# Carbon nanotube based transparent electrodes for flexible displays using liquid crystal devices

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## Abstract

*Transparent electrodes for a flexible display based on the liquid crystal (LC) were formed by carbon nanotubes (CNTs) on polyethylene terephthalate (PET) substrates. The thin multi wall carbon nanotubes (t-MWNTs) networks for electrodes were obtained by filtration- transfer method from well-dispersed CNTs solution.*

## 1. Introduction

The liquid crystal display (LCD) is a well-known device and its performances are highly developed. But the LCD has a limitation in their bendability to perform as a flexible display because of its glass-based substrates and stiff oxide electrodes. Although some groups tried to realize flexible LCD[1,2] the limitation caused by oxide based conducting layer still remained.

To make a pliable conducting layer, we formed CNTs random networks on PET substrates. The CNT is electrically conductive and mechanically robust[3,4]. Sparsely woven CNTs are transparent and fluent due to the low spatial density and the anisotropic structure of individual consistent. Most of case all the fabrication processes to form a CNTs network are done in the room temperature[4,5,6] except synthesizing CNTs. This point makes it possible using nearly all kinds of polymers as substrates. Even a hard distortion, CNTs layer keeps its adhesion with the substrate and its conducting paths still remained. From these reason CNTs can be chosen as a material for the conducting layers in LC-based flexible displays[1,2, 7,8].

There are some methods in forming CNTs network on a certain substrate. From spraying, CNTs are successively attached to the substrate[5]. It is most general process to form a CNTs layer. But the yield of the spraying film is quite low and its uniformity is not good. Filtration based processs[5,6] is a considerable counterproposal of spraying method. By filtrating well dispersed CNTs solution through a membrane filter that has nano-size pores, highly uniform CNTs film is easily obtained. CNTs film made by this process has nearly all of CNTs in the solution. We made t-MWNTs network on the membrane filter by filtration method. CNTs network is finally obtained by dissolving membrane filter.

## 2. Experimental

Purified t-MWNTs which made by high pressure carbon monoxide process (Carbon Nanotechnologies, Inc.) were mixed with 1 wt% sodium dodecyl sulfate (SDS) solution as 1 mg/ml concentration. 30 minutes sonication and 1 hour centrifugation in 10000 rcf were induced to the mixture. Well dispersed suspension was gathered and diluted in de-ionized water as 100 times. Various amount of the diluted CNTs solution was filtrated through the cellulose nitride membrane which has 200 nm pores. The membrane filter covered with CNTs was attached to the PET substrate as the CNTs side face to the substrate. After drying on fixing them, we carefully dropped acetone to remove the membrane filter. Residual organics washed out with methanol rinsing. We finally obtained clean and homogeneous CNTs network on the PET substrate.

The transmittances at 550 nm wavelength and the sheet resistances of the films were measured by UV visible spectrometer (Shimadzu UV-3300) and 4-point probe resistance meter (CMT-SR2000N). To confirm flexibility we measured the changes of linear resistances of the films with bending as they have certain curvatures.

## 3. Results and discussion

From well dispersed solution we obtained clear and homogeneous t-MWNTs networks (Fig.3). CNTs network has various transmittance and sheet resistance as the amount of solution which used in filtration process. The thicker CNTs network shows the lower transmittance. And sheet resistance is decreased as increasing amount of the solution.

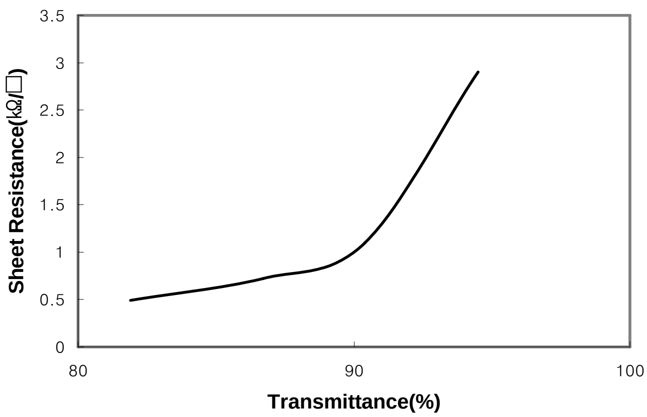


**Fig. 1. Transmittance and Sheet resistance of t-MWNTs network.**

The t-MWNTs network shows about 500 ohm/sq sheet resistance at 82% transmittance (Fig. 2). This value is better than MWNTs network but somewhat higher than single wall carbon nanotubes (SWNT) networks[4,5,6]. A main factor of this difference is the average diameter of CNTs. T-MWNTs is about 5 times thicker than SWNTs. It allows much less conducting paths in a same area compare with SWNT[8]. The transmittance of t-MWNTs network is in inverse proportion to the sheet resistance. This tendency is also observed in SWNTs network and it can be explained by same model[9].

$$T = \frac{1}{\left(1 + \frac{2\pi}{cR_{\square DC}} \frac{\sigma_{ac}}{\sigma_{dc}}\right)^2}$$

There was only little change in resistance of the t-MWNTs even a hard deformation. As Fig.3 we bend CNTs film and ITO film from 1.2 cm curvature to 0.2 cm and release it (Small radius of curvature means that the film was sharply deformed.). In the CNTs film, there are almost no changes in the resistance from 1.2 cm to 0.6 cm. In harder deformation resistance increased however the deviation is less than 20 percent. In contrast ITO film shows a huge increase of the resistance as bending harder than 0.4 cm. The resistance of the hardly bended ITO reaches to 48 times of its initial value.

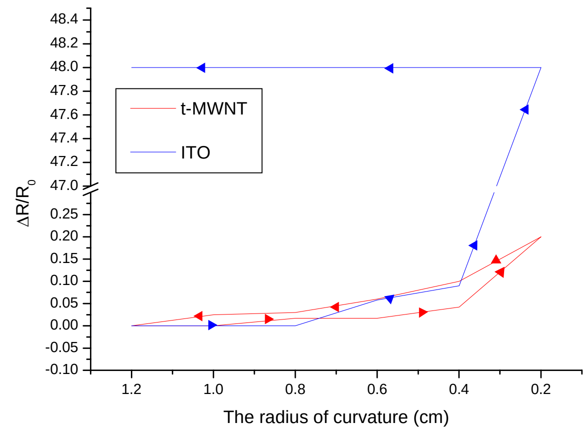


**Fig. 2. The resistance change through the bending (from left to right) and relaxing (from right to left) in t-MWNTs network (red) and ITO (blue).**


**Fig. 3. Clear and homogeneous t-MWNTs network.**

The relaxation behavior is also different between CNTs film and ITO. Relaxing the film, the resistances recovered from increased to the initial value in CNTs network. On the other hand the resistance never gets back in the ITO film.

When a conducting film and a substrate bend to one direction, the tension is involved into the conducting layer because of difference of the radius of curvature between two layers. Most of oxide films get cracks and their conductivity sharply drops in this situation. But in the case of CNTs networks the cracks like in the oxides may not be generated due to their web like structure. CNTs networks just stretch to the direction of the tension and rearrange as their initial shapes.

## 4. Summary

Using t-MWNTs we produced transparent electrodes for flexible LC devices. CNTs layer on substrate shows somewhat high resistance but it has an advantage in flexibility. In the case of polymer dispersed liquid crystal (PDLC), PET substrates are usable. However to use as electrodes of formal LCD the substrates must be optically isotropic like a polyethersulfone (PES).

## 5. References

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