Dielectric-Metal-Dielectric (D-M-D) infrared (IR) heat reflectors

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Abstract. Sunlight is the primary source of light in the buildings and automobiles. However, infrared (IR) radiations in the sunlight result in heat generation. In this work, dielectric-metal-dielectric (D-M-D) heat reflectors are demonstrated which is transparent for visible light 400-700 nm while reflecting IR radiations above 700 nm. These reflectors are based on a TiO₂-Ag-TiO₂ sandwich structure with 22 nm of the thickness of each layer shows the maximum transmission of 83 % theoretically and 81 % experimentally in the visible wavelengths region observed by ellipsometer; a maximum reflection of IR wavelengths was also observed. The study was also extended to experimental verification of heat transmission by testing these reflectors both under IR lamp and sun in the month of June 2016. Experimental results confirm less heat transfer through these filters as compared to the commercially available tinting paper. As a practical application, these reflectors can be used in automobiles and houses during summer to reflect back the excessive heat from the sun.

1. Introduction

Smart buildings and automobiles with minimum consumption of electrical energy are designed so that sunlight can be used as a source of light during daytime in buildings using large windows [1]. However, exposure to sunlight results in heating and eventually consumption of extra electrical energy as air-conditioning to remove trapped heat in buildings [2] [3] and automobiles especially when they are parked without any shadow [4] [5]. Conventional windows pass both visible and Infrared (IR) wavelengths, eventually IR radiations are mainly responsible for heating [6] and also harmful to human skin [7]. Thin film design techniques have been improved over the years for efficient design of optical filters with selective transmission and reflection [8]. Dielectric-Metal-Dielectric (D-M-D) reflectors based on thin film coatings are widely used to transmit visible light and reflect IR wavelengths [9]. These reflectors can be effective to reduce heating in buildings and automobiles. Easily available solutions for heat reflectors include aluminium foil and tinting paper to blind the windows of the car. Tinting paper can reduce the transmission of sunlight resulting in a low transparency. New cars have adopted techniques like vacuum glazing to reduce heating from sunlight [10], however, they are expensive and not beneficial for people with old cars. In this work, we have fabricated D-M-D reflector design which has high transparency with a maximum transmission of visible light and maximum reflection of IR wavelengths based on thin film coatings that can be used in glass windows of buildings and automobiles.

These D-M-D reflectors are basically a filter that transmits visible light and reflects heat causing IR wavelengths. Filters are of two types: absorption filter that absorbs the wavelengths that need to be stopped and interference filter that reflect the undesired wavelengths [11, 12, 13]. Transmission and reflection properties of interference filters are dependent on materials refractive index and layer thickness of
materials. To model the IRC, open source software Open Filter is used. Open filter calculates optical properties of filters. It uses transfer matrix method to calculate the transmission and reflection properties of filters/IRC based on the absorption and materials refractive indices [14]. Optimization techniques are available in this software like needle synthesis (Adding an extra layer to give targeted transmission). However, in this work, the designs are optimized manually.

2. D-M-D design and characterization
Based on our modelling results [15], we carefully selected an optimized design which presents a promising visible wavelengths transmission and highly IR reflections. To fabricate these reflectors, thin films of metal and dielectric material were deposited on the glass substrate with the help of Magnetron sputtering AJA International Inc. ATC Orion-8- HV. At first, TiO$_2$ layer was deposited on glass substrate by using RF power of 150 W, 20 s.c.c.m of Ar flow at 3 mTorr pressure for 30 min, followed by metal (Ag) layer deposition: DC power of 150 W, 20 s.c.c.m at 3 mTorr pressure for less than 1 min and then again TiO$_2$ layer was deposited on top. Good quality TiO$_2$ dielectric layers can also be obtained by annealing Ti metal layer [16].

2.1. Measurement of heat transfer through D-M-D reflector by using IR lamp source
To scrutinize the heat transmission through D-M-D reflector, we designed a hollow cylinder made of plastic and a thermocouple was placed inside the cylinder connected to multi-meter in order to record the temperature caused by an IR lamp placed directly over the cylinder as shown in the inset of Figure 1.

In that very case, we are only considering the heat transmitted through the open end of the cylinder. Therefore, we are not taking into account the heat transmission through the sidewalls of the box. This phenomenon was considered while measuring the temperature under the sun, as the light falls from all possible directions. We noticed the temperature inside the hollow cylinder rises to 86 °C in 15 minutes when the regular optical glass was placed. On the other hand, when a D-M-D reflector (TiO$_2$-Ag-TiO$_2$=25-25-25 nm) was placed over the cylinder, the temperature elevated gradually and arrived at 38 °C in 30 min and stabilised as shown in figure 2. Furthermore, we found that our D-M-D reflector has shown best results as compared to commercially available tinting paper. Temperature is marginally above the room temperature by using D-M-D reflector; this temperature can easily be controlled in buildings and automobiles by using simple fans for cooling which results in an economical and energy efficient solution.
Figure 2. Temperature versus time graph. Heat transfer through the optical glass, a gold layer, tinting paper and D-M-D reflector.

2.2. Measurement of heat transfer through D-M-D reflector under Sunlight

This experiment was conducted under sunlight in the hot month of June in Samara, Russia. The room temperature on that day was 32 °C and weather was partially cloudy. We wanted to observe the temperature through the filter, therefore, we make a special box covered with aluminium foil to protect the heat transfer from the sidewalls of the box. But the light was falling on the box from all directions so we noticed some increase in temperature which was caused by the heat transfer through all four sides of the box as shown in Figure. 3.

Figure 3. Temperature measurement through the D-M-D reflector placed on the open end of the box under sunlight. Whereas the sidewalls of the box are covered with aluminium foil.
The temperature measurement results are shown in Table I. In the experiment, the temperature in the cylindrical box wasn’t stabilized for optical glass. It was increasing with time so we can expect that if this experiment is performed on the total sunny day for a long time then the temperature could rise to 50 °C. Contrary to this, the temperature was stabilized when designed D-M-D reflector was used in the experiment.

Table I: Temperature measurement in a cylindrical box under different heat sources

| Heat source  | Type of filter   | Initial temperature (°C) | Final temperature (°C) | Time (min) |
|--------------|------------------|---------------------------|------------------------|------------|
| IR lamp      | Optical glass    | 25                        | 86                     | 15         |
|              | D-M-D reflector  | 25                        | 38                     | 30         |
| Sunlight     | Optical glass    | 32                        | 42                     | 30         |
|              | D-M-D reflector  | 32                        | 38                     | 30         |

2.3. Measurement of optical transmission of D-M-D reflector, gold layer and tinting paper

The optical transmission of the gold layer (25 nm), commercially available tinting paper and D-M-D reflector was measured with the help of ellipsometer as shown in figure 4. It can be seen that D-M-D reflector provides the best result as compared to gold layer and tinting paper. It is well noting that the D-M-D reflector provides ~81 % of transmission in visible wavelength region whereas tinting paper and the gold layer can offer even less than 40 % of transmission. So our designed reflector provides two benefits: Enhances visibility at night and heat protective during day time.

![Figure 4](image-url)

**Figure 4.** Optical transmission of light of gold layer (25nm), tinting paper and D-M-D reflector in visible and IR region.

3. Conclusions

In this work, we demonstrated a D-M-D reflector based on TiO₂-Ag-TiO₂ thin films which show a significantly high transmission in the visible spectrum and extraordinary reflection in IR wavelengths. These reflectors can be used to control the heat accumulation in the automobiles and houses during the
hot weather. Commercially available tinting papers have a high reflection of IR wavelengths but very low transmission of visible light; reduces their transparency which can affect the visibility at night while driving. However, our designed reflectors have high transmission of ~81 % in the visible region and less than 10 % of transmission of IR wavelengths.

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