Transparent Oxide Semiconductor and Nano-semiconductor Thin Films and Properties

We have fabricated transparent and nano-structured oxide semiconductor thin films, by the employment of sputtering, chemical vapour deposition and chemical solution deposition methods. These thin films include undoped and doped zinc oxide (ZnO), indium zinc oxide (IZO), and copper aluminium oxide (Cu-Al-O). Although these materials are fundamentally insulators due to their wide band gaps which are greater than 3 eV (electron volt), we are able to make them into semiconductors or conductors by introducing shallow donor or acceptor levels in the band gaps. Unlike the traditional semiconductors (such as silicon and gallium arsenide) and conductors (such as gold, copper and aluminium), these materials are transparent to visible light. A combination of electrical conduction and optical transparency make these semiconductor or conductors unique with a lot of existing and future indispensable applications as transparent electrodes, high energy light emitting devices and so on. The nanostructures of these films further lead to some special properties, such as quantum confinement and surface states, and we have found out that a significant increase of gas sensing properties with lowered working temperature for some of our films.

Fig. 1a shows an example of the nano-structured the film. It is seen from this high resolution transmission electron microscopy image that the thin film is composed of nano-crystals in amorphous matrix. It is evident that the sizes of the crystals are about 3-5 nm. In addition to nanocrystal thin films, we are also able to fabricate amorphous transparent oxide conducting/semiconducting thin films (see Fig. 1b) with different conditions. Films with polycrystalline structures can also be made.

Fig. 1a (left) and Fig. 1b (right)
Fig. 1  High resolution transmission electron microscopy images of two IZO films, fabricated under different conditions, with (a) nanocrystals embedded in amorphous matrix, and (b) amorphous phase.

![High resolution transmission electron microscopy images of two IZO films](image)

Fig. 2. Variation of the optical transmittance in the wavelength range of 1100 nm to 2500 nm; a, b, c, d, e, f, and g represent different IZO films prepared under different conditions. The lowest resistivity of our IZO films has reached $4 \times 10^{-4}$ Ω cm, close to that of a commercial indium tin oxide (ITO) film and approaches those of metals. It should be noted that our IZO films have a very wide optical transparency wavelength range from about 300 nm to more than 2000 nm (Fig. 2), better than that of ITO. This wide range of optical transparency makes it an excellent candidate applicable to fibre optics telecommunication with a window of 1300-1550 nm.

Highly conductive, high and wide-range optical transparency oxide n-type semiconductor thin films have been fabricated. Although the fabrication of p-type transparent oxide semiconductors (TOS) has proven difficult worldwide, we have also succeeded in p-type zinc oxide and copper aluminium oxide TOS after concentrated efforts. Furthermore, ultraviolet (UV) and blue light emission have been obtained for some films. Various properties of the materials have been studied.

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