Protection from electromagnetic pollution by using metal based shielding materials

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Abstract. At first time a comprehensive investigation of properties of different types of filters protecting from electromagnetic (EM) radiation of to-date electronic devices for personal using – notebooks or laptops, mobile phones, WiFi devices, microwave ovens etc. has been performed for all components of EM pollution including electric and magnetic field strength and radiation power. The shielding filters were made by using different technologies including nanoparticles of transition metals implanted into glass, metal-plastic foils, glasses with different kinds of ITO coating. Values of the EM pollution reduction factors for different shielding filters types have been obtained that allow make recommendations for their practical application.

1. Introduction

The goal of the paper is to investigate properties of filters protecting from electromagnetic (EM) radiation of to-date electronic devices for personal using – notebooks or laptops, mobile phones, WiFi devices, microwave ovens etc. The shielding filters can be made by using different technologies from the point of view of both RF absorbing layer and substrate.

Electromagnetic shielding is defined as absorption and/or reflection of the electromagnetic radiation by the materials which work as a block against radiation permeation crossing out of protective materials. These materials prohibit the transmission of the EM radiation by the EMR absorption and/or reflection or repressing the EM signals. Thus, the electromagnetic waves cannot influence the functioning and reflection, they are widely used to isolate area or tools from surrounding EM waves. This reflection shielding is referring to the principle of the Faraday cage, in which inside the cage, space is completely impervious to external electric fields; furthermore, the absorption shielding is associated with permeable material, sometimes magnetic materials. Accordingly, metal conductors are devoid of flexibility, weight, and high cost in the meantime; ferromagnetic or ferromagnetic materials have an essence cut off frequency, commonly, under the low GHz range; however they handicap use in the EMI shielding over broad GHz range.

In many cases development of protective materials, especially in construction, was directed for shielding from both radio waves and radioactivity [1-3]. For protection from the radio frequency (RF) radiation of electronic devices the shields should be compact and light-weight, besides, efficient
for the RF absorbance. A review of materials for electromagnetic compatibility of electronic devices with a description of some shielding filters are presented in [4-7].

To-date Institute of Glass, Moscow, developed an approach to make mass production glass materials reducing the EM radiation that can be used in construction, electronics, medicine, space and other areas [8-11]. The glass absorbing the RF waves is transparent in visible spectrum range. The RF shielding effect is achieved by implantation of accelerated ions of transition elements (Ti, V, Cr, Mn, Co, Fe, Ni, Cu, W and Mo) into the surface glass’ layer with thickness less than 100 nm. This process results in formation of nanoparticles in this layer that absorbs the EM radiation [8, 12 - 14]. The structure of such glasses was investigated by EPR method [15]. The greatest radiation protection effect is observed on glasses implanted with nickel (Ni+) and cobalt (Co+) [8].

Many other groups work with metallized plastic or foiled RF shielding filters because of their flexibility, light weight, easy processing (they can be cut). Most known are Silver and LLumar films.

The Silver film looks like a non-transparent mirror. It transmits light only in one direction. The films are fabricated by a deposition of a metallized layer onto transparent polyester. The polyester roll reels up onto a water coolable roller in a big vacuum chamber. Metal (usually Al) is evaporated onto the cool surface of the film. Such metallized film reduces the EMR by 18-22 dB at frequency 300 MHz and by 35-38 dB at 2000 MHz. The Silver films 37.5 µm thick and 62% transparent are used in architecture for both EMR protection and creation of comfortable light environment. Analogues of the Silver film with Sintered Silver Nanowires are described in [16, 17].

The LLumar film are made of flexible radio absorbing materials EXSOB and FAM [18]. The composition is not disclosed in the publications. In accordance with technical specifications the FAM3-0.75mm film 0.75 mm thick for shielding notebooks and mobile phones provides RF absorbance -0.90dB (18.72%) at 0.9 GHz, -1.42dB (27.91%) at 1.8 GHz, -1.87dB (35.03%) at 2.4 GHz. The FAM films have advantages as follows: they provide high efficient noise suppression in frequency range from 10MHz to 60GHz; they suppress resonance frequencies and repeat reflections of the signals from the screens; high surface resistance (10⁶ - 10⁸ Ohm); they are easily cut from big size sheets (400*400 mm) and easily assembled.

Among international companies most known commercial shielding films are made by Hollandshielding Co. and Soliani EMC [19,20]. An example of very light EM shielding material is presented in [21].

Many other plastic filters with sophisticated structure of a composite material are in progress [22-24], e.g., shields composed of carbon fibers’ reinforced plastics and metal wire mesh based composites [22] or the shielding film coated with a hybrid solder-magnetic powder mixture on a PET substrate [23].

Therefore, development of new shielding material and investigation of their properties is an urgent task from the point of view of both basic and applied science. It is to note that the EM shielding properties should be studied for the full set of the electromagnetic field parameters including both electric and magnetic field strength as well as radiation power.

2. Methods and materials

In this work we investigated an effect of reduction of the exposure of electromagnetic pollution index (EMPI) which was caused by four radiofrequency sources with a few shielding materials and compare these values with values obtained without the shielding material. Therefore, we did our measuring by monitoring and observing all values which include four sources with shielding cases presented in table 1 for the EMPI components: magnetic field strength (mA/m), electric field strength (V/m) and radiation power density (W/m²).

The paper assesses the level of the reduction of the electromagnetic radiation generated by the following devices radiating in MHz and GHz range:

- portable computer (LC) Lenovo ideapad 100-15IBD Processor Intel ® core (TM) i3-5005u CPU@2.00GHz;
• Wi-Fi 2300 MHz;
• mobile Huawei Y7 Prime 2018 with frequency 1.4 GHz + 1.1 GHz and 1800 MHz;
• microwave oven with frequency 2450 MHz.

The experiment with all the devices was tested in their natural operating state. The EM shielding filter was positioned between the device and the meter – portable TM-195 RF three-axis field strength meter TENMARS TEST & MEASUREMENT INSTRUMENTS device.

Figure 1 illustrates the experimental method. The distance between the shields and the meter device is 5cm.

We have investigated two groups of the shielding materials. The first group includes samples of Russian institutions issuing commercial glasses or foils. They are presented in Table 1.

Table 1. EM shielding cases

| Case | Details |
|------|---------|
| 1    | Without filter |
| 2 (material No 1) | Al foil |
| 3 (material No 2) | glass 1 |
| 4 (material No 3) | glass 2 |
| 5 (material No 4) | glass 3 |
| 6 (material No 5) | SSiSR PS4 Silver film |
| 7 (material No 6) | LLumar film |

Three glass samples of Institute of Glass with the NPs of the transition elements implanted into the glass were investigated. A sample SSiSR PS4 (Silver) looks like a shining foil film. The EM protection is provided by a metal layer coated onto a thin polymer film. Another flexible sample is a LLumar film.

We have also investigated the EMR reduction by a few glass samples coated with different ITO (In$_2$O$_3$) modifications. This material is used as a transparent electrode in electro-optic (displays) and optoelectronic (photo-voltaic) devices. For many purposes it is important that the material would provide both transparency and RF absorption.

The ITO sample of type A was deposited by the method of reactive magnetron sputtering from two targets of In and Sn in an oxygen medium within the UNIP-900P unit [25], equipped with a Chola-type ion source for pre-cleaning and activation of the substrate surface.
Samples of the ITO coatings of types B, C, and D were obtained by direct current magnetron sputtering (DC mode) in an Argon working medium from an \((\text{In}_2\text{O}_3)_{0.9-}(\text{Sn}_2\text{O}_3)_{0.1}\) target at the VUP-11M [26], MIR-2 and Kurt J Lesker PVD 75 units, accordingly. The target for the samples of types B and C was produced by Girmet LLC, Russia; the target for the sample of type D was produced from Kurt J. Lesker Company Ltd, USA. The samples of types C and D were deposited onto glass substrates with the addition of oxygen to improve the optical characteristics of a transparent conductive layer (3% of oxygen for the type C sample and oxygen pressure 4.8x10^{-4} at chamber pressure 3x10^{-3} Torr for the D sample).

The ITO samples of types C and D were deposited onto the glass substrate, but the ITO layer of type B was deposited onto the PET substrate (polyethylene terephthalate). Preliminary purification of the substrate was carried out by washing it in baths with isopropyl alcohol and deionized water, following with the activation of polymer films which was performed on a laboratory plasma activation unit UMP-500 in Argon plasma at a pressure of 1.1 Torr, a voltage of 350 V and discharge power of 150 W.

The thickness and sheet resistance of the obtained samples are shown in Table 2.

### Table 2. Parameters of the applied ITO layers

| Sample number | Coating thickness, nm | Sheet resistance, Ohm/□ |
|---------------|-----------------------|-------------------------|
| Type A        | 100                   | 150                     |
| Type B        | 83                    | 201                     |
| Type C        | 150                   | 102                     |
| Type D        | 98                    | 190                     |

For this samples’ group optical transmission was measured besides of the EM shielding parameters. The transmission coefficient of the ITO samples under study was determined using a Shimadzu UV-3600i Plus spectrophotometer in the wavelength range from 380 to 780 nm with a resolution of 1 nm at normal incidence of light onto the sample.

Schematic structure of different samples is illustrated in Fig.2.

**Figure 2.** Schematic structure of different samples. Left – samples of Institute of Glass; right – other samples.

### 3. Results

#### 3.1. EM shielding properties of commercial glasses and foils

The results are presented in Figures 3-6 and Tables 3-6.
Figure 3. Three EMPI components caused by mobile phone (mobile Huawei Y7 Prime 2018 with frequency 1.4 GHz + 1.1 GHz, 1800 MHz) with and without EM shielding

Table 3 shows the reduction factor the EMPI caused by mobile phone for the three EMR components. It can be defined as follows:

\[
\text{Reduction factor} = \frac{V_{sh}}{V_{wsh}},
\]

\(V_{sh}\) - measured signal value with shielding, \(V_{wsh}\) - without shielding.

Table 3. Reduction factor of EMPI caused by mobile phone

| Sample No | Magnetic field strength | Electric field strength | Power density |
|-----------|------------------------|------------------------|--------------|
| 1         | 0.94                   | 0.39                   | 0.27         |
| 2         | 0.97                   | 0.43                   | 0.48         |
| 3         | 0.81                   | 0.75                   | 0.86         |
| 4         | 0.76                   | 0.61                   | 0.53         |
| 5         | 0.54                   | 0.41                   | 0.31         |
| 6         | 0.51                   | 0.77                   | 0.33         |

From figure 3 and table 3 one can notice that the sample with the material 1 reduced the electric field strength (E) and power density (P) to the minimum values but magnetic field strength (H) value keeps still near to value before the shielding; but in case of shielding by the material 5 we get a small value factor for each of the three components: reduction factor is as high as 0.41 in case of E, it reduced also P to factor 0.31. While in case of reduction H the material 5 has also a small factor 0.54 when we compared these values with the values without the shielding material. Therefore, we can recommend the material 5 in case of the mobile phone shielding, it is very effective in order to reduce the EMPI exposure.
Three EMPI components caused by laptop (Lenovo idea pad 100-15IBD Processor intel ® core (TM) i3-5005u CPU@2.00GHz) with and without EM shielding.

Table 4 shows the reduction factor for the EMPI caused by the laptop for the three EMR components.

### Table 4. Reduction factor of EMPI caused by laptop

| Sample No | Magnetic field strength | Electric field strength | Power density |
|-----------|-------------------------|-------------------------|---------------|
| 1         | 0.41                    | 0.41                    | 0.11          |
| 2         | 0.55                    | 0.54                    | 0.23          |
| 3         | 0.74                    | 0.74                    | 0.61          |
| 4         | 0.39                    | 0.42                    | 0.18          |
| 5         | 0.43                    | 0.43                    | 0.13          |
| 6         | 0.35                    | 0.47                    | 0.17          |

From data in figure 4 and table 4 one can notice that the material 1 reduced E to factor 0.41 when we compared the value by the value without shielding and also it reduced P to factor 0.11 when we compared the value by the value without shielding material. While in case of reduced H we get the minimum reduced factor in case of using the material 6. The material 1 also has a small factor 0.41 when we compared the value with the value without the shielding material. Because of that we recommended in case of the laptop shielding by the material 1 that is very effective in order to reduce the EMPI exposure.
Figure 5. EMPI (three components) which were caused by microwave oven (2450MHz) with and without shielding

Table 5 shows the reduction factor for the EMPI which was caused by the microwave oven for the three components of EMR.

| Material No | Magnetic field strength | Electric field strength | Power density |
|-------------|-------------------------|-------------------------|---------------|
| 1           | 0.66                    | 0.66                    | 0.44          |
| 2           | 0.94                    | 0.94                    | 0.89          |
| 3           | 0.95                    | 0.98                    | 0.95          |
| 4           | 0.84                    | 0.84                    | 0.38          |
| 5           | 0.89                    | 0.86                    | 0.79          |
| 6           | 0.86                    | 0.95                    | 0.56          |

From figure 5 and table 5 one can notice that the material 1 reduced H to factor 0.66 when we compare the value with the value without shielding material. It reduces E to factor 0.66 when we compare the value with the value without shielding. We get the minimum reduced value of P in case of the material 4, but also the material 1 has the small value (factor 0.44) when we compare this value with the value without the shielding material. Because of this, we can recommend for the microwave shielding the material 1 that is very effective in order to reduce the EMPI exposure.
Table 6 shows the reduction factor for EMPI which was caused by Wi-Fi for the three components of EMR.

| Material No | Magnetic field strength | Electric field strength | Power density |
|-------------|-------------------------|-------------------------|--------------|
| 1           | 0.38                    | 0.38                    | 0.17         |
| 2           | 0.15                    | 0.95                    | 0.19         |
| 3           | 0.14                    | 0.14                    | 0.016        |
| 4           | 0.16                    | 0.16                    | 0.022        |
| 5           | 0.13                    | 0.13                    | 0.013        |
| 6           | 0.27                    | 0.27                    | 0.068        |

From figure 6 and table 6 one can notice that the material 5 reduces the H to factor 0.13 when we compare this value with the value without the shielding material, and it reduces E to factor 0.13 when we compare this value with the value without shielding. It also reduces P to factor 0.013 when we compare the value with the value without the shielding material. Because of this we recommend in case of the Wi-Fi shielding the material 5 that is very effective in order to reduce the EMPI exposure.

3.2. EM shielding properties of ITO based materials
The list of samples is presented in Table 7.

| Case | Without ITO | ITO (Type A) | ITO (Type B) | ITO (Type C) | ITO (Type D) |
|------|-------------|--------------|--------------|--------------|--------------|
| Case 1 | Without ITO | ITO (Type A) | ITO (Type B) | ITO (Type C) | ITO (Type D) |

Figure 6. EMPI (three components) caused by Wi-Fi (2300) MHz with and without shielding
The transmission spectrum of the test samples is shown in Figure 7.

![Figure 7. Transmission spectrum of the test ITO samples](image)

Tables 8-11 and figures 8-11 show the reduction factor the EMPI caused by the devices investigated for the three EMR components.

**Table 8.** The factor of protecting from electromagnetic pollution of the mobile phone by using ITO coated metal shields.

| Case No | Coating materials | Power density (W/m²) | Electric field strength (V/m) | Magnetic field strength (mA/m) |
|---------|------------------|----------------------|-------------------------------|-------------------------------|
| 1       | Without          | 1.00                 | 1.00                          | 1.00                          |
| 2       | Type A           | 0.51                 | 0.71                          | 0.71                          |
| 3       | Type B           | 0.58                 | 0.78                          | 0.78                          |
| 4       | Type C           | 0.56                 | 0.85                          | 0.85                          |
| 5       | Type D           | 0.52                 | 0.82                          | 0.82                          |

**Table 9.** The reduction factor of protecting from electromagnetic pollution of the laptop computer by using ITO coated metal shields.

| Case No | Coating materials | Power density | Electric field strength | Magnetic field strength |
|---------|------------------|---------------|-------------------------|-------------------------|
| 1       | Without          | 1.00          | 1.00                    | 1.00                    |
| 2       | Type A           | 0.87          | 0.93                    | 0.93                    |
| 3       | Type B           | 0.92          | 0.96                    | 0.96                    |
| 4       | Type C           | 0.93          | 0.96                    | 0.96                    |
| 5       | Type D           | 0.90          | 0.95                    | 0.95                    |

From figure 8 (see below) and table 8 we can notice that the case 2 from the Table 7 (Type A) reduces H to factor 0.61 when we compare this value with the value without the coated metal shields. It reduces E to factor 0.60 when we compare this value with the value without the coated metal shields. It also reduces P to factor 0.40 when we compare the value with the value without the coated metal shields. Because of this we recommend in case of the mobile phone it is better to coat the shielding filter by using ITO metal shields of the case 2 (Type A) that is very effective to reduce the EMPI exposure.
Table 10. The reduction factor of protecting from electromagnetic pollution of WI-FI by using ITO coated metal shields

| Case No | Coating materials | Power density | Electric field strength | Magnetic field strength |
|---------|------------------|---------------|-------------------------|------------------------|
| 1       | Without          | 1.00          | 1.00                    | 1.00                   |
| 2       | Type A           | 0.40          | 0.60                    | 0.61                   |
| 3       | Type B           | 0.40          | 0.61                    | 0.62                   |
| 4       | Type C           | 0.90          | 0.91                    | 0.92                   |
| 5       | Type D           | 0.39          | 0.65                    | 0.66                   |

Table 11. The factor of protecting microwave oven from electromagnetic pollution by using ITO coated metal shields

| Case No | Coating materials | Power density | Electric field strength | Magnetic field strength |
|---------|------------------|---------------|-------------------------|------------------------|
| 1       | Without          | 1.00          | 1.00                    | 1.00                   |
| 2       | Type A           | 0.34          | 0.69                    | 0.69                   |
| 3       | Type B           | 0.37          | 0.77                    | 0.71                   |
| 4       | Type C           | 0.32          | 0.65                    | 0.65                   |
| 5       | Type D           | 0.37          | 0.69                    | 0.69                   |

From figure 9 and table 9 one can notice that the case 4 from the Table 7 (Type C) reduces H to factor 0.65 when we compare this value with the value without the coated metal shields. It reduces E to factor 0.65 when we compare this value with the value without the coated metal shields. It also reduces P to factor 0.32 when we compare the value with the value without coated metal shields. Because of that we recommend in the case of the laptop it is better to coat the filter with ITO metal shields of the case 4 (Type C) that is very effective to reduce the EMPI exposure.

Figure 8. Protecting from electromagnetic pollution of mobile phone by using ITO coated metal shields
From figure 10 and table 10 one can notice that the case 2 (Type A) reduces $H$ to factor 0.71 when we compare this value with the value without the coated metal shields. It reduces $E$ to factor 0.71 when we compare this value with the value without the coated metal shields. It also reduces $P$ to factor 0.51 when we compare the value with the value without the coated metal shields. Because of that we recommend in case of the Wi-Fi it is better to coat the filter by using the ITO metal shields of the case 2 (Type A) that is very effective to reduce the EMPI exposure.

For the last device (microwave oven) from figure 11 and table 11 one can notice that the case 2 from the Table 7 (Type A) reduces $H$ to factor 0.93 when we compare this value with the value without the coated metal shields. It reduces $E$ to factor 0.93 when we compare this value with the value without the coated metal shields. It also reduces $P$ to factor 0.87 when we compare the value with the value without the coated metal shields. This is the smallest value in this situation but it is not effective enough to be recommended for the EM shielding.
Figure 11. Protecting from electromagnetic pollution of microwave oven by using ITO coated metal shields

Conclusion

The paper is addressed to the protection from electromagnetic pollution by using metal coated shields, which was caused by some radiofrequency sources. Depending on our plan and main goal of this paper let us review figure 12. It illustrates comparison of the three components of EMR of the properties of two groups of filters protecting from the electromagnetic pollution (EMP). We have obtained the reduced factors values for the EMPI by using two groups coated metal shields. In figure 11 one can notice that these types of coated shields are effective in sources 1, 2 and then 3. But they are not efficient for the microwave oven. In the last case it is recommended to search for other materials.

The study indicated the cases when the EMR level is significant and protection from these devices – EMP sources is necessary. Hence this information can be exploited to use the devices safely and securely. Additionally, the research includes two groups of metal coated shields for daily life devices which are mobile phone, laptop, Wi-Fi and microwave oven without risk.
Figure 12. The comparison of the reduction factor values for the two groups of the shields caused by four sources (devices)

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