Energy-saving light-control film that automatically controls sunlight transmission in summer and winter

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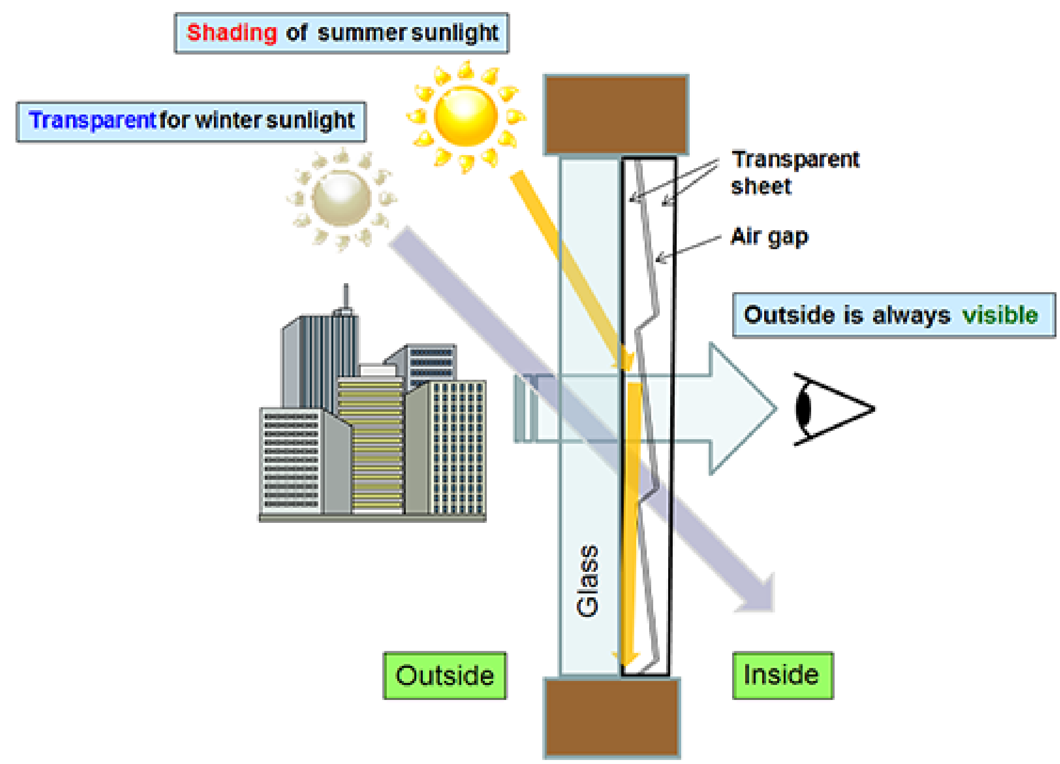

Structure and function of the automatic light-control film

The National Institute of Advanced Industrial Science and Technology (AIST; President: Ryoji Chubachi) and Sumitomo Chemical Co., Ltd. (Sumitomo Chemical; President: Masakazu Tokura) have developed a novel energy-saving, automatic light-control film. This is the achievement of a research group consisting of Kazuki Yoshimura (Leader), Energy Control Thin Film Group, the Materials Research Institute for Sustainable Development (Director: Mamoru Nakamura) of AIST, and Basic Chemicals Research Laboratory (Director: Yoshiaki Takeuchi) of Sumitomo Chemical.

This light-control film is based on the fact that there is a change in the incident angle of sunlight between summer and winter. The film blocks sunlight in summer by using total reflection but transmits it in winter. Unlike other light-control films, the film can control the transmission of direct sunlight while always allowing people inside to see the view outside the window. Without any inherent changes, the film automatically controls light transmission depending on the season. Light transmission can be controlled simply by attaching the film to an existing window. Therefore, if the film can be efficiently produced, it will save energy by substantially reducing cooling and heating loads.

This light-control film will be exhibited in Sumitomo Chemical's booth at the Automotive Engineering Exposition 2013, to be held from May 22 to 24, 2013, at Pacifico Yokohama, Yokohama, Kanagawa Prefecture.

Social Background of Research

AIST has been developing resource-saving, environment-improving building materials that help reduce CO2 emissions from the use of energy at home and at work. Cooling and heating account for about 30% of energy use at home and at work, and windows are building components that substantially affect energy use for these purposes. The purpose of a window is to let light in. Normal window glass transmits heat, as well as visible light, and deteriorates the heat insulation of buildings. Therefore, improving the heat insulation of windows alone substantially saves energy. In recent years, double-pane glass and low-E glass (eco glass) with high insulating properties have become widely used. Light-control glass itself controls incoming and outgoing light and heat to improve energy efficiency by effectively blocking sunlight, in addition to heat insulation.

The glass is required to meet two conflicting requirements: in summer, it needs to block as much sunlight as possible to reduce the cooling load while still letting in some light from the view outside the window. To meet these requirements, energy-saving light-control glass has been commercialized; such types of glass include low-emissivity glass that transmits visible light and reflects near-infrared light, and electrochromic glass that can switch between blocking and transparent states.

There is a seasonal change in the incident angle of sunlight on a window. Sunlight comes at a larger incident angle in summer. If a window can block only light with a large incident angle, it would be possible to block direct sunlight and let in light from the view outside the window. However, glasses and films with this type of light-control function had not been developed so far.

History of Research

AIST believed that glass could be developed to control light transmission according to the incident angle of sunlight by utilizing total reflection at the interface between two transparent media. It has developed a ray-tracing program specifically for analyzing the reflection and transmission of sunlight to optimize the structure of a light-control film. It has found the structure of the film that can block as much direct sunlight as possible in summer while letting in as much light from the view outside as possible.

The fabrication method of a light-control film with this structure was the key to the commercialization of the film. Sumitomo Chemical, which has strong capabilities in technology for the fabrication of transparent films, developed the fabrication process, and the researchers developed a prototype total-reflection light-control film.

Details of Research

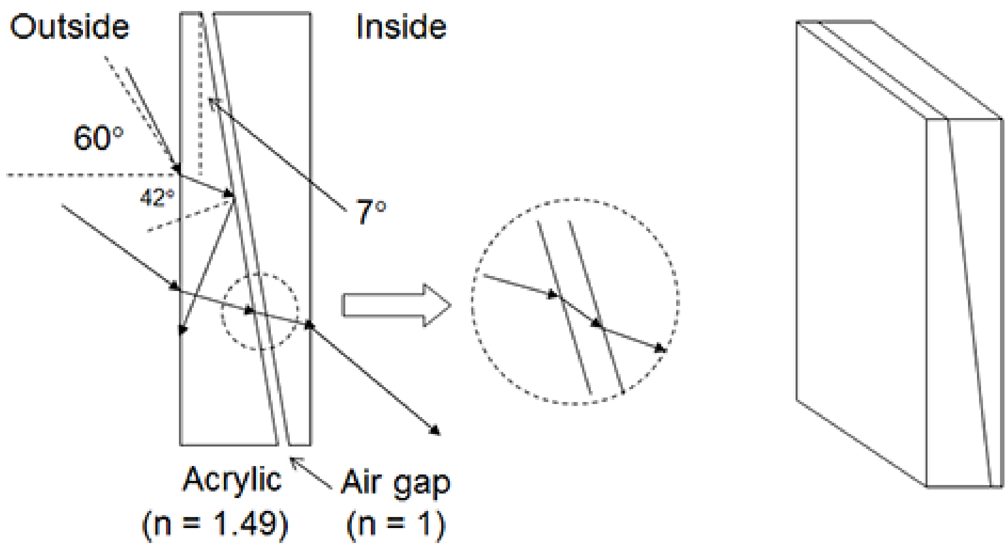

Figure 1 : Basic structure of the total-reflection light-control film

Figure 1 shows the basic structure of the developed total-reflection light-control film. The film uses a transparent medium with the front and back surfaces not parallel to each other. For example, when an acrylic material (refractive index n = 1.49) is used as the transparent medium, with the back surface angled at 7°, and light comes from air onto the surface of the medium at an incident angle larger than 60°, the light refracted in the medium is incident on the back surface at an angle larger than the critical angle and total reflection occurs. However, if a transparent film with non-parallel surfaces is used as a window pane, the light from the view outside of the window is refracted and the view looks suspended in air. To prevent this, another film with the same cross-section is layered upside down to the first film. As a result, the refractions of the light passing through the films cancel out and the view looks the same as with a single pane of clear glass. A very thin layer of air is automatically formed by layering the two films.

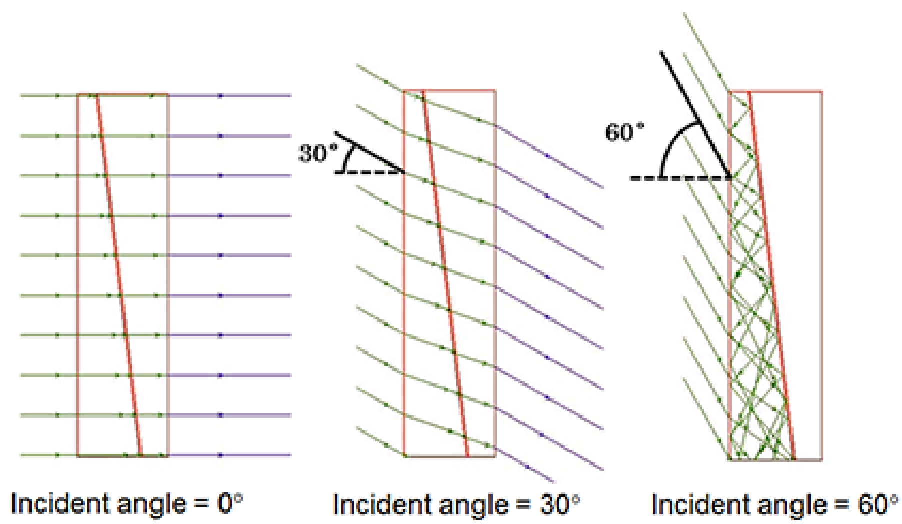

Figure 2 : Light-transmission characteristics of the total-reflection light-control film (single step)

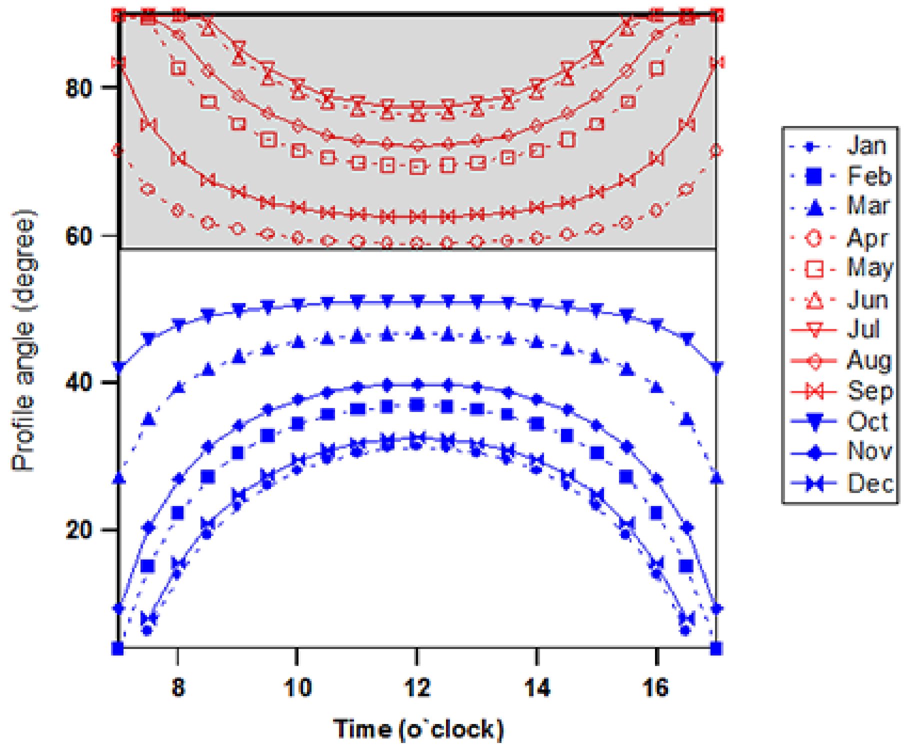

Figure 3 : Change in profile angle on a south-facing window (in Nagoya, at 35.1°N) In the morning and evening in summer, the sun is on the north side of the room and does not hit the south side.

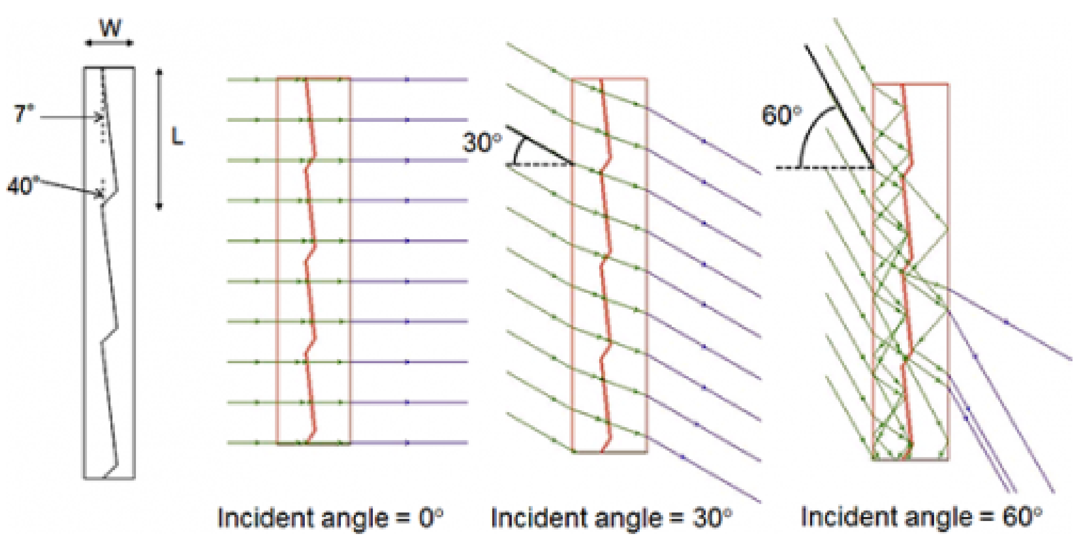

Figure 4 : Structure of a multi-step total-reflection light-control film and light-

transmission characteristics of total-reflection light-control glass with four steps

However, a film with the structure in Fig. 2 cannot be used on window glass without modification. If the film were 1 m square, its thickness would be as much as about 10 cm. However, if the cross-section is similar to that in Fig. 1, the incident angle dependence of light transmission remains unchanged. Therefore, as shown in Fig. 4, a multi-step light-control film with similar total reflection characteristics can be made by shortening the vertical length of the step and providing more steps. If the length L of one step is 10 cm, the width W can be 1 cm. If L is 1 cm, W can be 1 mm. A light-control film with such dimensions can be attached to window glass to achieve similar total reflection characteristics to a single-step film. If the angle of the bottom of a step from the vertical is less than 42°, the light in the horizontal direction passes through and the view looks the same as with transparent glass.

An investigation of the light-transmission characteristics of a multi-step total-reflection light-control film shows that the incident light exits at the same angle when the incident angle is smaller than 60°, as with the single-step film. When the incident angle is 60° or larger, total reflection occurs. However, unlike with the single-step film, the light is not blocked completely; instead, about 75% is blocked. Figure 5 shows a clear acrylic model of the light-control film with such a structure. When the incident angle of sunlight is 60° or larger, shadows are created.

All of these sunlight-transmission characteristics are those for direct sunlight. In real-life applications, indirect as well as direct sunlight must be considered. The research group ran a field test to determine the light-blocking performance of the total-reflection film in a real-life environment.

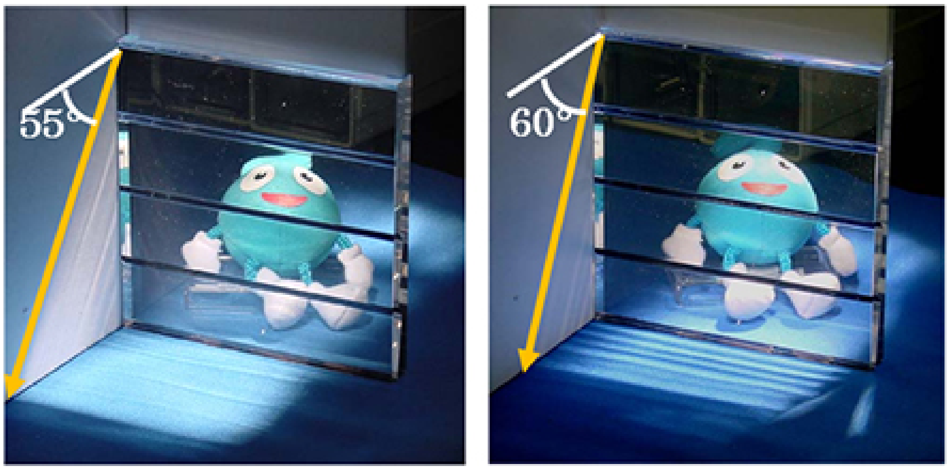

Figure 5 : Acrylic model of a total-reflection light-control film Although the model is transparent, shadows are created because a considerable amount of light is blocked when the incident angle of sunlight is 60° or larger.

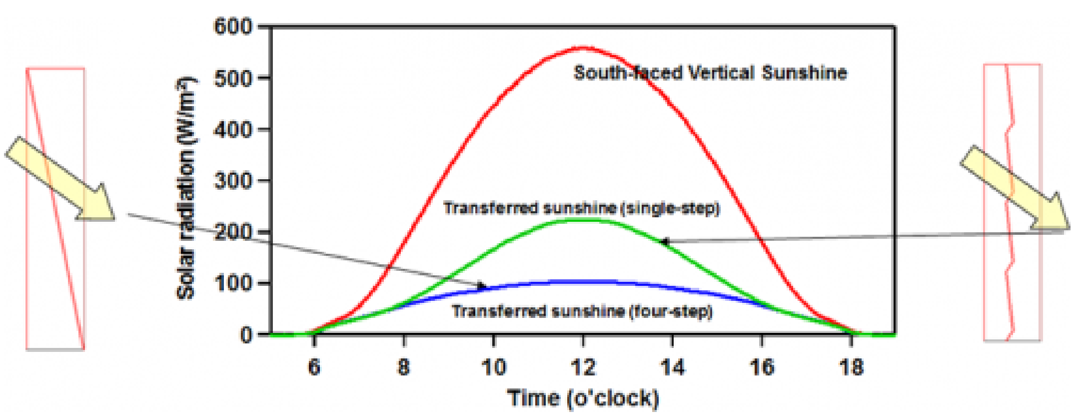

Figure 6 : Sunlight transmission through total-reflection films attached to window glass, as measured in a real-life situation

Figure 6 shows the time dependence of the amount of sunlight transmitted through single- and four-step acrylic total-reflection light-control films (12 × 12 cm) attached to a south-facing window. The measurements were made in September and therefore show the performance of the films in summer. The single-step total-reflection light-control film blocked almost all direct sunlight and transmitted only indirect sunlight. The sunlight transmittance was determined by integrating the intensity of the transmitted direct and indirect sunlight and dividing the total amount of sunlight transmitted in one day by the total amount of vertical direct sunlight incident on a south-facing surface. The sunlight transmittance is 23% for the single-step total-reflection light-control film and 38% for the four-step total-reflection light-control film. The sunlight transmittance of the four-step total-reflection light-control film is 80% in winter, indicating that the four-step film can automatically block about 40% of solar energy from passing through it.

Measurements of light-control characteristics were made on a prototype total-reflection light-control film. The film exhibited the ability to automatically control light transmission before and after the vernal equinox. Although this ability has not yet reached the theoretically predicted level, it has been demonstrated for the first time that a light-control film with such a structure can be realized.

Future Plans

To commercialize the total-reflection light-control film, the structure shown in Fig. 4 needs to be fabricated with precision at a fairly short pitch (i.e. step length) and in an efficient manner. The research group is developing an efficient film-fabrication process based on the continuous formation of molten thermoplastic resin using a precision mold.

With the goal of commercialization within a few years, the fabrication process will be improved by Sumitomo Chemical to improve its light-blocking performance and a better method for applying the film to window glass will be developed.