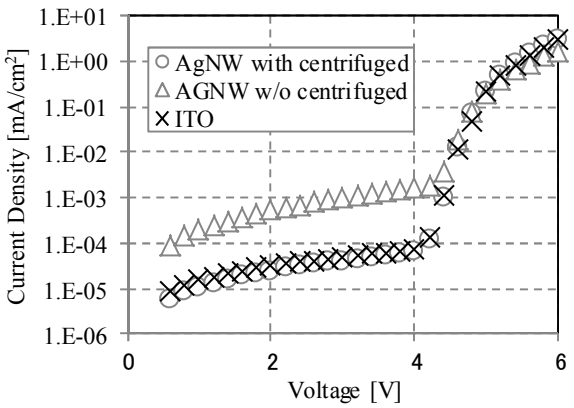

Fig. 2 Current density and Voltage of OLED devices

Table II Performances of OLED devices

Anode	Sheet Resistance	Luminance	Voltage	E.Q.E.	Efficiency
	[Ω/square]	[cd/m^2]	[V]	[%]	[lm/W]
AgNW	10	1000	5.3	94.0	103
ITO	10	1000	5.3	92.7	104

3. Conclusions

A smooth transparent electrode structure was produced by covering conductive polymer on the silver nanowire film before removing binder resin which prevents aggregation of silver nanowires. And the composite electrode without peaking structures was produced by reducing micro sized organic aggregates in silver nanowire film. The OLED device using this composite electrode decreased the electric contact failure between the anode and the cathode, and reduced leakage of current to 1/10. As a result, the performance of the white OLED device with silver nanowire was equivalent to that with ITO, and high efficiency of 100 lm/W device was developed. It is showed that the transparent electric conduction film using silver nanowire could be adapted for the OLED devices, even with vapor deposition organic layers which are needed flat ground.

References

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