Compensation Filters for Visualization of White Leds through the Ceramic Glass in Induction Cooktops

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Abstract: White LEDs visualization in induction cooktops is hindered by the non-uniformity in wavelength of the transmission of the ceramic glass used as the cooking surface, as it modifies the chromaticity of the LEDs. In this work, a compensation filter is developed by thin-film interference filter deposition techniques, which has a transmission spectrum that allows for the preservation of the light source intrinsic chromaticity. This permits a perfect visualization of white LEDs across ceramic glasses.

1 INTRODUCTION

Nowadays, induction heating cooktops are one of the most common home appliances. One main feature of these cooktops is the fact that they use a ceramic glass as cooking surface, by means of which they successfully isolate the electronics of the device from the user. Such ceramic glass must have some very specific characteristics, as a very low coefficient of thermal expansion, so that it can withstand high thermal gradients without cracking (Siebers et al., 2013).

Currently there are two types of ceramic glasses, which mainly differ in their optical properties, particularly in their visible transmittance. On the one hand, bulk absorption ceramic glass is the typical black-coloured glass (with low reflection and high absorption) integrated in most low-medium range cooktops (SCHOTT, 2010). On the other hand, transparent ceramic glass can be used on cooktops, but it requires the deposition of a coating that confers a proper aesthetic appearance to the cooking surface (SCHOTT, 2012). This second option is more expensive and is at present aimed at top-of-the-range products.

A serious disadvantage of the black-coloured bulk absorption ceramic glass is the non-uniformity of its transmittance over the visible spectrum range (Fig.1). Its transmittance increases with wavelength, and that is the main reason why signalling and illumination in induction cooktops has been traditionally based on red LEDs, as the value of transmittance at the wavelength of the colour red (630nm) is higher than for other visible colours (blue, green…). At present, the strong attenuation the ceramic glass produces over blue can be compensated by the enhancement in the performance of blue LEDs and the use of high power LEDs.

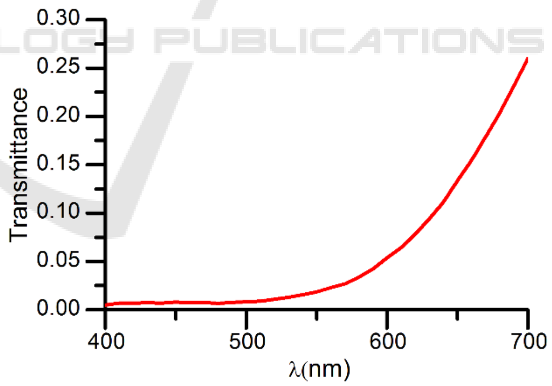

Figure 1: Visible transmittance of “Brigther HighTransECO (Schott)” ceramic glass.

Another significant effect of the use of ceramic glass on cooktops is the fact that when a light source with a relatively wide spectrum as a white LED is used (Fig.2), the non-uniform transmittance of the glass notably changes the chromaticity of the LED. This effect implies that a white LED seen through a bulk absorption ceramic glass is visualised as a pink-orange colour (Fig.3).

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This work tackles the problem of the chromaticity change for wide spectrum light sources. A compensation interference filter has been designed so that the filter+ceramic glass system has a closely neutral transmittance in the visible range of the spectrum. The compensation filter is based on a multilayer structure of $SiAlO_x$ and TiO_x thin films deposited by magnetron sputtering.

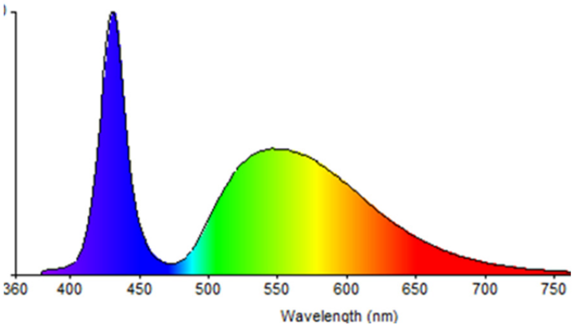

Figure 2: Visible spectrum of a white LED.

Figure 3: Visualization of a white LED through a ceramic glass.

Interference filter development by means of dielectric thin films is a well-known technique (J. A. Dobrowolski, 1995; Macleod, 2010; Thelen, 1989). In this way, using one dielectric material with a high refraction index, as TiO_2 with n=2.34 @550nm (Palik, 1985), and another dielectric material with a low index of refraction, as $SiAlO_x$ with n=1.47 @550nm, a transmittance curve can be achieved that compensates for the non-uniformity of the ceramic glass transmittance.

TiO_2 is a commonly used dielectric material with a high index of refraction, so one can easily find several references in this regard (Willey, 2002). As a low index material, SiO_2 is more typically used (Gao et al., 2013; Thelen, 1989), but we have rather deposited $SiAlO_x$ films which comprise a low percentage of Al, because it enhances deposition conditions (faster sputtering rate, fewer electric arcs occur during deposition…) and has a very similar refraction index to that of SiO_2.

This proposed solution also presents some advantages for its use with transparent ceramic glass, because this type of glass requires a multilayer deposited over its entire surface, while the compensation filter is only needed in the user interface area of the cooktop, where the illumination and signalling elements are placed. Furthermore, the thermal requirements for the multilayer are less and can be easily achieved because the filter does not cover the cooking area.

2 MATERIALS AND METHODS

Optical interference filters were deposited in a semi-industrial high vacuum magnetron sputtering system by the DC pulsed technique (Martin, 2009; Mattox, 2010) using rectangular targets with dimensions 600x100mm and 12mm thick. Substrates were microscope slide pieces of 76x25mm and 1mm thick. Substrates were cleaned with a detergent solution (ACEDET 5509) and finally rinsed with distilled water.

Thin films were grown with a base pressure of $2.0 \cdot 10^{-6}$ mbar and working pressure in the range of 10^{-3} mbar. Ar and O_2 (both 99.99%) flows were introduced into the process chamber and controlled via mass flow controllers. The substrate was maintained at room temperature during deposition. Thin films of $SiAlO_x$ were deposited by reactive sputtering from a SiAl target (90% Si and 10% Al, 99.99% pure). Applied power was 2500W, equivalent to a power density of 4.17W/cm^2. The Ar flow was fixed at 160sccm (Standard Cubic Centimeters per Minute) and the O_2 flow at 40sccm (In our deposition system a flow of 200sccm is approximately equivalent to a pressure of $1.5 \cdot 10^{-3}$ mbar). Thin films of TiO_2 were deposited by reactive sputtering from a Ti target (99.99% pure). Applied power was 5000W, equivalent to a power density of 8.33W/cm^2. This power is high because the sputtering rate of TiO_2 is very low, in this way we get a reasonable deposition rate. The Ar flow was fixed at 140sccm and the O_2 flow at 60sccm.

Spectrophotometric measurements were performed with a home-made spectrophotomer (designed and built by some of the authors) in the visible region of the electromagnetic spectrum, between 400nm and 700nm with 10nm intervals, at an angle of incidence of 8º. Only specular transmittance was measured, without an integrating sphere, because the "low" roughness of the substrate minimizes the scattered component to negligible values and because the specular measurements are more precise.

The macroscopic roughness of the internal side of the ceramic glass makes it difficult to measure its specular transmittance. An epoxy resin (epo-tek 301 type) with a low optical absorption and an index of refraction similar to that of the ceramic glass was applied to correct that roughness, and to stick the compensation filter to the ceramic glass.

3 RESULTS

The transmittance spectrum of the compensation filter should be one that meets the following expression in the visible region of the spectrum:

$$T_{filter}(\lambda)\cdot T_{glass}(\lambda)=cte \qquad (1)$$

If the filter+ceramic glass system has a constant transmittance, it won't unbalance the wide spectrum of the illumination source, so there won't be certain wavelengths gaining weight and the compensation effect won't be achieved.

Therefore, one can calculate the transmittance curve of the compensation filter from the measured transmittance curve of the ceramic glass. Once we knew the target transmittance, we proceeded to the design of the multilayer using a simulation software that is based on formalisms used for the calculation of optical properties for interference coatings (Macleod, 2010; Thelen, 1989).

A 9-layer structure was estimated as satisfactory enough to achieve the necessary contrast between high and low transmittance areas for an adequate compensation filter (Table 1).

Figure 4 shows the transmittance curves for an ideal filter+ceramic glass system (calculation, blue line) and for the real system (measured, green line). The transmittance absolute value of the ideal system has been located at 0.65% because the ceramic glass transmittance in the wavelength range of the blue colour is around 0.70%, and this value represents an upper limit. The transmittance curve of the experimentally made system is close to the ideal value, although in the limits of the visible range of the spectrum we find more discrepancies, but in this range the human eye sensitivity is low, so this zone has less relative weight when determining the chromaticity of the light source that is used. In this way, a discrepancy lower than 15% is accomplished between the ideal and real measured values of transmittance, whereas the ceramic glass without the filter has a transmittance which is 10 times lower at 460nm (blue peak of a white LED spectrum) tan at 620nm (where the phosphorescent emission of the LED is still high and human eye sensitivity is still considerable).

Table 1: Thin film structure and layer thicknesses of the compensation filter.

Material	Thickness (nm)
Substrate	1 mm
TiO_2	85
$SiAlO_x$	143
TiO_2	72
$SiAlO_x$	116
TiO_2	70
$SiAlO_x$	104
TiO_2	69
$SiAlO_x$	93
TiO_2	78

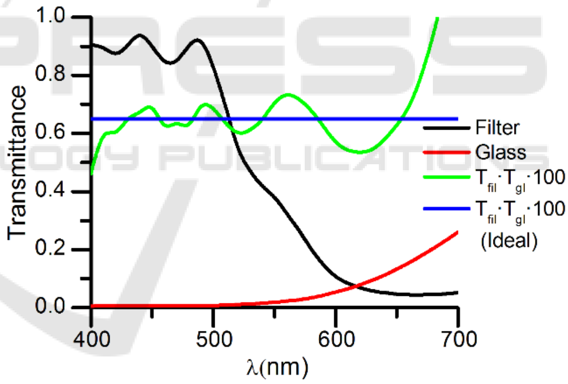

Figure 4: Transmittance curves for: compensation filter (black line), ceramic glass (red line), real filter+ceramic glass system (green line) and ideal filter+ceramic glass system (blue line).

By using a greater number of layers, we can better adjust the experimental system to the ideal one, as a greater number of adjustment parameters for the multilayer appear (i.e., the thicknesses of each layer). Nevertheless, it has been proven that the developed filter achieves good results and manages to correct the chromaticity change for white LEDs. Figure 5 finally shows the visualization of two white LEDs through a ceramic glass, illustrating the effect of the compensation filter, which accomplishes the goal of a good colour reproduction.

The chromaticity coordinates of a light source having the spectrum of the D65 illuminant seen through a ceramic glass are far from the white colour coordinates, as well as those of a typical white LED seen through a ceramic glass. However, when the compensation filter+ceramic glass system is used, the chromaticity coordinates in both cases are within the zone of the white colour (Table 2).

Figure 5: Visualization of a white LED through a ceramic glass: without compensation filter (left) and with compensation filter (right).

Table 2: Chromaticity coordinates for the ceramic glass and for the compensation filter+ceramic glass system, expressed by using the D65 illuminant and a white LED (Osram model LW W5SM).

	Ceramic glass		Cer. glass+filter	
Illuminant	D65	LED	D65	LED
x	0.54	0.52	0.31	0.32
y	0.37	0.38	0.33	0.32

4 CONCLUSIONS

This work verifies that thin-film interference optical filters can be used to compensate the non-uniformity in transmittance of the ceramic glass that is used in induction cooktops. There are several alternative manufacturing methods for such filters, but optical interference filters allow a greater adjustment of its transmittance curve. In this case, a nine-layer structure alternating TiO_2 (high index of refraction) and $SiAlO_x$ (low index of refraction) layers is necessary. Adding this filter into the illumination and signalling area of induction cooktops, we can correct the chromaticity change that the ceramic glass introduces for wide spectrum light sources, such as white LEDs. This effect has been verified not only visually but also by calculation of the chromaticity coordinates for light sources with spectra of the D65 illuminant and of a white LED.

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