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Thin film coated energy-efficient glass windows for warm climates

A.M. Al-Shukri

Physics Department, King Fahd University of Petroleum and Minerals, Saudi Arabia
email: alshukri@kfupm.edu.sa

Abstract

The main objective of this work was to develop laboratory-scale versions of (a) multilayer thin film coated energy-efficient glass windows for applications in warm climates. For this purpose a three-layer system of dielectric/metal/dielectric (D/M/D) on glass was used to achieve the above mentioned spectrally selective coatings. The design parameters for optimum performance of D/M/D on glass systems for various dielectrics, such as TiO_2, WO_3, and ZnS, were obtained theoretically. Based on these parameters, D/M/D systems on glass were fabricated. Upon testing these systems, it was concluded that the system with any of the three dielectrics performed well and the efficiencies of the systems with different dielectrics were nearly the same.

Keywords: Thin films; Multilayer energy-efficient; Dielectrics; Warm climates; Heat mirrors

1. Introduction

Over the past 40 years the introduction and development of an important new area of technology in the architectural field has occurred, namely, the use of thin film coatings to enhance the thermal performance of window glazings and to afford a new dimension in the aesthetic aspects of building design. Previously, the glass manufacturers had made significant advances in the thermal area through development of sealed insulating glass and tinted/heat absorbing glasses. However, there were practical limitations in these developments, and serious thought began to be given in the 1950s to the possibilities of using coatings for additional product enhancement. Introductory installations of filmed glass began in the 1960s with the development of large-scale coating facilities, and these were expanded considerably over the last two decades as the merits of coatings began to be appreciated. Most of the applications have been in the commercial area. Now, in view of the growing energy crises, there is widespread interest world over for higher performance products, especially those that more strongly affect the insulating properties of glazings [1–3].

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An energy-efficient window is a device capable of providing lighting and thermal comfort at minimum demand of paid energy (air-conditioning in summer). In a warm climate, when overheating from excessive solar input is a problem, one can obtain energy efficiency by using multilayer thin film-coated glass windows called heat mirrors that are transparent for visible light and reflecting for infrared (IR) solar radiation. A three-layer system of dielectric/metal/dielectric (D/M/D) on a glass substrate could be used as a spectrally selective filter that reflects IR radiation and transmits most of the visible spectrum. The highly reflective metal film (that would otherwise be opaque to the visible light) is sandwiched between the two dielectric layers that act as antireflection coatings for the visible thus increasing the visible transmission. By varying the material and thickness of the three layers, the optical properties of the D/M/D films can be tailored to suit different applications.

Heat mirrors have been constructed by forming dielectric–metal–dielectric layers on glass substrates. For example, TiO_2–Ag–TiO_2 [3,4], ZnS–Ag (or Al)–ZnS [5], ZnS–Ag–ZnS [6], and tin doped indium oxide [7], coatings on glass have been used to fabricate heat mirrors that are energy efficient for cold climates. However, our aim was to fabricate heat mirrors that are energy efficient for warm climates. We intended to fabricate heat mirrors by depositing multilayers such as TiO_2–Ag–TiO_2, ZnS–Ag–ZnS, and WO_3–Ag–WO_3 on glass substrates.

Performance of the heat mirror depends critically on the optical constants and thicknesses of the Ag and the metal oxide films used. Oxide coatings depend heavily upon stoichiometry, impurities and defects in the films [7]. Metal films are very dependent upon nucleation and coalescence phenomena (supersaturation, undercooling, interfacial energy and impurities). In all films the degree of crystallinity, crystal structure and impurities influence optical conductivity. It is common knowledge, however, that films produced by a similar process in different laboratories, or indeed, in different deposition systems of the same laboratory, have different optical constants. This is because different geometry and conditions give rise to different film structures and composition.

Thus, before a multilayer device is fabricated, it follows from above that, knowledge of the optical properties of individual layers is essential. Moreover, by varying the material and thicknesses of the three layers, the optical properties of the dielectric–metal–dielectric films can be tailored to suit different applications. Therefore, optical properties of single films were measured, and a computer code for an optimization of the performance of the heat mirror was developed.

2. Experimental

Thin films were prepared by physical vapor deposition in a vacuum of 10^{-6} mbar, using a Leybold model L560 box coater pumped by a turbomolecular pump onto glass substrates. A tungsten boat was used for evaporation of Ag, while molybdenum boats were used for WO_3 and ZnS. The TiO_2 films were prepared by electron beam evaporation. Purities of the materials used for evaporation were better than 99.9%. In order to produce films with uniform thickness, the substrates were rotated while deposition took place. For monitoring the evaporation process of these films, Leybold Inficon XTC quartz crystal monitor and evaporation controllers were employed. Calibration of the quartz thickness monitor for individual material was achieved by measuring the actual thicknesses of single films by optical methods [8,9]. Normal incidence T and R from films was measured using JASCO V570 spectrophotometer.

Various three-layered systems of D/M/D on glass were fabricated using Ag as a metal layer while for a set of two dielectric layers either ZnS or WO_3 or TiO_2 was used. The three-layered system was fabricated in one go without