Transparent Conducting Materials: An Investigation into Replacements for Tin-Doped Indium Oxide

Tracey Hitt Literature Seminar November 8th, 2012

Transparent conducting materials are essential in modern technology. The use of these materials varies widely from use as an energy efficient coating to reflect IR heat on energy-conserving windows to use within flat-panel displays. Transparent conducting metal-oxides are the most common transparent conducting material used, specifically tin-doped indium oxide (ITO). This material is practical because it is extremely conductive, as well as being nearly transparent to visible light (>80%) when deposited as a thin film.[1,2] Although ITO serves its purpose well as a transparent conducting material, the demand for ITO films has caused the price of indium to greatly increase. Although electronics recycling programs have reduced the price of indium in recent years, demand is still increasing.[3,4] Because of this, and because of other properties that may be desirable in the field of flexible electronics, alternative materials are being investigated. In order to be a successful transparent conducting material, there are many properties that the film must satisfy. Most importantly, the conductivity should be high, and the visible light absorption coefficient should be low. There are other materials-specific purposes that are important as well, such as flexibility, transparency to IR light, and thermal stability.

In order to find a successful ITO replacement, other doped metal oxide films were found. Promising candidates include impurity-doped ZnO, and impurity doped SnO_2. Since 1970, the obtained minimal resistivity of materials made from ITO and doped SnO_2 have remained unchanged, but the resistivity of ZnO is still decreasing. Even undopedZnO has impressive electronic properties. [5,6]

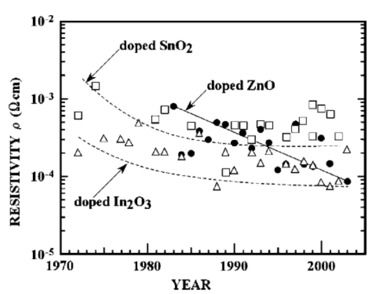

Figure 1: Trend of obtained minimal resistivity for doped SnO_2, doped ZnO, and doped In_2O_3.

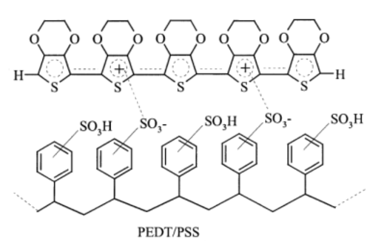

Figure 2: Structure of PEDT/PSS

Polymer-based transparent conducting materials have also become more important in recent literature. These materials facilitate electron movement through their sp^2 hybridized backbone. Polymer-based transparent conducting materials have previously had a higher sheet resistance than ITO (350 Ω/□vs. 30-80 Ω/□, respectively)[7,3], but recent processing methods have improved the sheet resistance to values that are more competitive (46 Ω/□)[8].they can be made into flexible thin films, making them possible in the use of flexible electronics. PEDT/PSS is the most commonly used transparent conductive polymer.

Conductive carbon nanotube (CNT) thin films are possible as an ITO replacement. The nanotubes are made into a thin, optically homogeneous film. The small thickness of the film renders them over 90% transparent to visible light, as well as being transparent to IR light in the 2-5 µm wavelength region. CNT thin films also have a high elastic modulus and tensile strength, which gives them much more flexibility than ITO films.[9] The sheet resistance is comparable to ITO, and the fact that it is a p-type semiconductor means that it can be used in unique ways, such as a p-type ohmic contact in GaN LED devices.[10] The problem with this method, is that when CNT thin films are made in bulk, they contain both semi-conducting and undesirable metallic CNTs, but there are methods of separation.

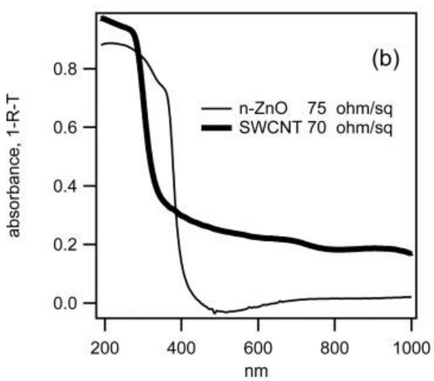

Figure 3: Absorbance of CNT sheet vs. n-doped ZnO sheet

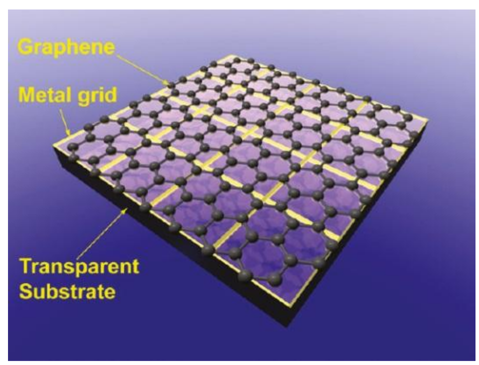

Figure 4: Structure of a graphene/metal grid hybrid material

Hybrid graphene materials are also being looked at as an ITO replacement. Although graphene is highly transparent (>98% for single layer) and is minimally resistant (resistivity ~10^{-6}Ω cm),[11] graphene sheets grown epitaxially and through CVD are lower quality, and the preparation needs to be improved in order to display characteristics similar to ITO.[12]There are two main ways to combat this problem. The synthesis method of graphene could be improved to give higher quality graphene sheets, or the graphene can be combined with other materials to form a hybrid transparent conducting material. Synthesis of graphene through CVD is being improved by many groups, and, if perfected, could ultimately be the future method of synthesis of high-purity graphene.[13]Until then, hybrid materials are being investigated.

One hybrid material of interest is created by covering a layer of CVD-grown graphene by a CNT network.[14]This improves the conductivity, a result thought to arise from the fact that the cracking of the graphene sheets, due to differences in thermal expansion coefficients between graphene and its substrate, is corrected by the CNT layer. Another interesting material was developed by other team of scientists involves depositing a thin graphene layer atop a metal grid that lay on a transparent substrate.[11] The metal grid will improve the conductivity of the graphene through increasing the charge carrier density, as well as being relatively simple to synthesize. The method by which the grid improves the conductivity can be explained through the concept of sheet resistance. Although graphene has a smaller resistance than metal, the metal can have a smaller sheet resistance by having using a thick film of metal, because sheet resistance is inversely proportional to film thickness. This method also avoids the increase in resistivity that is introduced through impurities when graphene is grown on copper or nickel substrates. Also, the introduction of the metal grid introduces a level of control with regards to the desired transparency of the transparent conducting film, because the thickness of the metal grid can be adjusted to make the transparent conducting film more or less transparent.

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