

Preface

Transparent conductors (TCs) have been used in a wide variety of optoelectronic and photovoltaic devices, such as liquid crystal displays (LCDs), solar cells, optical communication devices, and solid-state lighting. Thin films made from indium tin oxide (ITO) has been the dominant source of TCs, and demand of indium from the explosive growth of LCD computer monitors, television sets, and smart phones has risen rapidly in recent years, which now account for 50% of indium consumption. In 2002, the price was US \$ 94 per kg, and it rose to over \$ 1000 kg recently, a 1000% increase in 10 years. Graphene, a two-dimensional monolayer of sp^2 -bonded carbon atoms, has attracted significant interests recently because of the unique transport properties. Due to the high optical transmittance and electrical conductivity, thin film electrodes made from graphene have been considered an ideal candidate to replace the currently used expensive ITO films. Compared with the ITO films, graphene films have high mechanical strength, flexibility, chemical stability, and are much cheaper to produce.

A key to success in such applications is to develop methods to produce large-size graphene sheets with high yields and deposit them onto a substrate layer-by-layer in an orderly manner. The graphene sheets in current study for the fabrication of TCs are very small, mostly with an area of hundreds of square micrometers. The small graphene sheets result in high intersheet contact resistance due to a large amount of intersheet junctions. To reduce the number of intersheet tunneling barriers, production of inherently large-size graphene sheets are highly desirable. Although mechanical cleavage of graphite was shown to prepare high quality graphene with a millimeter size, the yield of this method is extremely low, being unsuitable for mass production. Alternatively, graphitization of Si-terminated SiC (0001) in an argon atmosphere could produce monolayer graphene films with a domain size of several tens of micrometers. However, the graphene obtained thereby was difficult to transfer to other substrates and the yield was very low. The CVD technique has been extensively explored to grow extremely large-area graphene on Ni films or Cu foils. This technique usually requires specific substrate materials that have to be removed chemically after the growth of graphene. The high cost of single crystal substrates and the ultrahigh vacuum conditions necessary to maintain for the CVD growth significantly limit the use of the CVD method for large-scale applications.

In spite of the significant progress for CVD grown graphene achieved so far, these important challenges must be overcome before the industry applications.

Owing to the scalability of production and the convenience in processing, graphene oxide (GO) has been considered an important precursor for the fabrication of TCs. GO sheets are hydrophilic and can produce stable and homogeneous colloidal suspensions in aqueous and various polar organic solvents due to the electrostatic repulsion between the negatively charged GO sheets. These GO dispersions are easy to be processed to produce TCs on a substrate. Transparent conducting films (TCFs) containing GO or chemically reduced GO sheets have been deposited via several well-established techniques, including spin- or spray coating, transfer printing, dip coating, electrophoretic deposition, and the Langmuir–Blodgett (L–B) assembly, followed by chemical reduction and/or thermal annealing.

While there are some books that specialize in fabrication processes and properties of graphene and GO, very few books are available specifically dealing with the following topics for their application in transparent conductors: (i) how to produce TCs by using CVD grown graphene; (ii) how to synthesize GO with different size and control their surface functionalities to enhance the electrical conductivity; (iii) how to incorporate these nanostructured materials into thin films with layered structure; and (iv) how to improve the conductivity and transparency. In light of the authors' experiences on graphene fabrication and application for TCs in the past few years, this book is aimed to provide a comprehensive overview of traditional and novel techniques in producing and functionalizing graphene for highly conductive transparent thin films. It will offer a systematic presentation of the principles, theories, and technical practices behind the structure–property relationship of the thin films, which we believe to be the key for the development of high-performance TCs.

The book is intended primarily for an audience of graduate students, research scientists, and professors in the area of carbon materials, transparent conductors, and related fields, as well as to professionals from the electronic and chemical manufacturing industries. Nanotechnology, as an emerging new subject, has been established as a major in postgraduate level in many universities and research institutes. This book would be well suited as a textbook for an intermediate level class in nanotechnology and/or materials science and engineering as part of such a program or as a stand-alone course. It will be accessible equally to readers with either science or engineering background. At the same time, the unique perspectives provided in the applications of graphene as TCs will serve as a useful guide for design and fabrication of these thin film materials for specific applications.

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