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Electrostatic flexible film based smart window: Optical design, performance and residual charge investigation

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Abstract

The authors report the design and performance of a dynamic polymeric window shade (smart window) based on electrostatic flexible film with rolling electrode. The device consists of a transparent glass substrate, a low-E conductive fixed electrode, an insulating dielectric polyimide layer and a coiled spiral conductive layer used as a rolling electrode. The application of a voltage in this device creates an electrostatic force that unrolls the curled film, reducing the intensity of radiation passing through the window. The influence of the dielectric layer thickness on operating voltage at different temperatures has been investigated and agrees with the simulated results. It is shown that the device carries residual charges after 2400 cycles of repeatable extension and retraction testing. Measurement results show that the residual surface potential increased with the thickness of dielectric layers as well as the temperature in dynamic polymeric window shade. The possible residual charge storage generation mechanism, namely, ionization based on modified Panchen law, is introduced in the paper, which shows good agreement with experimental results at higher dielectric layer thickness.

Keywords: Smart window; Electrostatic force; Residual charges; Modified Paschen Law

1. Introduction

Glass windows, skylight, doors, and the like which are used in building and other structures are known to waste large amounts of energy. A new class of window called "smart window" has attracted recent attention because of its potential to reduce the energy consumption in buildings. The smart window is a device that can change light transmission by responding to external stimuli such as voltage, light, and heat.

Over the past twenty years, numerous devices, including electrochromic (Granqvist et al., 1998 and Kullman et al., 2000), photochromic (Mir and Masoud, 2012 and Palgrave and Parkin, 2004), and thermochromic (Nitz and Hartwig, 2005) devices have been developed. The electrochromic smart window, for example, uses an insulated glass (IG) window that incorporates one or more functional electronic layers between the two or more sheets of glass of the IG window. The electronic layers are transparent in the absence of an applied voltage. When the voltage is applied, the particles change their orientation, which allows heat and radiation to pass through. The materials used are typically liquid crystal layers, electrophoretic layers and electrochromic layers. However, IG windows that incorporate functional electronic layers are difficult and costly to

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manufacture, have a questionable operating life, undesirable operating temperatures and very slow response times. This issue is likely to become even more serious as the size of devices increase to cover large window. It is therefore desirable to reduce the passage of heat and radiation through a window that avoids the tradeoffs and drawbacks of the above known approaches and provides a manufacturing process for such windows that can be used by traditional manufacturers of window glass, thereby adding another economic advantage to the manufacture of such windows.

Unlike the devices described in (Granqvist et al., 1998 and Kullman et al., 2000 and Mir and Masoud, 2012 and Palgrave and Parkin, 2004 and Nitz and Hartwig, 2005), the latest design of smart window (dynamic polymeric window shade) described here does not require special design for the electronic layers. The investigated dynamic polymeric window shade (DPWS) device is mainly composed of low-E coated tempered glass, coiled spiral conductive layer, dielectric coated low E glass via slot die method at nTact, TX, USA and an electro controller. Comparing with initial invention of DPWS device (Schlam and Slater, 2010) that needs to laminate dielectric film with adhesive on low E glass, the latest dielectric substrate design in DPWS prevents the dielectric layer shrink and it is easy to obtain the variable thickness. When a voltage is applied between two electrodes in the device, an electrostatic attraction is established. As the electrostatic force overcomes the device rigidity, the flexible end of the coiled spiral conductive layer begins to unroll, moving to the point in contact with bottom stop, and subsequently establishing a new layer to reduce the intensity of radiation passing through the window. When the roll extends or retracts as a window shade in the system, the residual charge storage will be formed to possibly impact the shade's behavior in long term applications, like uneven extension or retraction speed. Considering the potential disadvantage in DPWS by charge storage accumulation on dielectric surface, it is necessary to study the residual charge generation mechanism and eliminate the charge storage to develop a viable DPWS technology.

The way in which residual charge is built-up on the surface of an insulator, and the mechanism by which it spreads in different discharge system (Baytekin et al., 2013 and Gaur et al., 2010 and Kishi et al., 2009), can be explained as charge storage under uniform electric field in Dielectric Barrier Discharge (DBD) system (Sessler, 1987 and Jones, 2013). The DBD system is built by two parallel electrodes which were separated by an insulating dielectric barrier with an air gap. The residual charge on the dielectric surface in DBD system has been extensively investigated by a lot of researchers. The charge storage is typically formed on dielectric surface by ionization in air gap, polarization and charge injection also contributed to form residue charge as temperature increases. The ionization in air gap of DBD occurs on the dielectrics in air with normal atmospheric conditions and results from Townsend electron avalanches. The higher the intensity of the electric field, the larger the fraction of streamers developed from Townsend avalanches, namely, overvoltage above Paschen breakdown value cause those streamers. The Pashchen Law was extensively applied to uniform electric fields, and modified Paschen Law was also developed and widely used in the case of asymmetric electric fields or quasi-homogeneous electric fields (Hoshi and Yoshida, 2009 and Ficker, 2003). For example, laser-triggered discharge (LTD) under the air breakdown in asymmetric electric field was also studied, the researchers introduced a virtual gas with Npd ($N = 2.8$–3) instead of classic pd in Paschen's Law to explain the LTD phenomenon (Hoshi and Yoshida, 2009). In this paper, a configuration of a microscopic wedge-shaped discharge gap, namely, nip area between the coiled spiral conductive roll with polyimide surface in DPWS with the electrical discharge issue is investigated with the assumption of quasi-homogeneous electric field.

The present study of charge storage in new design of DPWS device is divided into two parts. The first part deals with the operating voltage dependence on the thickness of coated dielectric polyimide. The second part focus on the residual charged stored in DPWS device. The surface potential is first measured with different dielectric layers thickness at 25 °C and 85 °C respectively and then the modified Paschen's Law and a surface potential factor are introduced to evaluate how the thickness of the dielectric polyimide impacts the electrical discharge buildup in the system.

2. Experiment

The investigated DPWS device is composed of low-E coated tempered glass, coiled spiral conductive layer, dielectric layer, low-E coated substrate and an electro controller. The cross section of a DPWS cell is shown in Fig. 1. The first and second low-E coated glass panes were spaced apart facing each other using plastic spacers. The bottom transparent low-E conductive layer served as a fixed position electrode. A dielectric polyimide layer was coated atop the conductive layer by nTact, Texas, US. Three layer composite films of ITO (60 Ω/□), Polyethylene Naphthalate

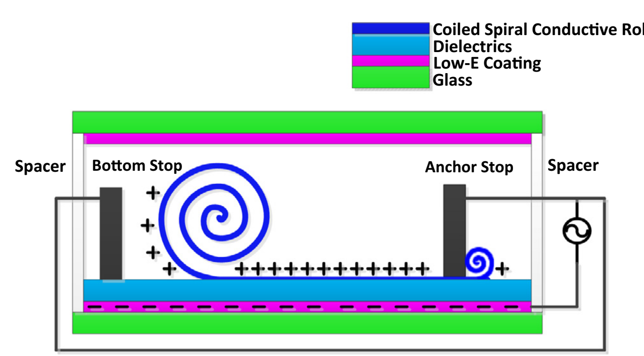

Fig. 1. Schematic cross-sectional view of latest design of DPWS device.