Solar Optical Properties and Daylight Potential of Electrochromic Windows

T. Häusler[1], U. Fischer[1], M. Rottmann[2], A. Kraft[2], K.-H. Heckner[2]
[1]Brandenburg University of Technology Cottbus, Department of Applied Physics, Postbox 101344, 03013 Cottbus, Germany, tobias.haeusler@tu-cottbus.de
[2]Gesimat GmbH, Koepenicker Str. 325, 12555 Berlin, Germany, info@gesimat.de

1. Introduction

Modern buildings with large area glazing require not only a low heat loss in winter (low U-value), but also protection against overheating and sun glare in summer (low g-value) even in moderate climatic zones. However, a high g-value is necessary during winter months to realize solar energy gains. Because of the possibility of user controlled or automatic change of the optical properties, electrochromic (EC) windows can match very well these demands and can guarantee adequate daylight levels on workplaces. Large energy savings up to 50 % due to lowering of the climatisation costs can be realized [1].

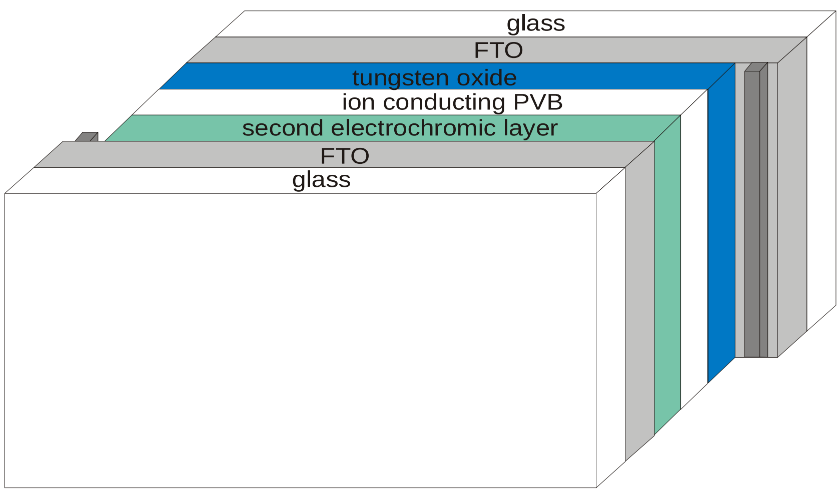

Fig.1:Scheme of the construction of electrochromic glazing with ion conducting PVB-foil

A new electrochromic system (Fig. 1) consists of two K-glass panes, coated with FTO (fluorine-doped tin oxide), which are laminated together by an ion-conducting PVB (polyvinyl butyral)-foil, according to laminated safety glass technique. The two K-glass panes are secondly coated with complementary electrochromic layers. One layer is usually tungsten trioxide (WO_3), the other can be an electrochromic inorganic complex compound (e.g. Prussian Blue PB: $[FeIIIFeII(CN)_6]^-$) or a polymeric layer system (e.g. Polyaniline, Polythiophene). The fact that a complementary electrochromic system is used, is a big advance. The difference in the transmittance between the bleached and the colored state is much bigger and the coloration rate is faster in comparison to existing electrochromic systems with only one electrochromic film and a so-called ion-storage layer. The system was developed by GESIMAT and partners [2].

2. Solar optical properties

Performance parameters such as the visible light and solar transmittance at different tinted states, the reflectance, the switching time for bleaching and coloring and the durability and reliability of the glazings were investigated. These investigations on many different composed samples of electrochromic glasses are part of the development and improvement of the system for a projected production of durable electrochromic windows. The solar transmittance curves in the wavelength range of the solar radiation at 20 °C were measured using a UV-VIS-NIR spectrometer. The bleaching and coloring processes were interrupted every 30 seconds for about 6 minutes for measuring the time-dependent transmittance. The solar transmittance T_{solar}, as well as the visible transmittance T_{vis}, were derived from the spectrometer data according to the European standard EN 410. One of the best of the investigated samples can switch the visible light transmittance from up to 8 % at the colored to 77 % at the bleached state.

The visible transmittance is important for lighting whereas the solar transmittance determines the energy saving properties. Very good values for the photopic transmittance ratio (PTR = $T_{vis\text{-}bleached}/T_{vis\text{-}colored}$) were achieved, which is up to 9:1 due to the use of two complementary electrochromic layers which both take part in the desired light regulating effect of the investigated test-samples (Fig. 2). The switching range for other systems with only one electrochromic layer is usually lower, with a PTR of about 3.5:1. Short switching times for full bleaching and coloring of a sample with a size of (0.30 × 0.10) m² were measured (Fig. 3). The switching time depends on the construction of the electrochromic system, the windows area and the temperature of the glazing. For existent EC-windows with an area of 1 m² the switching time for a complete change from the fully bleached to the fully colored state or vice versa is in the range of a few minutes.

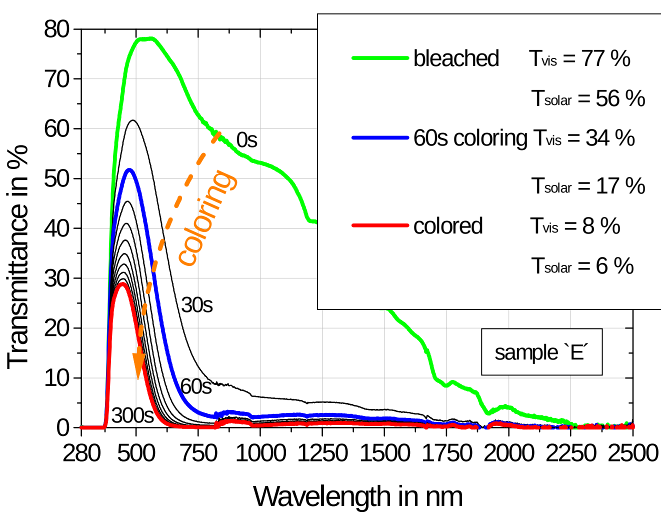

Fig. 2: Transmittance during coloring

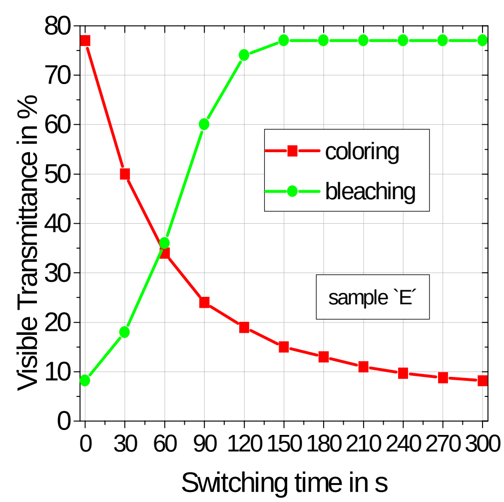

Fig. 3: Coloring and bleaching time

Electrochromic glazings for architectural applications should reach a lifetime of 20 years or more with good performance parameters. The assessment of their durability and reliability is possible by means of forced environmental stress which could cause degradation and failure. A number of accelerated aging tests have been discussed during the last years [3]. Many different samples of the electrochromic glazings made by Gesimat were investigated by several aging tests. During the tests the samples cycle continuously between the bleached and colored states or are only in the bleached state or only in the colored state and are at the same time subjected to different temperature conditions or to simulated solar radiation. The temperature stress used consists of one temperature cycle per day with temperature stages of 30 °C, 80 °C and –25 °C, each for 4 hours. In response to the results of the aging test the details of the composition of the ion conducting polymer foil and the thickness of the electrochromic layers were modified and optimized. With optimized samples good results for very hard conditions of up to 144 temperature cycles and simultaneous up to 34,560 bleaching/coloring cycles were achieved (Fig. 4). Due to first experiences on the expected number of daily bleaching/coloring cycles in a test room with electrochromic windows, this high number of bleaching/coloring cycles should be sufficient during a 20-year lifetime. For the solar radiation stress a special metal halide bulb generates a spectrum with an irradiance of about 1,000 W/m², which is close to that of natural sunlight (AM 1.5). There were few indications of decomposition and delamination of some electrochromic glass samples by UV radiation in the past. After further developments in UV-stability of the system encouraging results were reached with simulated solar radiation (Fig. 5).

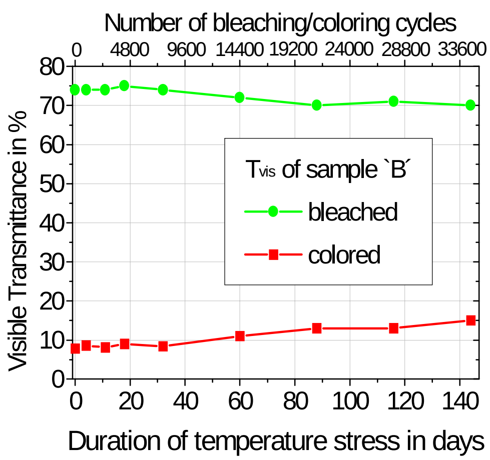

Fig. 4: Aging test by temperature and bleaching/coloring cycles

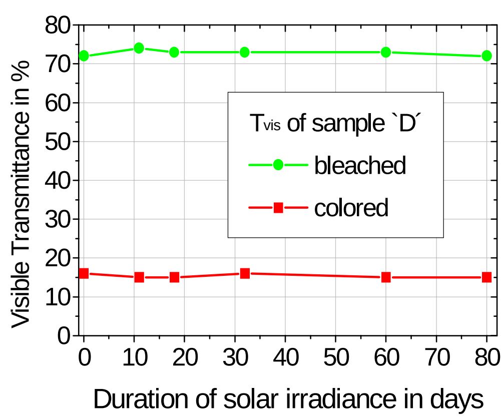

Fig. 5: Aging test by simulated solar radiation on a bleached sample

A promising composition of an electrochromic glass with good results for the transmittance, the PTR and the durability was developed. On this basis double glazing units were constructed, consisting of this complementary electrochromic glass, a 16 mm gap filled with air and a low-e interior pane. These test windows have a size of (1.20 × 0.80) m². Measurements concerning thermal and optical parameters and comfort were started.

3. Daylight potential

The practical use of EC-windows was investigated on two test facades, the „facade 1“ with EC-windows with one electrochromic layer and the „facade 2“ with the described new EC-windows with two electrochromic layers. The facades, with a height and a width of 2.7 m and a transparent windows area of 2.5 m² were built into two climatic test rooms with a depth of 5 m. The facades face south, with natural climate and sunshine outside. The walls and the ceilings of the test 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. Former investigations on „facade 1“ have shown [4] that an adjustable range for the illuminance from 500 lx up to 2000 lx at the desk in a distance of 1.5 m from the window is possible depending on the coloration of the EC-windows. These values were measured for full sunshine conditions in April. But with overcast sky the illuminance is falling below the recommended minimum value of 500 lx due to the quite low visible transmittance $T_{vis\text{-}bleached}$ = 50 % of the EC-windows of „facade 1“. A solution of this problem should be a greater range of adjustable transmittance, like available for the EC-windows of „facade 2“. Falsecolored luminance pictures, made by a special digital camera (type Technoteam LMK mobile), are used for the evaluation of glare on the EC-windows or on the walls besides (Fig 6). The camera is calibrated according to a luminance calibration source, so that every value of luminance in cd/m² is corresponding to a determined color in the pictures.

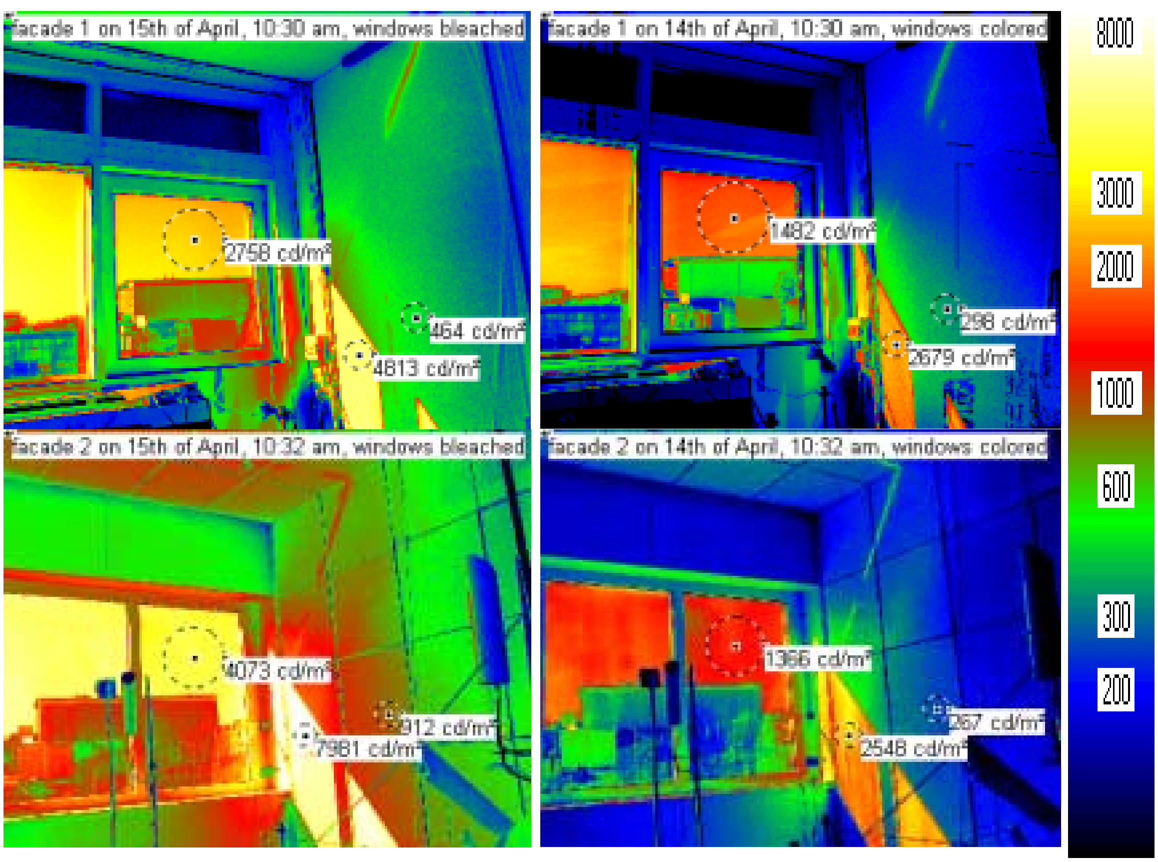

Fig. 6: Comparison of luminance between facade 1 and 2 on days with clear sky

cd/m²

The result of the greater range of adjustable transmittance of the EC-windows in „facade 2“ is the correlating greater range of luminance and illuminance. The comparison of the two facades concerning the luminances between the bleached windows and the colored windows shows ranges from 2758 cd/m² to 1482 cd/m² for „facade 1“ and 4073 cd/m³ to 1366 cd/m² for „facade 2“. These values were also verified and completed for other seasons and weather conditions by simulations with the software Adeline/Radiance. As a result the advantages of „facade 2“ are in particular in the morning and afternoon hours and on overcast sky conditions, due to the higher transmittance of the windows with up to $T_{vis\text{-}bleached}$ = 65 %, which is nearer to the value for an usual double glazing with one low-e pane ($T_{vis} \leq 76$ %) compared with $T_{vis\text{-}bleached}$ = 50 % for the windows of „facade 1“. More adjustable range means more daylight potential and that causes more lighting comfort. The lower limit of visible transmittance of both facades seems still too high, as it is shown in the quite high luminance values even of the full colored windows and of the direct light spots on the walls. The maximum value for the mean luminance of surfaces, which could reflect on a screen and so could cause glare and disturbing reflections is 1000 cd/m². But more reduction of the windows luminances causes also more reduction of the illuminance on the workplace, which is already nearby the upper limit of 500 lx on the described conditions. That means windows with some more luminance should be accepted for the benefit of a sufficient natural daylighting. Workplaces should be well placed near the window with screens which face towards walls with low luminance. In that case the investigation has shown, that electrochromic glazings make additional protection against the sun nearly unnecessary. There is a good lighting of offices during the whole sunshine period especially and with more color-neutrality in combination with daylight re-directing elements. Automatic adjustment of the windows transparency controlled by the indoor illuminance was also tested and is recommended for comfortable adjustment of the transmittance to the desired illuminance.
In contrast to the investigated facades with a transparent area of about 33 % there are new all glass facades with much more transparent parts. Such glass facades could provide the room with the required illuminance also far from the windows during the whole day, but the prevention of glare by too high luminances especially in the field of vision of workplaces will become much more important. Further development of EC-windows with high PTR and investigations on all glass electrochromic facades are planned.

Acknowledgment
This work was funded by the Federal Ministry of Economics and Labour, Contract No. 0327233G and 0327233F

References

1 H. Wittkopf: “Electrochromics for architectural glazing applications”, Glass Processing Days 1997, Conference Proceedings Book, pages 299-303.
2 H. Stenzel, M. Rottmann et al: “Electrochromic glazing with an ion-conducting PVB interlayer”, Glass Processing Days 2003, Conference Proceedings Book, p. 423-426.
3 H. R. Wilson: “Steps toward Appropriate Accelerated Ageing Tests for Architectural Chromogenic Glazing”, IEA SHC Task 27 Dissemination Workshop, Freiburg 2003.
4 T. Häusler: “Transmittance and Luminance Measurements on Electrochromic Glazing”, International Lighting and Colour Conference, p. 102-106, Capetown 2003.