Chapter 12
CNT Applications in Displays and Transparent, Conductive Films/Substrates

Contents

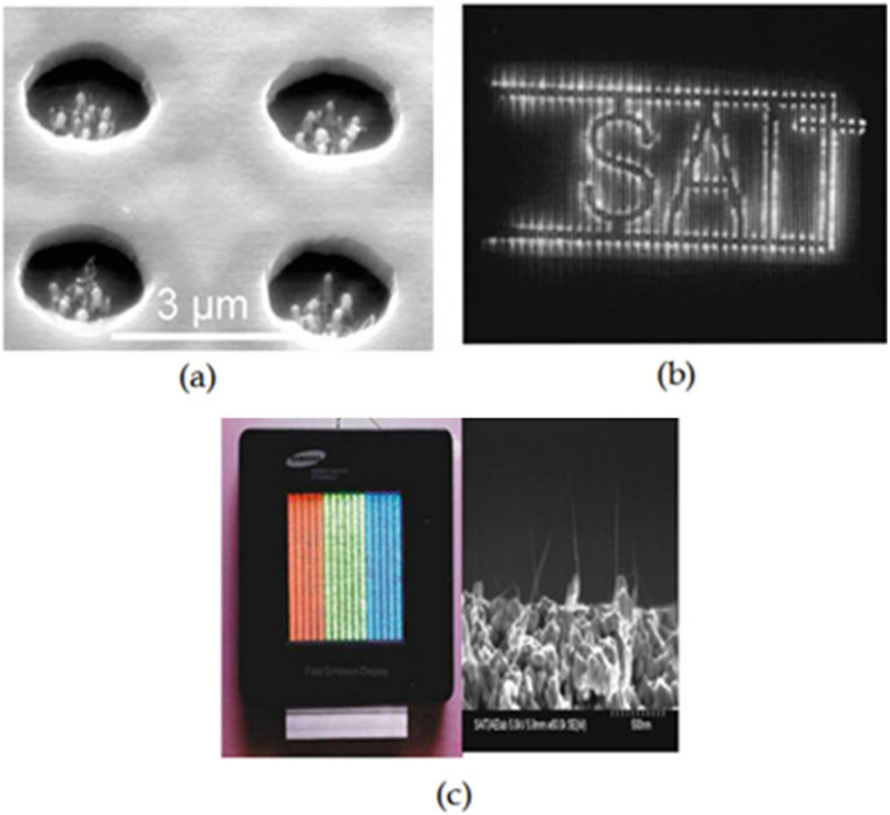
12.1 Overview

This chapter covers *displays and transparent*, *conductive films/substrates*. This especially includes field emission displays and conductive replacements for such industry workhorses as transparent, conductive ITO (indium tin oxide) coatings.

12.2 Displays and Light Sources

One of the first display applications of CNTs was in *field emission displays*. The principle behind CNT-based field emission displays is that when a potential is applied between a CNT surface and an anode, electrons are emitted from the CNT tips due to electron tunneling from the tips into the vacuum associated with the CNT curvature and defects therein such as dangling bonds. Applications of such CNT-based field emission sources potentially include flat-panel displays and intense light sources [12, 178, 372–375, 376]. The purported advantages of CNT-based field emission displays over other types include the possibility of much cheaper methods of fabrication than conventional field emission displays, which use conventional semiconductor fabrication methods, stable field emission over prolonged time periods, long lifetimes of the components, low emission threshold potentials, high current densities, no requirement for ultrahigh vacuum, and the possibility of achieving reasonably large current densities of about 4 A/cm^2 [12, 178, 377].

P. Chandrasekhar, *Conducting Polymers, Fundamentals and Applications*,
https://doi.org/10.1007/978-3-319-69378-1_12



(a) (b)

(c)

Fig. 12.1 Schematic and actual photos of a CNT-based field emission display, as fabricated at Samsung (After [378])

Samsung scientists reported CNT-based field emission displays with a threshold electric field of about 2 V/µm as early as 1999 [377, 378]. And as early as 2004, Samsung produced low-cost prototypes of 25 cm CNT color displays for the TV market [375, 379, 380]. Figure 12.1 shows a schematic and an actual such display.

CNT-based displays using the field emission principle have been fabricated into prototype, matrix-addressable, diode flat-panel displays; these used pulses of ±150 V switched between anode and cathode to produce images [194, 382].

However, in spite of all the above, promising work, to date (2016), there has been no successful CNT-based display product.

CNTs have also been studied for use as *bright light sources and X-ray sources*. It was demonstrated experimentally that CNT-based lamps were comparatively cheap to fabricate and possessed high efficiency and lifetimes of 8000 h. X-rays could be generated from these if the phosphorous screens used were replaced by metal targets and the accelerating voltage were increased. Imaging of human bones was demonstrated [376, 377, 384, 385]. Again, however, to date, nothing further has come of this pioneering work.

12.3 Conductive Coatings

In the early years of CNT research, there was much speculation that transparent, conductive CNT coatings would replace standard workhorses of the industry such as indium tin oxide (ITO) coatings [385]. One of the many purported advantages of CNTs was claimed to be that they would afford greater flexibility as compared to brittle ITO. In this regard, however, the best performance achieved to date for transparent CNT coatings has been a sheet resistivity of about 100 Ohms/square at 90% transmission on glass (integrated through the visible spectral region), still considerably poorer than ITO/glass, which can be fabricated at as low as 15 Ohms/square at 90% transmission [386]; it has been proposed that these best-performing CNT coatings may be adequate for such applications as thin-film heaters [13].

Nevertheless, there has been no dearth of studies of CNTs for transparent conductive coatings, especially to replace ITO *only*, *since some are theses*, etc. [387, 388]. For example, in an early study, Glatkowski [388, 389] showed that coatings could be deposited on various transparent substrates with a simple wet coating process that showed 90% T in the mid-visible with a 200 Ohms/square surface resistivity.

More recently (2014), Akhmadishina et al. [390] demonstrated a method for the large-scale growth of thin CNT films from solution on the surface of flexible, transparent substrates, via the preparation of a stable colloidal CNT solution using an aqueous surfactant. They observed that the optical transmittance of the films decreased linearly with increasing film thickness, whereas their resistance decreased quadratically; they attributed this to 3D CNT percolation in the films. They reported that, with increasing film thickness, the sheet resistance of the films dropped from 400 to 15 kΩ/square, while their % T decreased from 85 to 40%.

12.4 Problems and Exercises

1. Describe the principles of an LED based on CNTs. Sketch the components of the LED “sandwich” in schematic. Detail the active process that gives rise to the visible display. Consult figures in this chapter only minimally, if at all, for your answer.
2. Describe the similarities and differences between OLEDs based on CPs and those based on other organic molecules such as tetrathiafulvalene derivatives. Although such information is mostly proprietary, in your estimation, which of these two classes were actually found widely in OLEDs as of 2016? As of your reading today?
3. What in your estimation is the critical parameter that will allow CNT-based transparent conductive coatings to displace those based on ITO (indium tin oxide)? In your answer, include such parameters as surface resistivity values (in Ohms per square). Has this already happened as of your reading today?