Large Area Electrochromic Safety Glass; Switching Behaviour and Transmission Control of Solar Radiation

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Keywords

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Abstract

Large area scaling of electrochromic glass samples can be reached only with so called "all solid states" types ,which show an inner adhesion. A very advantageous concept is the EC safety glass consisting of two coated K-glass panes which are laminated together with an ion-conducting PVB film. It has a safety glass construction and shows similar mechanical properties. Because of its inner adhesion scaling up to large areas becomes possible. The chosen electrochromic system consists of two complementary electrochromic layers, which enables important improvements in optical switching data compared to other systems. The electrochromic system works inside of the laminated double pane and is very resistant against environmental attacks. Construction as well as detailed optical switching behaviour and results of long term solar radiation control in facades tests were presented.

1. Introduction

Electrochromism can be defined as the change of the optical properties of a material due to the electrochemical alteration of its oxidation state. It can be used for the construction of devices with user controllable optical transmittance. Other techniques which can be utilized for this purpose are e.g. photochromism, gasochromism, thermochromism and electro-optical field effects in liquid crystals or suspended particles [1]. Electrochromism is the most promising of these technologies.

Since the discovery of electrochromic effects in thin films of tungsten oxide by Deb [2] a multitude of device concepts for its practical utilization in applications such as smart windows have been proposed [1, 3 - 6]. However, after more than 30 years of intensive research and development still no reliable, large area scalable product has entered the market. The reason for this lies in the drawbacks of recent device concepts. Often the use of liquid or sol gel electrolytes prevents upscaling to areas of some square meters. Other drawbacks are high production costs, too low switching speed and range and lack of long term durability under severe environmental conditions.

In the last few years Gesimat together with its cooperation partners has developed a new concept for an all solid state electrochromic glazing [7] with laminated safety glass features.

2. Construction of electrochromic (EC) safety glass

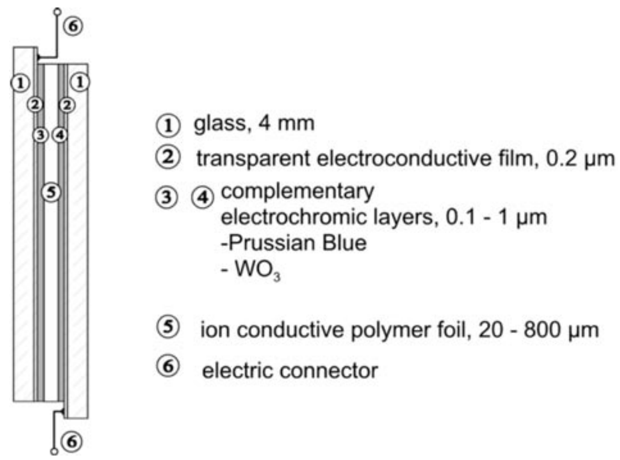
Figure 1 shows the scheme of EC safety glass. Two glass panes (1) with a transparent conductive film (2) were coated by electrodeposition with complementary electrochromic layers (3,4). The coated glass panes were laminated together with an ion conducting PVB interlayer (5) by use of safety glass production techniques (pre-niproller, autoclave). Sealing and application of electrical connecting (6) complete the preparation of electrochromic safety glass. Because of its inner adhesion due to lamination with a modified PVB film the upscaling to large areas becomes possible.

There are some important differences compared to other EC-concepts:

- the use of two complementary inorganic electrochromic layers,
- a large area electrodeposition process for electrochromic materials,
- an ion-conducting PVB interlayer as solid polymer electrolyte and
- the use of state-of-the-art laminated safety glass production technologies for the production of EC safety glass

Figure 1

Schematic illustration of the EC safety glass construction.



For more details on construction and production of EC safety glass see references [7-9].

3. Solar transmittance

Due to electrical switching EC samples show a strong change of transmittance in the solar spectral region (280 to 2500nm). A good characterization method for optical changes during switching are time dependent transmittance measurements. The spectral reflectance can be neglected, because there are only small changes during switching [8, 10]. Measurements were done using UV-VIS-NIR spectrophotometer (Perkin-Elmer Lambda 19). The switching processes were interrupted in 15 or 30 seconds steps for the measurements of time dependent transmittance. The light transmittance τ_V and the solar direct transmittance τ_e were calculated according to the European standard EN 410 using the spectrometer data. Figure 2 and 3 show the change of transmittance spectra of the electrochromic glass samples during colouring (figure 2) and bleaching (figure 3) with 1.4V. The spectrum indicated with 0 sec in figure 2 shows the transmittance in fully bleached state, followed by the transmittance spectra at subsequent colouring steps. The full coloured state is reached after 300 seconds.

In figure 3 the corresponding transmittance spectra during bleaching with 1.4 V of reversed polarity are depicted. The spectrum indicated with 0 sec here shows the maximum coloured state. It can be recognised that the fully bleached state is earlier reached after about 180 sec. For a full colouring step 300 sec are necessary.

In general, switching time strongly depends on size of the EC glass. Switching becomes slower as the size of the glazing rises. Therefore, the switching times given above are valid for the size of the samples: 10 cm x 30 cm.

The light transmittance τ_V and the solar direct transmittance τ_e are also indicated in figure 2 and 3 for the fully bleached and coloured states and for one intermediate state. The chosen electrochromic system enables the electrochromic safety glass to realize a switching range of the light transmittance τ_V between about 0.08 in coloured and 0.77 in fully bleached state. This corresponds to a photopic transmittance ratio (PTR) of 9.63:1. The solar direct transmittance τ_e can be varied between about 0.06 in coloured and 0.56 in fully bleached state.

The very high values for the light transmittance τ_V and solar direct transmittance τ_e in the bleached state are due to the use of two electrochromic materials (tungsten oxide and Prussian Blue) which both have bleached states with very high light and solar transmittance. This is in contrast to other systems [11] in which only one electrochromic layer is combined with an ion storage layer as counter-electrode. Such a switching system achieves only moderate light and solar direct transmittance in the bleached and relatively high transmittance in the coloured state. Of course, the quality of the ion-conducting PVB sheet is also important for the good dynamic optical data of the system presented here.

In figure 4 the values for τ_V and τ_e during switching with 1.4 V time intervals of 30 sec are shown. This plot shows obviously that the bleaching process is much faster than colouring. However, also during colouring in the first part of the switching time the largest change in τ_V and τ_e are found, e.g. in the first 60 sec of colouring τ_V goes down from 0.77 to 0.34 whereas in the next 240 sec it decreases only from 0.34 to 0.082.

4. Solar transmission control in facade test

The practical use of EC-windows was investigated in two rooms of an office building. Two EC-windows (size 1.2 m x 0.8 m and 1.2 m x 0.5 m) were installed in one of the rooms whereas the other room was equipped with two conventional double glazing windows with the same sizes. The EC-windows consist of the described electrochromic safety glass, a 10 mm gap filled with air and an interior low emissivity

Figure 2

Change of spectral transmittance during colouring.

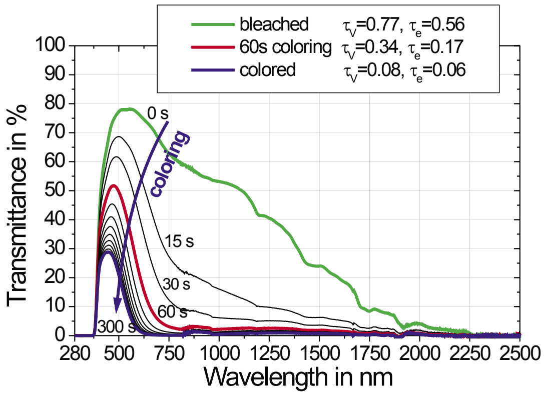


Figure 3

Change of spectral transmittance during bleaching.

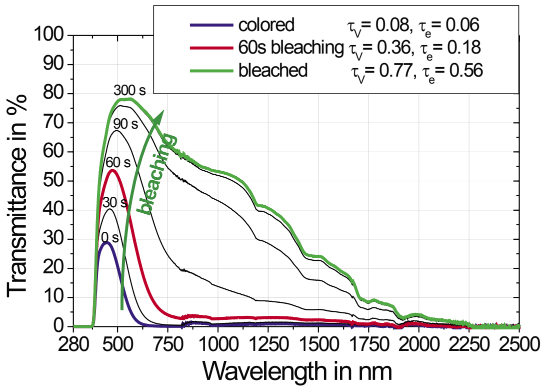


Figure 4

Change of the light transmittance τ_V and the solar direct transmittance τ_e during switching.

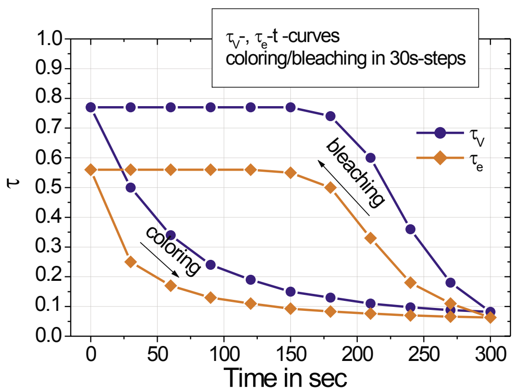
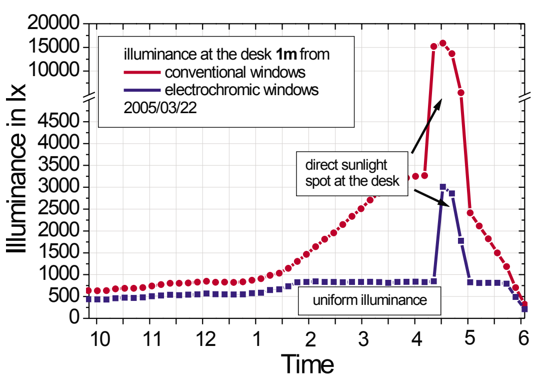


Figure 5

Comparison of illuminance between conventional windows and electrochromic windows with automatic adjustment of transparency controlled by illuminance at the desk.



pane. All windows face in a westward direction. The walls and the ceilings of the rooms are white and the floor is dark. For the extensive use of daylight in buildings and offices it is required to adjust the very unsteady sunlight to the user's demand. There are limit values concerning the illuminance and the luminance on workplaces recommended in some standards. The recommended minimum value for the illuminance is 500 lx. Some more illuminance is often also accepted, but 17,000 lx, which are reached with conventional windows, is too bright and causes glare (Fig. 5). In contrast to that there is a good uniformity of the illuminance at the desk with the automatic adjustment of the transparency of the EC-windows except in the time of the direct sunlight spot at the desk.

The recommended maximum value for the mean luminance of surfaces, which could reflect on a screen and causes glare and disturbing reflections is 1,000 cd/m². False-coloured luminance pictures, made by a calibrated luminance camera, were used for the evaluation of glare on the windows and on the walls besides (Fig. 6). There were measured more than 6,000 cd/m² on the wall for the light spot of the bleached window, whose transparency is similar to a conventional window. In contrast to that there were measured only 1,825 cd/m² for the coloured window. This wide reduction of the luminance is sufficient in most cases, because some more luminance on few surfaces (windows, light spot) should be accepted for the benefit of sufficient natural daylighting and illuminance. A complete prevention of the glare is difficult in most cases, when the altitude of the sun is low and the illuminance in the room shall not fall down below the minimum value.

Work stations should be well placed near the window with screens and displays which face towards walls with low luminance. In that case the investigation has shown, that electrochromic glazing make additional protection against the sun nearly unnecessary. Automatic adjustment of the windows transparency controlled by the indoor illuminance was tested and is recommended for comfortable adjustment of the transmittance to the desired illuminance.

5. Durability tests of EC safety glass

5.1. Accelerated aging tests

For facade applications a life time of EC windows of about 20 years is expected. Observations and measurements have shown that some performance parameters can deteriorate over time by the influence of weathering factors. Important stress factors for EC windows are solar radiation (especially the UV part), high temperature because of heating, thermal shock (day/night), high humidity, shock rain, and last but not least electrochemical stress due to

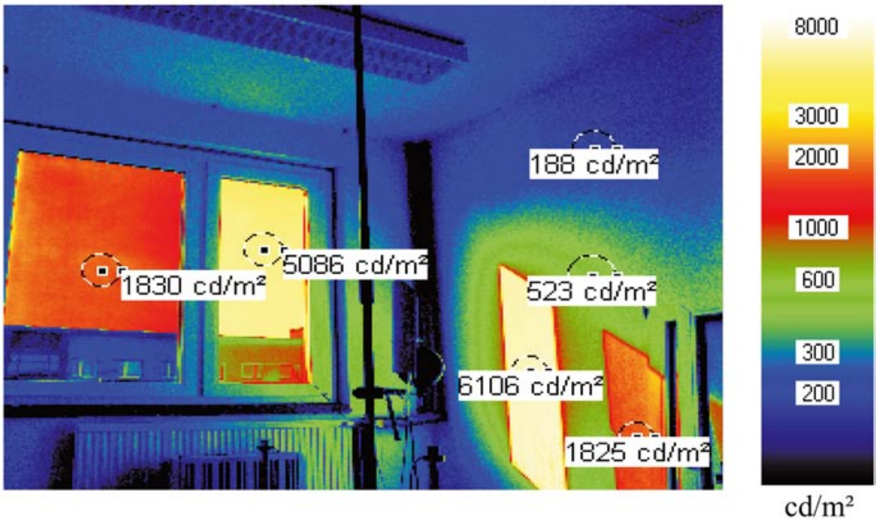
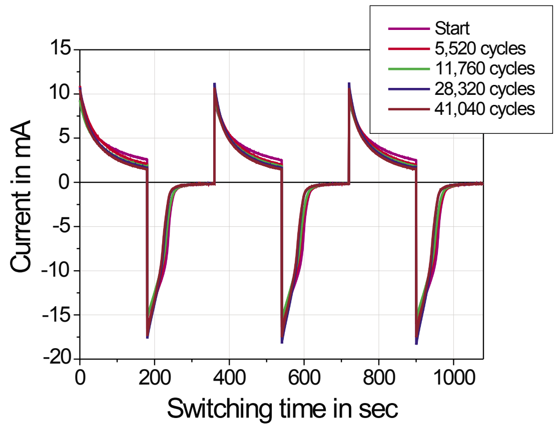


Figure 6:

Luminance of one coloured and one bleached window during low sun altitude on 23th of March 2005, 3:15 PM

Figure 7

Cycling durability of a EC safety glass sample, current – time relationships



switching. Because it is impractical to wait for results from real time testing, durability of EC windows is tested by accelerated aging tests. All tests were done under electrical switching of the elements. The following important tests were performed:

- 40,000 times alternated colouring and bleaching at room temperature (simulating a life time more than 20 years)
- 35,000 times alternated colouring and bleaching while 144 times thermal cycling between –25 to +80°C, duration of thermal aging 144 days.
- 10,000 times alternated colouring and bleaching while exposure with simulated 1.5 AM solar irradiance (1,000W/m²) in a temperature-controlled environmental chamber (45-50°C).

The electrical switching behaviour of EC samples can be described with current - time relationships [9]. Any aging effects or degradations result in a change of electrical switching characteristic quite earlier than they are visible with human eye. We recorded the current – time relationships of 3 colouring-bleaching cycles of a EC sample which was permanently cycled between coloured and bleached state up to 40,000 cycles. Figure 7 shows corresponding current – time curves before, during and at the end of the test. No significant changes were observed which indicate aging or degradation. The switched electrical charge is about 80% after the tests compared to the starting value.

Alternated colouring and bleaching of EC samples were also performed under thermal cycling stress. Figure 9 shows the corresponding temperature profile. During the process 3 temperature stages of -25°C, +30°C and +80°C were hold for 4 hours. With temperature change duration of 4 h the whole process takes one day. Best constructed samples passed the test without any visible change or damage. In 144 days 34,560 colouring/ bleaching cycles were performed. To control thermal aging behaviour the test was interrupted at certain times and spectral transmittance in UV/VIS/NIR-region of samples was measured for the fully bleached and coloured states. Figure 8 shows the course of calculated light transmittance τ_v and solar direct transmittance τ_e in dependence of duration of thermal aging and number of electrical switchings. There is a small deterioration of switching range; τ_v, τ_e

is slightly increased for the coloured and slightly decreased for the bleached state. At the end of the test switching ranges of 0.55 for light transmittance τ_v and 0.39 for solar direct transmittance τ_e are very good values compared to other EC-glazing systems [11].

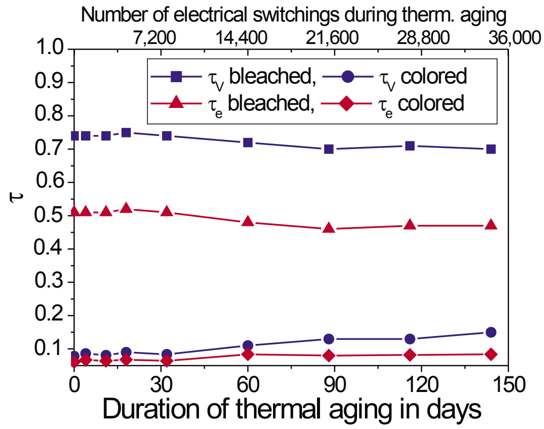


Figure 8

Change of light transmittance τ_v and solar direct transmittance τ_e by electrical switching at thermal aging

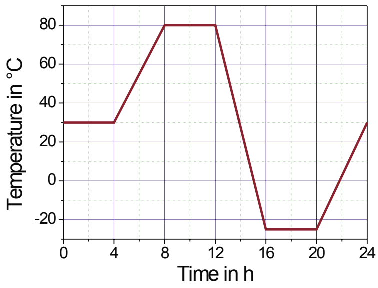


Figure 9

Temperature profile of thermal aging

Very important for future architectural application are aging tests under solar irradiation. According to our experience solar irradiation tests are the hardest weathering tests for EC window systems.

For solar radiation tests a special exposing chamber was built with a metal halide bulb which provides an excellent match of an AM 1.5 solar spectrum with illumination power of 1,000 W/m². EC-samples were exposed while continuous electrical switching between fully coloured and bleached states. Irradiation tests were performed up to switching 10,000 cycles. For test sample evaluation both electrical and optical parameters were measured before and after the tests.

First samples did not pass the test. Visible degradations (decolourations, bubbles, delaminations) were observed. A small improvement was achieved by changes in sample construction. Further steps were done by optimising the chemical composition of the PVB interlayer but the final goal passing the test was achieved by applying a special conformed electrical switching procedure. Rigid switching with rectangular or trapezoidal voltage profiles [12] under illumination results in earlier degradation.

Figures 10 and 11 show the performance parameters for the latest EC-samples which passed the test. No visible changes or degradation effects appeared. The changes in light transmittance τ_v and solar direct transmittance τ_e (fig. 10) are below 10%. Also the electrical switching behaviour indicates no significant changes due to the test. The switched electrical charges decrease only slightly by 7% to 93% at the end of the test (fig.11).

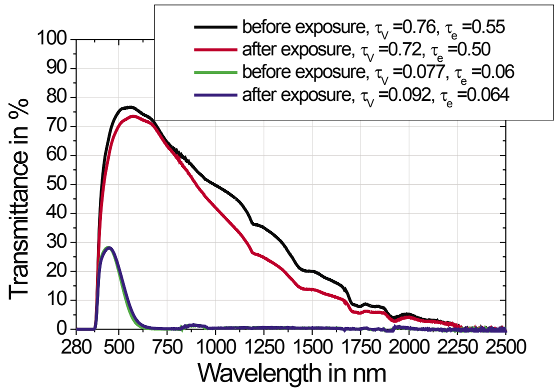


Figure 10

Spectral Transmittance for fully bleached and coloured state of a EC sample before and after 10,000 switching cycles under exposure with AM 1.5 simulated solar irradiation

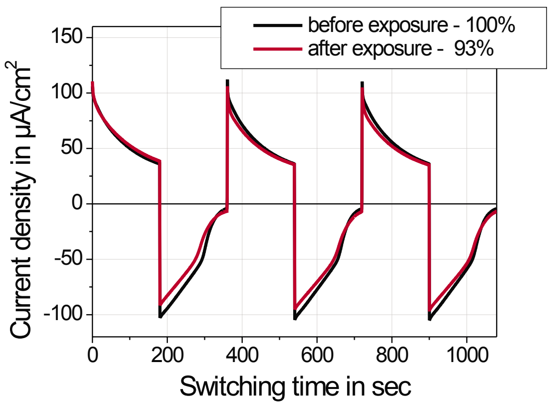


Figure 11

Current density - time relationships of a EC sample before and after 10,000 switching cycles while exposure with AM 1.5 simulated solar irradiation

Table 1

Laminated safety glass test results with ion-conducting PVB interlayers.

Safety glass tests	Test value	Test value	Typical value
CST F/Sn	14.2 N/mm²	8.11 N/mm²	8 - 20 N/mm²
Pummel F/F	6-7	7-8	6-10
Pummel Sn/Sn	8-10	8-9	6-10
Foil-type	ion conducting PVB	ion conducting PVB	standard PVB
Test date	2003-12-12	2004-09-22	

5.2. Safety glass tests

In table 1 some selected results from two safety glass tests with ion conducting PVB films are compared with typical test results using standard PVB interlayer. In these experiments two types of ion-conducting PVB film were laminated with uncoated glass (F… fire side; Sn… tin side) to examine if this newly developed PVB interlayer can pass laminated safety glass tests. These tests are the compressive shear test (CST) and the Pummel test [13]. The test values of both ion-conducting PVB types are within the typical limits of laminated safety glass produced with conventional PVB films.

Summary

Construction, solar optical properties and durability tests of a new developed electrochromic safety glass were presented. This innovation is the result of a long term research and development of the company Gesimat in cooperation with partners [7]. The focus was set on the development of a new laminated electrochromic glazing by using low cost technologies as well as state-of-the-art processes with materials and processes which are compatible with the glass processing industry. The resulting new EC safety glass and fabrication concept therefore offers the possibility for a cost effective production of large area electrochromic glazing with high transmission contrast ratio and long term stability in the near future. The product construction is actually conformed to architectural application but also other uses are like automotive or optoelectronic adaptations are possible. The market entrance for Europe is scheduled for the next years, for other regions potential glass partners are welcome.

Acknowledgements

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