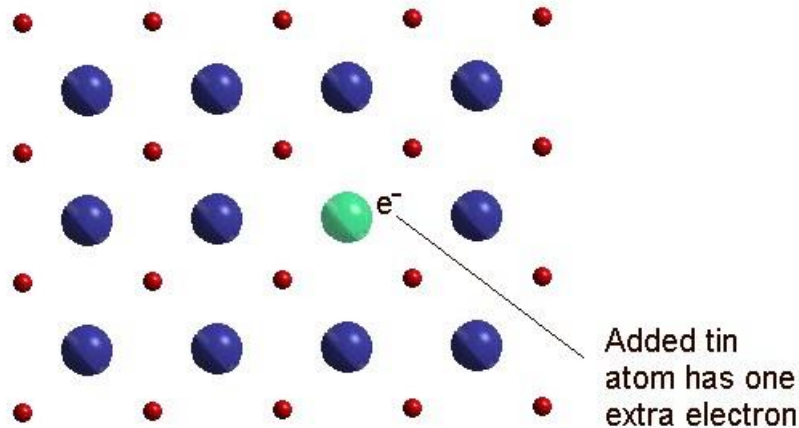


Indium Oxide, although a semiconductor, is not a particularly conducting material. This is because it lacks any free electrons. Electrons are normally added by doping with a similar element but one that has one more electron than the basic material. So in the case of Indium Oxide we add Tin. At low concentration this fits neatly into the Indium Oxide structure and adds the required electrons (figure 2). There is an upper limit to the amount of Tin that can be added as the Tin not only adds electrons but reduces the mobility of these electrons. The optimum doping level is about 5 - 10% of Tin. This Tin doped Indium Oxide is known as Indium Tin Oxide or ITO.

Figure 2 : Tin has one more electron than Indium, when Indium oxide is doped with Tin this extra electron becomes free making the Indium Tin Oxide conducting.



There is an upper limit on the speed with which electrons can respond to electric or magnetic fields. The electron density in ITO is not as high as it would be in a metal. This means that this response limit is in the infra-red for ITO (whereas it is past the visible for a metal). The consequence is that ITO is transparent in the visible but becomes conducting (and therefore reflecting/absorbing) in the infra-red (3 micron wavelength or 1×10^{14} Hz). So at all frequencies below 10^{14} Hz we can use ITO as a shielding material.

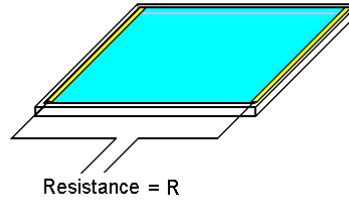
So to summarize : Indium Tin Oxide (ITO) is a semiconductor material, it is conducting at frequencies in the infra-red and below, and insulating at the frequencies of visible light. So at the frequencies of visible light ITO is insulating and therefore transparent. This means that ITO is transparent to visible light but still electrically conducting at the frequencies of interest for EMC shielding and anti-static applications (GHz to DC).

Specifying – (ohms/square and surface resistivity)

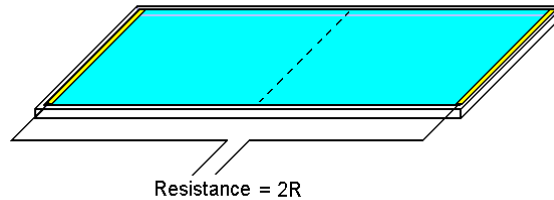
Historically ITO has come from a vacuum/semiconductor background, the electrical resistance of the coating is termed sheet resistance and measured in ohms/square. For EMC shielding and particularly anti-static applications it is common to use surface resistivity (according to standards such as IEC60093), measured in ohms. This causes a fair amount of confusion with two camps calling the same thing by a different name (sheet resistance and surface resistivity). It is worthwhile just to clarify this confusion.

The usual question on meeting “ohms per square” for the first time is “ohms per square what?”. The ‘per square’ just indicates that resistance of an ITO panel is dependant on it’s shape (how many squares) but not on the size of the panel. So here we want to demonstrate that the resistance depends on the shape of the panel but not on it’s size.

1. Imagine a square conducting sheet with two electrodes on opposite edges. The resistance across the square is the sheet resistance. Call this R .

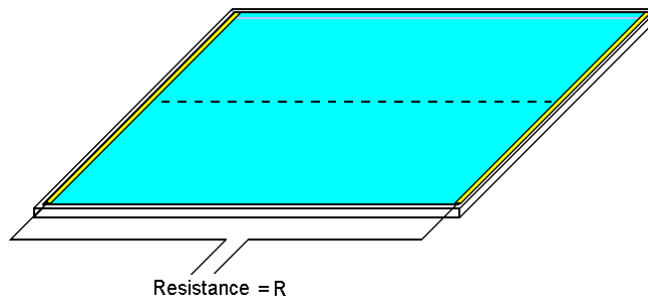


2. Now make the conducting sheet twice as long. It is twice as long as it is wide (= 2 squares), then we have two of the case 1 resistors in series. The series resistance simply adds and we have a resistance $R + R = 2R$.



3. Now if we make the sheet twice as wide, it is back to a square but now twice as big as the original. So we have two resistors like case 2 but in parallel. The resistance is then $1/(1/2R + 1/2R) = R$.

That is we've doubled the size of the square and the side to side resistance hasn't changed.



So the resistance of a square is independent of the size of the square. This value R (the resistance across one square) is termed sheet resistance and measured in ohms/square (ref Powell and Rossnagel).

Especially for anti-static applications it is common to use surface resistivity (often just termed resistivity). Surface resistivity is defined in standards such as IEC60093 or ASTM D257-93 (1998). IEC 60093 allows various measurement geometries for measuring the surface resistivity. One geometry detailed in the standard is a concentric ring electrode arrangement. The resistance is measured between two concentric rings and then a correction made for the geometry of the measurement (ref IEC 60093). This correction brings surface resistivity (measured in ohms) almost exactly back to sheet resistance (measured in ohms/square). The agreement is certainly better than the +/-10% referred to in IEC 60093 as a typical reproducibility (ref IEC 60093).

So sheet resistance (Ohms/square) and surface resistivity (ohms) are just two conventions for specifying the same thing. There is no correction when swapping between these two conventions, for example a sheet resistance of 1000 ohms/square is equivalent to a surface resistivity of 1000 ohms.

Shielding performance

You can't give a single figure for shielding effectiveness (attenuation) of a particular coating, as this depends on many things besides the ITO resistance. It will vary with :-

- earthing of the ITO sheet (earthed or connected to the rest of the shielding enclosure is best)
- the shape of the field that it is to be shielded (near field or far field)
- the type of field (magnetic or electric)
- the details of the enclosure to be shielded (enclosure dimensions can cause resonances at particular frequencies)
- the frequency of the field to be shielded (attenuation is lower at higher frequencies).

You need to be careful about quoting a blanket figure for shielding effectiveness. It will vary according to the situation where it is finally used.

The far field shielding effectiveness is likely to be significantly higher than the near field. So when comparing suppliers it is important to make sure that you are comparing like with like (that is don't compare near field results from company x with far field results from company y).

The far field shielding effectiveness of ITO can be calculated as (ref www.cpfindusprod.com).

$$SE = 20 \log [(7 \times 10^{11}) / (f \times R)]$$

Where

f = frequency (Hz)

R = sheet resistance (Ohms/square)

SE = far field shielding effectiveness (dB)

Figure 3 : calculated far field shielding effectiveness of ITO coatings
- the effect of frequency

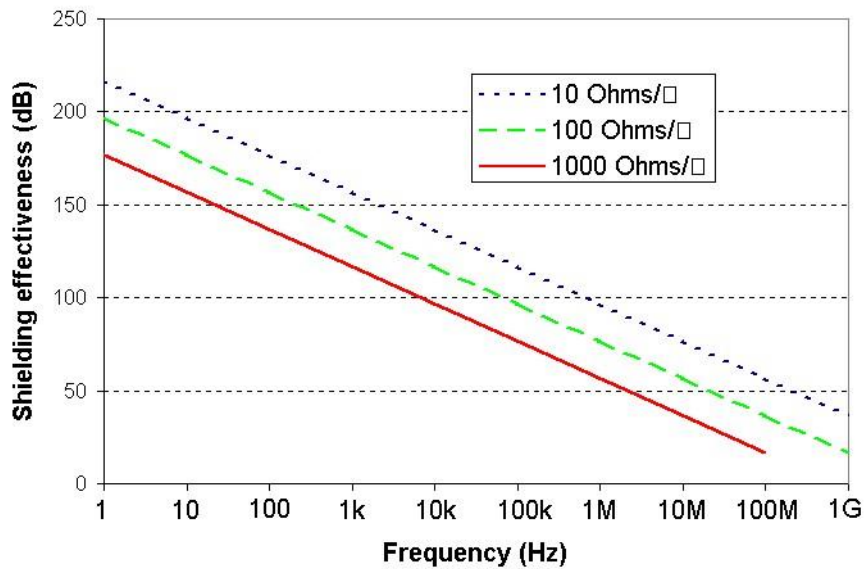
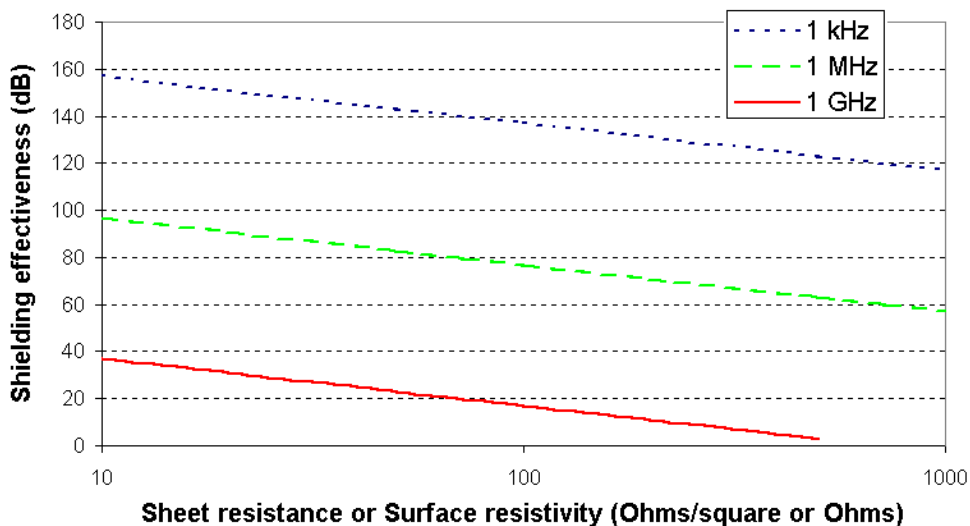


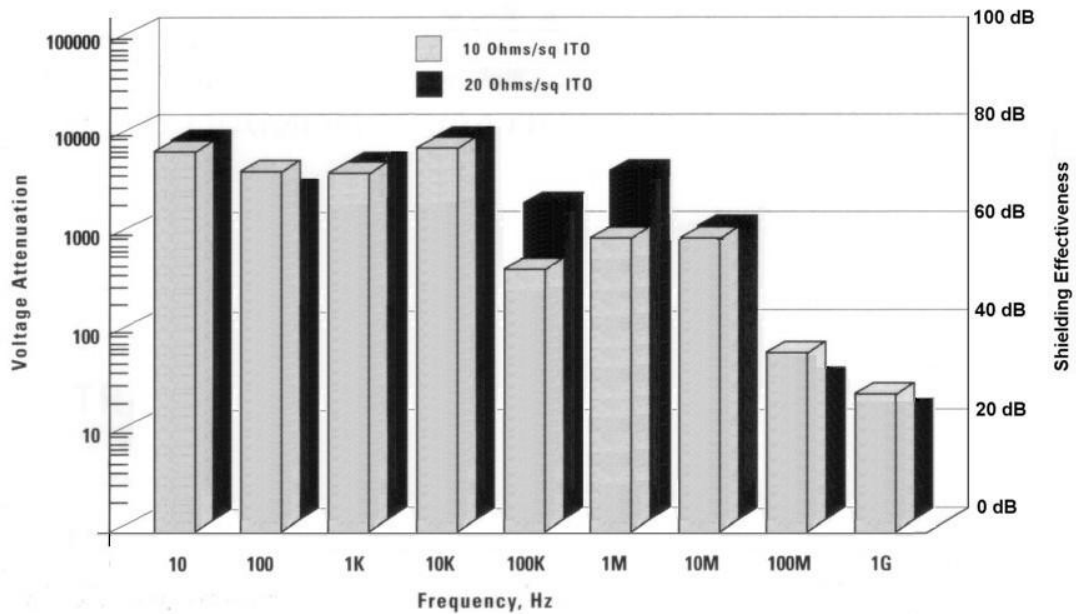
Figure 4 : calculated far field shielding effectiveness of ITO coatings
- the effect of sheet resistance (surface resistivity)



The above far field calculation assumes that the source to be shielded is distant from the shielding panel (i.e, the incoming electromagnetic wave is plane and arrives normal to the shielding panel). However in many real life cases the source of the electromagnetic interference is close to the shielding panel, in this case the waves will be neither plane nor arriving normal to the shielding panel. The shielding effectiveness is then much reduced.

This can be seen in figure 5 where the measured near field shielding effectiveness is much lower than the calculated far field shielding effectiveness (figures 3 and 4).

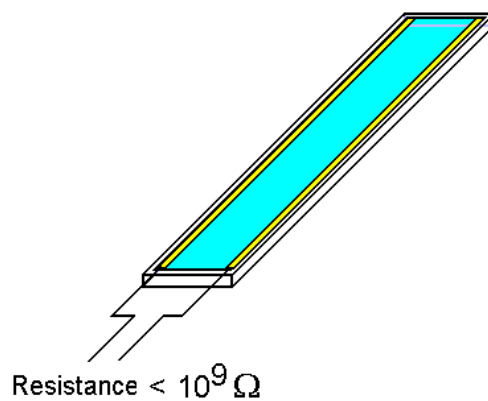
Figure 5 : measured near field shielding effectiveness of ITO coatings from Diamond Coatings



Anti-static applications

BS EN 50014:1993 section 7.3.2 ‘Electrical Apparatus for potentially explosive atmospheres’ defines a suitable anti-static coating. This specifies that a test sample 100mm long and 10mm wide must have a resistance of less than 10^9 Ohms. This 100mm x 10mm sample shape is 0.1 of a square. The thinnest ITO coating has a sheet resistance of the order of 1000 Ohms/square. In this case the test sample resistance will be $0.1 \times 1000 = 100$ Ohms. This is well inside the statutory requirement of a resistance less than 10^9 Ohms.

Figure 6 : Anti-static resistance requirement



Manufacture

Coatings of ITO are generally manufactured by vacuum coating (evaporation or sputtering). The size of the vacuum chamber controls the size of substrate that can be coated.

To get a uniform coating on a large area a sputtering process is preferable. A sputtering source gives a wide linear source of ITO, this combined with a linear motion gives good uniform coatings (typically a

few percent) (ref Hill and Nadel). In the case of Diamond Coatings we can coat substrates of upto 1m x 1m.

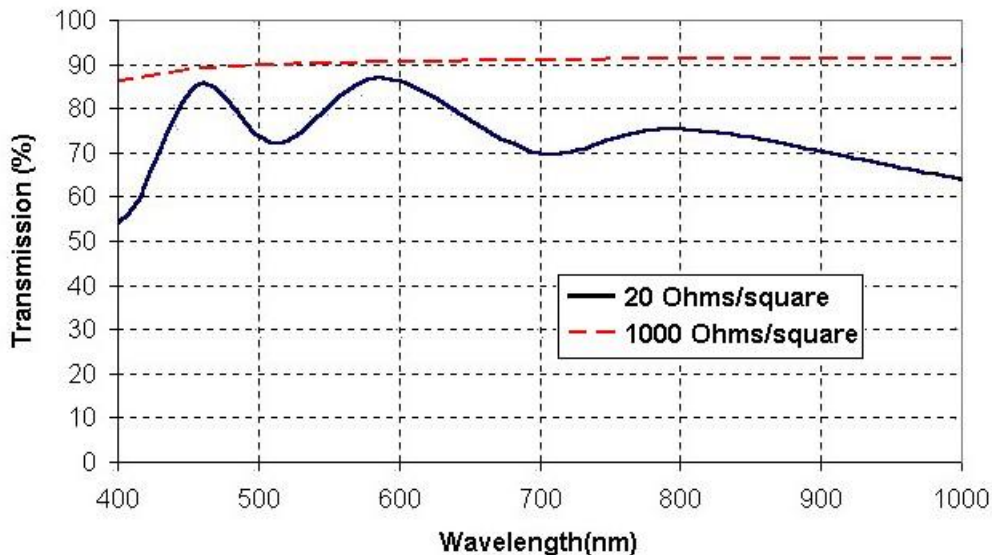
The substrate material for vacuum coating is typically glass, or plastic (flexible and rigid). Other materials can be coated provided that they are vacuum compatible. The sputter coating process is a cold process, so heat sensitive materials can be coated. Typical polymer substrates are polyester, polycarbonate or acrylic, while many others are possible. On rigid polymer materials (particularly polycarbonate or acrylic) it is best to use polymers that have been hard coated before ITO coating, this gives better scratch resistance.

A typical range of ITO coating thicknesses is from 10nm to 1micron. Layers thinner than 10nm tend to become discontinuous. Layers thicker than 1 micron become absorbing, stressed and expensive. This thickness range limits the sheet resistances (surface resistivities) available from 10 Ohms/square (Ohms) to 1000 Ohms/square (Ohms).

Visible transmission

The visible transmission falls as ITO is made thicker. A typical anti-static treatment of 1000 Ohms/square has a transmission almost identical to the 92% transmission of uncoated glass, or polyester. A typical EMC shielding film of 20 Ohms/square is much thicker (about 0.5 micron) and so shows interference effects (seen as ripple on the transmission curve), absorption (maximum transmission is below 92%) and increased reflection in the near infra-red (slight loss of transmission at 1000nm wavelength). These effects all combine to reduce the visible transmission to around 80%.

Figure 7 : Optical transmission of ITO coatings



Typical examples

Typical ITO products for EMC shielding or anti-static use would be :-

- 10 or 20 ohms/square EMC shielding coating
- 1000 ohms/square anti-static coating

The previous sections allow us to give approximate general performance figures (see table 1).

Table 1 : approximate general performance figures for typical ITO applications

factor	EMC shielding coating	Anti-static coating
Sheet resistance (resistivity)	10 or 20 Ohms/square (Ohms)	1000 Ohms/square (Ohms)
Visible transmission	≈ 80%	≈ 92%
Far field shielding @ 1 MHz	≈ 100 dB	≈ 60 dB
Near field shielding @ 1 MHz	≈ 60 dB	n/a
Far field shielding @ 1 GHz	≈ 35 dB	n/a
Near field shielding @ 1 GHz	≈ 25 dB	n/a
ITO thickness	0.5 - 1 micron	≈10nm

Conclusions

- Indium Tin Oxide (ITO) coatings offer a way to make transparent surfaces that are electrically conducting. ITO can be used for transparent conducting panels for electromagnetic shielding or for anti-static applications.
- For EMC applications ITO can have high visible transmission and still give a shielding effectiveness of
 - 100dB far field at 1MHz (60dB near field)
 - 35dB far field at 1GHz (25dB near field)
- For anti-static applications the surface resistivity is well inside statutory requirements while the ITO coating is virtually invisible.
- Typical visible transmissions will be
 - EMC applications ≈ 80%
 - Anti-static applications > 90%
- Two equivalent measurements are used for how conducting a coating is. These are
 - a) Sheet resistance (measured in ohms/square)
 - b) Surface resistivity (measured in ohms)

There is no correction when swapping between these two measurements. So for example a sheet resistance of 1000/square is equivalent to a surface resistivity of 1000 ohms.
- Panels of upto 1m x 1m can be coated with ITO
- Sheet resistances (surface resistivities) are available from 10 Ohms/square (Ohms) to 1000 Ohms/square (Ohms).

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<http://www.cpfindusprod.com/shielding/emi.html>, 11th August 2004.

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