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Transparent thermal insulation coatings for energy efficient glass windows and curtain walls

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ABSTRACT

Single layer, waterborne, transparent heat insulation coatings for use in energy efficient glazing products were prepared, and their optical, thermal, electrical and artificial accelerated weathering properties were systematically investigated. The coatings combine a high transmittance in the visible region, a low transmittance (a high absorptance) in the near infrared region, a low emittance in the far infrared region, low haze and a high transmission of radio waves. While the coatings' spectral and overall transmittances and reflectances decrease with increasing weight content of antimony doped tin oxides (ATO), their near infrared absorption, and consequently their thermal insulation, increases with increasing ATO concentration. The transparent thermal insulation coatings are electrical insulators and thus have a high transmission of radio waves. The transparent thermal insulation coatings possess good artificial accelerated weathering resistance.

1. Introduction

For esthetic purposes, large glass windows and curtain walls have become more and more popular in modern buildings. A typical ordinary glass (such as a float glass) has not only a high transmittance and a low reflectance in the visible (VIS) and near infrared regions (NIR) [1], but also a low transmittance and a low reflectance, and thus a high emittance in the far infrared region [1,2]. As a result, the use of large glass windows and curtain walls causes a large increase in a building's winter heating and summer cooling loads. From the standpoint of energy efficiency, it is of particular importance to reduce the energy consumption caused by glazing products.

Low emissivity glass (low-E glass), also referred to as heat mirror glass, has a high transmittance in the visible region, a high reflectance in the near infrared region and a low emittance (high reflectance) in the far infrared region [1–3]. It has been conventionally used in energy efficient windows because it not only prevents near infrared radiation (known as a source of heat) from penetrating the glass, but also blocks the emission of far infrared radiation of building interiors [2,4]. Deposition techniques for low-E glass include chemical vapor deposition (CVD), evaporation, sputtering, pyrolysis, atomic layer epitaxy and sol–gel processes, etc [1,3–8]. These processes require high glass substrate temperatures or high electron [1] or large vacuum equipment [4]. Therefore, they have the disadvantages of low productivity, high cost [4] and difficulty in retrofitting of existing architectural glass.

Generally speaking, the following three types of materials have been developed for low-E glass: (1) a sufficiently thin metal film, (2) a thin metal film embedded into metal oxide antireflective layers and (3) a heavily doped semiconductor with a wide band gap such as fluorine-doped tin oxide and indium tin oxide [1,3,9,10]. The common feature of these materials is that they have high electrical conductivity and IR reflectance. The film also reflects radio waves and shields radio signals, television signals and cell phone signals [4].

An alternative to manufacturing energy efficient glass products is to paint glass with transparent solar heat insulation coatings. This passive technique has several advantages over the conventional low-E glass: ease of application, cost effective and no radio wave shielding. In spite of this, to our knowledge, there appears to be a very limited number of papers published in peer-reviewed international journals that are related to this topic [11–15]. In these studies, antimony doped tin oxide (ATO), a well-known optically transparent, infrared light insulating and electrically conducting oxide [5–7], is most commonly used to prepare transparent heat insulation coatings [11–15]. In these studies, the underlying thermal insulation mechanism of these transparent heat insulation coatings

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was ascribed to the absorption of infrared light by antimony doped nano-SnO_2 inside the composite coatings [11–15]. While these five studies appear to focus almost exclusively on the optical and thermal properties of transparent heat insulation coatings, there is no information on the other pertinent properties such as electrical properties and artificial accelerated weathering properties of the coatings, which are very important for their applications.

To meet the needs of the market for an easily applicable, energy efficient glazing product, waterborne, silicon-based, transparent heat insulation coatings have been developed. In this paper, the optical, thermal, electrical and artificial accelerated weathering properties of the coatings have been systematically investigated. The last two properties are the primary focus of concern in this paper.

2. Experimental methodology

2.1. Selection of the materials and coating preparation

To prepare the transparent solar heat insulation coatings, a heat-cured silicone emulsion, grade GN-021, purchased from Wuhan Green Chemical Technology Co., Ltd, was used as a water-based binder. Its solid content, pH and viscosity are 27%, 3.7 and 6.0 Pa s, respectively.

To obtain transparent thermal insulation coatings, an aqueous solution of antimony-doped tin oxide nanoparticles modified by 3-methacryloxypropyltrimethoxysilane (KH570) (solid content: 50%) was purchased from Huzheng Nanotechnology Co. Ltd. and used as a functional filler. The particle size of ATO in the solution is smaller than 15 nm, as observed by Transmission Electron Microscope.

A paint hardening agent, grade HR-8510, kindly provided by Dongguan Hongrui Chemical Technology Co., Ltd, was selected to improve the hardness and scratch resistance of the coatings. A leveling agent and an antifoaming agent were also selected to improve the coatings' quality and their application performance.

The above binder, functional filler and additives were used as received to prepare transparent thermal insulation coatings. The preparation process was as follows. The silicone emulsion, paint hardening agent, leveling agent and antifoaming agent were first added into a container and stirred at high speed for 30 min, followed by the addition of the aqueous ATO nanoparticle solutions at various concentrations (4, 6, 8, 10 and 12 wt%). The mixtures were dispersed for 20 min and the waterborne transparent thermal insulation coatings were produced. The obtained transparent thermal insulation coatings were designated as S-X-Y, where X and Y stand for the weight content of ATO (X wt%) in the coatings and the dry film thickness (Y μm), respectively.

The substrates used were plates of float glass (thickness: 3 mm). They were cleaned, dried and then painted with the transparent thermal insulation coatings using different spreader bars (30, 50, 70 and 100 μm). The dry film thickness was measured by a digital micrometer screw gauge. All samples were dried for 30 min at 120 °C.

2.2. Spectral reflectance and transmittance measurements

A UV/VIS/NIR spectrophotometer (Perkin Elmer Lambda 750) equipped with an integrating sphere (150 mm diameter, Labsphere RSA-PE-19) was used to measure the transmittance and reflectance spectra of the samples from 250 to 2500 nm. The reference standard used for the measurements was a PTFE plate (Labsphere). The spectral reflectance and transmittance were calculated by integrating the measured spectral data against the Air Mass 1.5 global spectrum utilizing 105 weighted ordinates [16,17].

It is common knowledge that the sum of the reflectance *R*, transmittance *T* and absorptance *A* equals one ($R + T + A = 1$). Therefore, the spectral absorptance across the solar spectrum of the samples may be calculated from the transmittance and reflectance data.

2.3. FTIR measurements

A Fourier transform infrared spectrometer (Perkin Elmer Frontier) was used to measure the absorbance, transmittance and reflectance of the transparent thermal insulation coating in the infrared region (2.5–22.2 μm). The main focus of this paper is the absorbance of the transparent thermal insulation coating in that region. Therefore, the results of the transmittance and reflectance for the transparent thermal insulation coating will not be presented.

2.4. Haze measurements

The haze of the samples was examined with an automatic haze meter WGT-S (Jingkeall, Shanghai INESA Scientific Instrument Co., Ltd), according to ASTM D1003–11E1[18]. The haze meter consists of an integrating sphere, a condenser, a lens, a photodetector and an ultraviolet C-range light source. It can measure the total transmittance (T_t) and the diffuse transmittance (T_d) of the samples, and the haze of the coatings is given by:

$$Haze = \frac{T_d}{T_t} \times 100\% \quad (1)$$

2.5. Indoor heat insulation performance measurements

The indoor heat insulation performance of the transparent coatings was measured using a self-developed lamp illumination apparatus (Fig. 1). The apparatus consists of two infrared reflector-type lamps fixed on the support ceilings, a wooden box with four separate chambers and six type K thermocouples connected to a data acquisition system. Details of the device and its working principle are described elsewhere [19–21]. Two thermocouples held by two metal domes were used to measure the illuminated surface temperatures of the test panels, and four thermocouples fixed in the center of four chambers were used to measure the air temperatures inside. The illuminated surface temperatures of a painted sample and an unpainted reference panel, together with the four air temperatures of the chambers, were simultaneously monitored over time.

In the indoor illumination tests below, T_{abR} is the air temperature inside the chamber below the reference panel (denoted by R), T_{auR} is the air temperature inside the chamber above R, T_{abS} is the air temperature inside the chamber below the sample panel painted with a transparent coating (denoted by S), T_{auS} is the air temperature inside the chamber above S, TR is the illuminated surface temperature of R and TS is the illuminated surface temperature of S. Accordingly, the heat insulation effect $\Delta T = T_{abR} - T_{abS}$. (Unless otherwise indicated, identical variable symbols in the figures below have the same meanings).

2.6. Resistivity measurements

The surface resistivity of the transparent heat insulation coatings was measured with a surface resistivity meter (YFT-2006, Hongchang Binjiang electronic instrument Shenzhen Co., Ltd.).

2.7. Artificial accelerated weathering resistance

A Xenon lamp weather resistance test chamber (SN-66, Beijing Beifang LIHUI Test Instrument Equipment Co., Ltd.) was used to evaluate the artificial accelerated weather resistance of the