Transparent conductive oxides and their shielding efficiency against electromagnetic interferences

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Abstract: *The report presents a short overview on the most commonly used transparent conductive films and their applications, followed by a discussion on transparent conductive oxides and their electromagnetic interference shielding efficiency. The surface photo-charge effect is reviewed and the necessity to include a transparent shielding element to the experimental setup is highlighted. For this purpose, a transparent conductive oxide coated glass substrate is used to reduce electromagnetic interferences and increase the signal-to-noise ratio.*

Key words: *Surface Photo-Charge Effect, transparent conductive oxides, electromagnetic interferences*

INTRODUCTION – TRANSPARENT CONDUCTIVE THIN FILMS

Transparent conductive thin films (TCTF) are substances, which conduct electricity and are optically transparent when deposited as a thin layer. They can be thin metallic films (gold, silver), transparent conductive oxides, thin conductive polymer films, the novel graphene and graphene nanotubes among others.

The first application of TCTFs can be traced back to WWII when aircraft windshields were coated with a thin layer of a transparent conductive oxide (TCO). When electrical current is applied to this layer, it heats up, which prevents fogging and frosting of the windshield due to the lower temperature of the environment.

Another application of such films is for discharging static electric charges, such as the ones formed on the surface of a cathode ray tube screen. The requirement for such a film is high optical conductivity, regardless of its resistivity. TCTFs are also used as transparent electrodes. Depending on the current-carrying capacity, the latter are separated in two groups – Type I, which require very low current (in LCDs, for example), and Type II, which need to carry large currents (used in photovoltaic cells).

Energy efficient windows are coated with TCTFs that reflect infrared light, which aims for energy conservation by reflecting infrared light that is emitted when the interior temperature is higher than the environmental. TCTFs with low infrared light transmittance are also used to prevent heat from entering the interior in higher temperature areas.

The modern application of TCTFs in electronics includes the manufacture of antireflection screens and touchscreens. The latter can be separated into two distinct categories, resistive and capacitive, depending on the methodology used for detecting the touch position. [1]

TRANSPARENT CONDUCTIVE OXIDES

Transparent conductive oxides are usually a mixture of different metallic oxides, or an oxide, doped with an appropriate dopant, which results in a transparent and at the same time conductive layer. These have to be identified experimentally, as there is no guarantee that a certain oxide/dopant combination will yield the desired optoelectronic (O/E) properties.

Indium oxide (In_2O_3), tin oxide (SnO_2), cadmium oxide (CdO) and zinc oxide (ZnO) have been shown to behave as TCOs when doped with certain dopants. The most commonly used binary combination is indium oxide doped with tin (In_2O_3:Sn), usually regarded to as Indium-Tin Oxide (ITO). Its variations possess an optimal balance of O/E properties. Fig. 1 shows a comparison between the absorption spectra of two identical glass substrates one of which has an ITO layer.

There are also more complex multicomponent combinations, obtained by doping a binary TCO with a new dopant. These can sometimes possess excellent O/E properties, comparable to ITO, or be very poor TCOs.

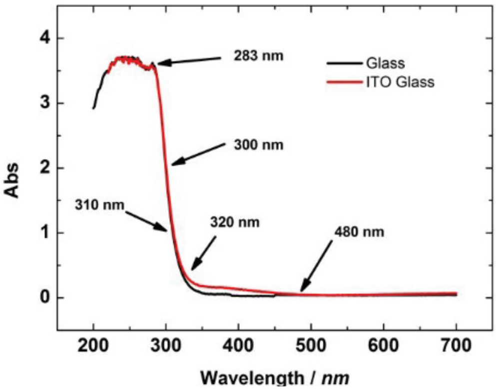

Fig. 1.
Absorption spectra of identical glass substrates, one of which is coated with ITO

The properties of the TCO layer depend not only on the component combination, but also on the oxide/dopant mass ratio, the properties of the substrate, the process used for coating, the process parameters and others. [2] For example, an ITO layer with fixed composition and thickness will exhibit different visible light transmission and resistivity, depending on the temperature at which the coating process is carried out and the nature of the substrate. A glass sample with an ITO layer treated at a high temperature possesses 4 times less resistivity, compared to a plastic substrate treated at a low temperature. [1]

THE SURFACE PHOTO CHARGE EFFECT PHENOMENON

When a solid is illuminated with frequency modulated light an alternating potential difference is induced between the illuminated solid and another arbitrary solid with constant potential (electrode). The phenomenon that causes the formation of this alternating voltage is named Surface Photo-Charge Effect (SPCE). The setup which is used to generate and measure the SPCE voltage is schematically represented in Fig. 2.

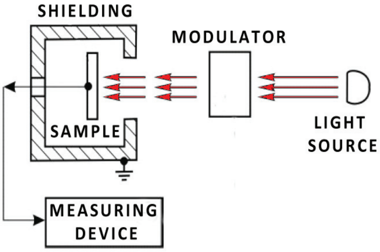

Fig. 2.
Setup for inducing and detecting SPCE-generated signal

It has been proven that the generated voltage is not due to external photoelectric effect by using light with frequency that would not induce the latter. In fact, the SPCE is present only when frequency modulated light is used for the illumination, if non-modulated light is used, there is no potential difference between the two solids. [3]

A very important peculiarity of this effect is that the generated voltage is heavily dependent on the properties of the illuminated solid sample. This makes it possible to analyze different features of the studied sample by observing the change in the SPCE-generated signal.

Some of the applications of SPCE for analysis include: determination of surface features [4], composition analysis of bricks [5], detection of counterfeit coins [6], investigation of liquids and determination of petrol octane number [7] and others.

During these investigations there exists a serious obstacle, that is the electromagnetic interference (EMI) caused by external electromagnetic fields. As the SPCE-generated signal is very weak (in the order of nV), even the slightest interference may result in a very low signal-to-noise (S/N) ratios, meaning that the measured signal no longer provides adequate information regarding the investigated property of the sample.

For this reason, a grounded metal box is used to contain the sample, which reduces the electrical interferences. Still, as it can be seen in Fig. 2, an opening must be provided for the modulated light to reach and interact with the sample, which also leaves the substrate unprotected from EMI.

USING AN ITO-COATED GLASS TO REDUCE THE EMI

A solution which reduces the EMI is to include a transparent substrate coated with a TCTF that encloses the shielding gap, while allowing the modulated light to reach the sample and generate the SPCE-signal. The advantages of using TCTFs in studies of the interaction of light with matter have been previously reported. [8]

It has been established that the conductivity of ITO films increases proportionally with film thickness due to charge carrier scattering, which also increases the EMI shielding effectiveness. [9] Having this in mind, we contacted a number of ITO-coated glass manufacturers with the following criteria:

- High visible light transmission (visible transparency).
- Low resistivity (high conductivity) of the ITO-film, in order to provide the most efficient shielding for our sensor structure.
- Stock dimensions that fit the gap, or, if available, the option to order samples with custom dimensions.
- A reasonable price.

Eventually, we acquired a set of ITO-coated glass plates and used one to cover the opening of the box. The parameters of the ITO glass sample are given in Table. 1. We have concluded that the combination of low resistivity and relatively high visible transparency they offer is adequate for our needs. The absorption losses can be compensated for by increasing the intensity of the light source.

Table. 1.
Parameters of the ITO coated glass

Parameter	Value
Substrate dimensions	*100x100 mm*
Substrate thickness	*1.8 mm*
ITO layer thickness	*1000±200 Å*
Resistivity	<17 Ω/sq
Transmittance (vis)	>82%

RESULTS

In this study, the sample we used was a silica plate. It was isolated in an aluminum box without a top, and connected to an electrode for measuring the SPCE signal. A preamplifier is included, that increases the signal voltage to the order of mV. The top of the box was covered with the ITO-coated glass to provide complete shielding of the substrate against EMI.

We have monitored the SPCE signal via a Rigol digital oscilloscope in two different cases – with and without an ITO glass covering the opening of the aluminum box. All other conditions and parameters of the laser illumination and modulation were kept constant. The oscillograms we observed are given in Fig. 4 and Fig 5.

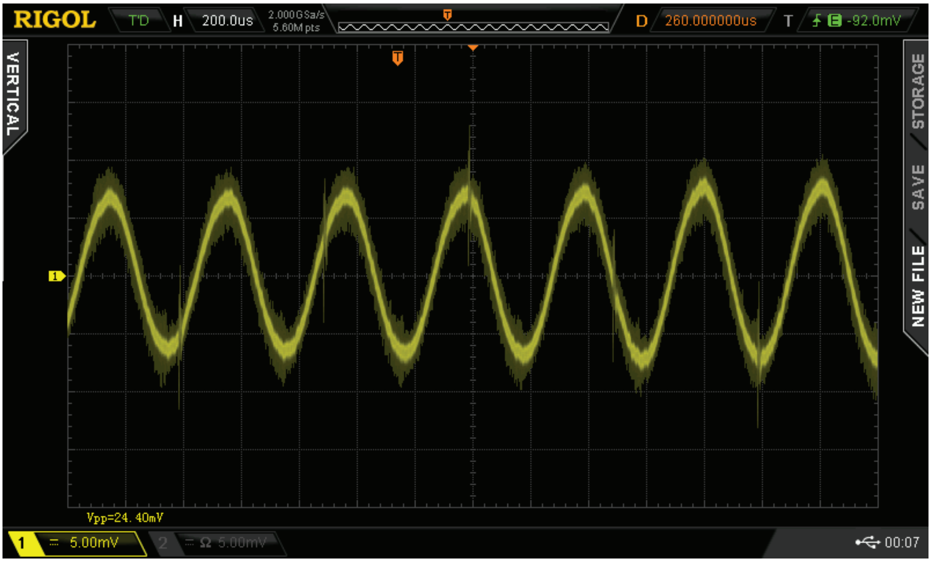

Fig. 4.
Signal taken from the experimental setup without ITO glass

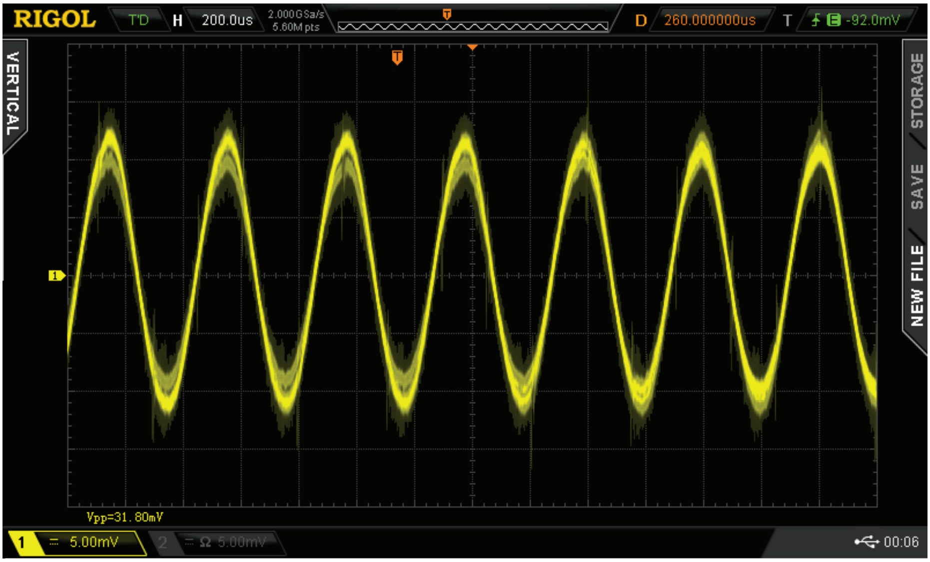

Fig. 5.
Signal taken from the experimental setup with an ITO glass (complete shielding)

When making a comparison, the difference in the two signal oscillograms is obvious. The signal from the setup without an ITO-coated glass (Fig. 4) is weaker and when observed for a longer period of time it fluctuates heavily. On the contrary, in the case when an ITO-coated glass is used (Fig. 5), the signal is stronger and more stable.

It can also be seen that the effective voltage increases from 24.4 mV to 31.8 mV, which is approximately a 30% relative increment in the signal amplitude. This is due to the reduced influence of the external electromagnetic fields, which were jamming the effective signal.

CONCLUSION

A glass substrate with a thin layer of ITO was used to reduce the noise in the SPCE signal, caused by external electromagnetic fields. Two different signal plots, taken via a digital oscilloscope were used to compare how the signal changes when the transparent shielding is used. The signal taken from the fully shielded setup fluctuates less and is visibly clearer, which is a qualitative indication that ITO-coated glass can be used to reduce the EMI noise which is present when making measurements of the SPCE signal. A quantitative evaluation shows that the effective signal voltage has increased by 30%.

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