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High transmittance, low emissivity glass covers for flat plate collectors: Applications and performance

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Abstract

Low emissivity coatings can significantly reduce radiative heat losses of glass panes for solar energy use. Their effectiveness is strongly dependent on their optical properties, which need to meet the requirements for the specific application. The paper analyzes the performance of newly developed, highly transmitting and spectrally selective glass coatings based on transparent conductive oxides (TCO) for the use in flat plate collectors: Uncovered, single-glazed and double-glazed designs are taken into consideration. As functional layers both tin-doped indium oxide and aluminum-doped zinc oxide have been investigated. Collector efficiencies and annual collector yields are presented and compared to those of state-of-the-art collectors. Theoretical calculations are complemented by measurements on collector prototypes. The results show that a significant performance increase is accessible both in single-glazed collectors with low or non-selective absorbers and in double-glazed collectors with highly selective absorbers.

Keywords: Coated glass; Low emissivity; Flat plate collector

1. Introduction

Spectrally selective glass has been investigated since long time both for active and passive solar energy use. In the literature, particularly works from the 70 s and 80 s of the last century have discussed low emissivity (low-e) coatings for glass covers to improve the performance of different collector types (Goodman and Menke, 1975; Apfel, 1975; Fan and Bachner, 1976; Yoshida, 1978; Frank et al., 1983).

Due to the successful development of highly selective metal absorbers, able to reduce radiation heat losses more effectively than low-e glazings, the proposed approaches were neither put into practice nor followed up. The use of a low-e cover in a single-glazed collector with a selective absorber, which represents the most common design today on the market, does not provide for any improvement, but rather negatively affects the collector performance, because selective coatings on glass are responsible for additional optical losses.

For other collector configurations, however, low-e glass can be used advantageously. The crucial factors are the properties of the coating, which have to meet special requirements. Based on the optical characteristics of prototype coated panes, that are being developed for solar thermal applications as part of an ongoing research project at ISFH, the present article examines the potential of low-e glass for different designs of flat plate collectors: single- and double-glazed as well as uncovered ones.

2. Requirements for spectrally selective glass

Glass represents an ideal material for the use in solar energy applications thanks to its high solar transmittance, long-term stability and low cost. To combine these advantageous properties with an additional heat protection

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Nomenclature

AZO	aluminum-doped zinc oxide	T_A	outdoor ambient temperature
AR	antireflective coating	T_{Sky}	sky temperature
ITO	tin-doped indium oxide	α_e	solar absorptance
G	irradiance	ε	emissivity
G_d	diffuse irradiance	τ_e	solar transmittance

function, spectrally selective coatings reflecting radiation in the infrared wavelength range, can be applied to its surface, thus significantly reducing thermal losses.

Suitable active materials for the coating, due to their physical properties, are either metals (mainly silver, but also copper or gold) or metal oxides (e.g. tin oxide, indium oxide or zinc oxide). These are embedded in appropriate layer systems, which can be deposited with different methods on glass (Lampert, 1981). The choice of the materials, the coating structure, and the coating technology is crucial for defining the optical properties and the stability of the glass and, thus, for its application. Commercially available products have been almost exclusively developed for architecture. To ensure thermal and visual comfort in buildings, coating systems based on silver are primarily used, which can provide for extremely low emissivity (less than 0.03) and high visible transmittance (up to 0.90). Solar transmittance, however, is rarely higher than 0.60. Values up to 0.75 and corresponding higher emissivity (between 0.08 and 0.20) can be achieved using very thin silver layers, which have been developed in the last years for triple glazing, or with metal oxides. The results of the works cited in Section 1 as well as our ongoing activities at ISFH confirm that these values are not high enough for collector applications (Föste, 2013). As the efficiency of a collector results from solar gains and thermal losses, proper combinations of the optical properties of a low-e cover (solar transmittance and emissivity) can theoretically be calculated, which lead to a higher performance than a conventional non-coated glass pane for different operating temperatures and collector constructions. For double-glazed configurations, for example, we identify solar transmittances above 0.80 and emissivities below 0.30 as target values to improve the efficiency of existing products.

Beside the performance of the coating, its resistance to temperature, humidity, mechanical stress, and their combined effect, depending on the configuration and corresponding exposure, plays a significant role in solar thermal collectors. Silver coatings for architectural glass, for example, are very sensitive to corrosion and can only be used in a dry and airtight environment such as in the gap of multiple insulating glazing.

As last criterion, the cost effectiveness of the coating (materials and coating technologies) has to be taken into account to ensure that the benefits (increased collector yield) can justify the additional expenses. As a general rule, the costs of commercially available collector covers, ranging from 8 to 10 €/m^2 for low iron, tempered glass and 15–20 €/m^2 for high performing antireflective glass, have to be regarded as reference for the development of new products. A comprehensive economical analysis should consider the details of the specific application (collector type, collector area, solar system configuration, etc.) and goes beyond the intention of the present work.

On the basis of these requirements, we are currently investigating and optimizing within an ongoing project in cooperation with industry partners two coating systems based on transparent conductive oxides for the use in highly efficient double-glazed collectors (Föste et al., 2011, 2013): aluminum-doped zinc oxide (AZO) and tin-doped indium oxide (ITO). The two systems differ in terms of performance, stability and cost: the ITO coating exhibits a higher chemical resistance as well as a lower emissivity at a comparable solar transmittance, thus providing for a better thermal insulation. Due to the limited availability of this material, the AZO coating, however, has to be favored with regard to ecology and economics.

Our investigations on the AZO system have shown promising results in laboratory (Ehrmann and Reineke-Koch, 2012); currently we are working at scaling the coating to large sizes while maintaining the achieved performance and durability. The ITO-coated pane is a special architectural glass, manufactured by the German company Euroglas, which is being adapted and optimized for the use in thermal collectors. The coating is originally intended for the use on the outer side of highly insulated multiple glazing to avoid condensation and it is, therefore, particularly resistant against weathering and mechanical loads (class A according to EN 1096-2, 2012). Long-term temperature stress tests at ISFH confirm its very good durability: our tests have been carried out with a self-developed rig, which enables to reproduce a targeted temperature distribution over a collector-sized glazing. Two ITO panes have been exposed for 1200 h to a profile, which is expected in stagnating double-glazed collectors, with maximum temperatures up to 160 °C. We evaluated the effects of the accelerating ageing by visually inspecting the glass and controlling its optical properties, without reporting any form of degradation of the coating. On the basis of calculated annual temperature occurrences in a solar system for space heating with high solar fraction (single family house, 30 m^2 collector area, 2 m^3 storage unit) we estimate a minimum