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Colored Solar Collectors

Annual Report 2006

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SFOE Project-No.	43971
duration of project	Phase II: 01/02/2004 - 15/12/2007

SUMMARY

The architectural integration of thermal solar collectors into buildings is often limited by their black color, and the visibility of tubes and corrugations of the absorber sheets. A certain freedom in color choice would be desirable, but the colored appearance should not cause an excessive degradation of the collector efficiency. Multilayered thin film interference filters on the collector glazing can produce a colored reflection, hiding the corrugated metal sheet, while transmitting the non-reflected radiation entirely to the absorber. These interference filters are designed and optimized by numerical simulation, and are manufactured by sol-gel dip-coating or magnetron sputtering. The novel colored glazed solar collectors will be ideally suited for architectural integration into buildings, e.g. as solar active glass facades.

Due to the tunability of the refractive index, nanostructured materials such as SiO_2:TiO_2 composites and porous SiO_2 are very useful for application in multilayer interference stacks. Novel quaternary Mg-F-Si-O films exhibit a surprisingly low refractive index and are therefore promising candidates for highly transparent coatings on solar collector glazing. The nanostructure of these thin films is studied by transmission electron microscopy, while the optical constants are measured precisely by ellipsometry.

For a convincing demonstration, sufficiently large samples of high quality are imperatively needed. The fabrication of nanocomposite SiO_2:TiO_2 films has been demonstrated by sol-gel dip-coating of A4 - sized glass panes. The produced coatings exhibit a colored reflection in combination with a high solar transmittance, a homogenous appearance, and are free of visible defects.

Film hardening by UV exposure will result in speeding up the sol-gel process and saving energy, thereby reducing costs significantly. The infrastructure for UV-curing has been established. A UVC radiation source can now be attached to the dip-coater, which is placed in a UV-screened laminar flow chapel.

An industrial partner for the prototype fabrication of colored collector glazing has been found. For a first attempt of industrial scale production, adapted multilayer designs have been proposed. First tests on the industrial magnetron sputtering equipment have shown encouraging results, but some adaptations are still needed.

Possible ways of implementation of the novel colored solar collectors/solar facades are investigated and discussed with facade manufacturers and architects.

Project Goals

Architectural integration of solar energy systems into buildings has become a widely recognized issue, which regards techniques ranging from photovoltaics and daylighting to thermal solar energy conversion. Thermal solar collectors, typically equipped with black, optical selective absorber sheets, exhibit in general good energy conversion efficiencies. However, the black color, and sometimes the visibility of tubes and unwanted undulations of the thin metal sheets, limit the architectural integration into buildings. A recent opinion poll [1] showed that 85% of architects would prefer other colors than black, even if a lower efficiency was the price to pay.

Several research groups have proposed to color the absorber sheets. This can be obtained by modifying the process parameters used for the production of black selective absorber coatings. An alternative approach is to establish a colored reflection not from the absorber but from the collector glazing [2,3,4]. Interference colors of dielectric thin films are ideally suited for this purpose. Multilayered interference filters on the cover glass can produce an energy-efficient colored reflection, hiding the corrugated metal sheet, while transmitting the non-reflected radiation entirely to the absorber. These interference filters are designed and optimized by numerical simulation, and are manufactured by sol-gel dip-coating or magnetron sputtering. Due to the possibility of tailoring the optical properties of nanostructured materials [5], nanocomposite and nanoporous thin films are perfectly suited for the considered application.

Goals defined for 2006 :

1. **Structural and optical characterization of advanced nanocomposite/nanoporous materials**

Structural investigations of nanocomposite $Ti_{1-x}Si_xO_2$ single- and multilayered coatings (tunable refractive index), and quaternary Mg-F-Si-O films (promising novel low refractive index material)

Precise determination of optical constants for low refractive index materials (nanoporous SiO_2 and novel quaternary Mg-F-Si-O films)

2. **Sol-gel deposition of nanostructured thin films on A4 - sized substrates**

The fabrication of nanocomposite thin films shall be demonstrated on a larger size scale. The tunable refractive index of nanocomposites provides a large degree of freedom for the optimization of the multilayer designs.

Multilayered coatings with a high solar transmission and a sufficiently high visible reflectance shall be designed and prepared by sol-gel dip-coating on substrates of the format A4.

3. Film hardening by UV-curing

For the industrial production of multilayers by the sol-gel process, UV-curing shall replace the thermal annealing step needed after the deposition of each individual layer. Film hardening by UV exposure will result in speeding up the process and saving energy, thereby reducing costs significantly.

The experimental infrastructure for UV-curing shall be established. The feasibility of a photosensitization of the used precursor solutions shall be studied.

4. Preparation of the prototype fabrication of colored collector glazing on the industrial scale by magnetron sputtering (substrate size 1.90 m x 3 m)

The fabrication of prototype glazing on the real scale is essential for a convincing demonstration of the novel solar collectors.

An industrial partner for the prototype fabrication of colored collector glazing shall be found. The possibilities and limitations of eventually existing production lines shall be discussed, and adapted multilayer designs shall be proposed according to the given boundary conditions.

5. Architectural integration of the novel colored solar collectors

The model collector “Demo-Box” shall be presented to facade manufacturers and architects, and the work to study possible implementations of the novel colored solar collectors/solar facades shall be started.

Description of Work and Results

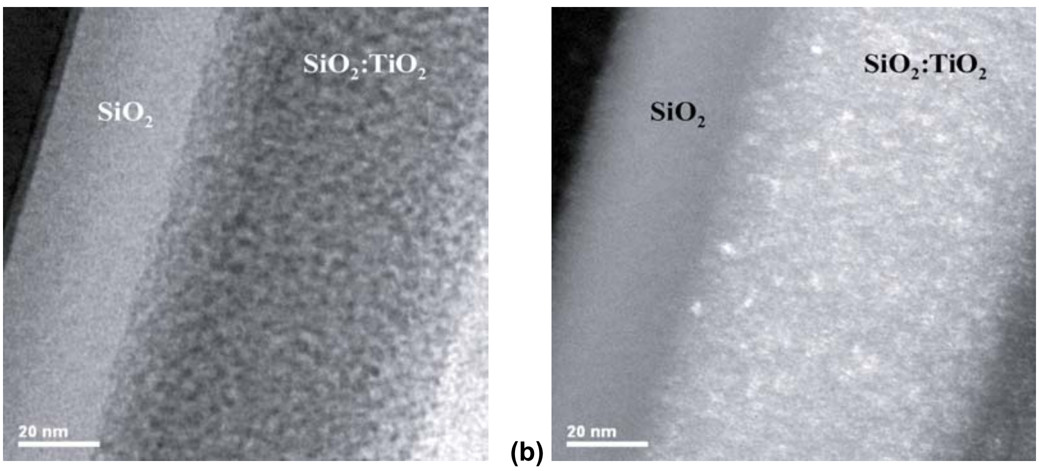
1. Structural and optical characterization of advanced nanocomposite/ nanoporous materials

Knowledge on the nanostructure of the sol-gel deposited thin films is extremely helpful for the optimization of the coatings. Transmission electron microscopy (TEM) is a valuable tool for investigations of film morphology and nanostructure. Access to transmission electron microscopes and facilities for TEM sample preparation are provided by the Interdepartmental Center of Electron Microscopies CIME at EPFL.

Reliable and precise data on the optical constants of the nanostructured thin films are necessary for precise simulations of the optical behavior of the multilayer stacks. Ellipsometry is a very accurate method for the determination of the refractive index n and the extinction coefficient k of thin films. The research group of Prof. Libero Zuppiroli (LOMM at EPFL) acquired recently a new ellipsometer (SOPRA GES5), and offered us access to their instrument. A corresponding license of the analysis software WINELLI has been acquired by the LESO.

1.1 Nanocomposite $Ti_{1-x}Si_xO_2$ films

By adapting the stoichiometry, the refractive index of nanocomposite $Ti_{1-x}Si_xO_2$ films can be tuned in a wide range, rendering this material very useful for the application in multilayer interference stacks. So far, it had only be assumed that the films produced in our laboratory are of nanocomposite nature, but clear evidence for a granular structure on the nanometer-scale has been found by transmission electron microscopy. Fig.1(a) shows a bright field image of a cross section of a nanocomposite $Ti_{0.5}Si_{0.5}O_2$ film. The film was deposited on a preoxidized silicon wafer. In bright field [Fig.1(a)], the titanium-rich regions appear as dark grains. Fig.2(b) shows a dark-field image of the same region of the sample. Here, suitably oriented nanocrystals appear as bright spots. It can be assumed that the material consists of TiO_2 nanocrystals embedded in a matrix of amorphous silicon dioxide.



(a) (b)

Fig.1: Transmission electron microscopy of a cross section of a nanocomposite $Ti_{0.5}Si_{0.5}O_2$ film.
(a) Bright field image: Ti - rich regions appear as dark grains
(b) Dark field image: TiO_2 nanocrystals with suitable orientation appear as bright spots

A cross-sectional TEM view of a multilayer stack is shown in Fig.2. In bright field, the nanocomposite $Ti_{0.5}Si_{0.5}O_2$ layers appear in dark grey, while the SiO_2 layers appear in light grey. In contrast to the homogeneous SiO_2 layers, the granular nanostructure of the $Ti_{0.5}Si_{0.5}O_2$ layers can clearly be distinguished.

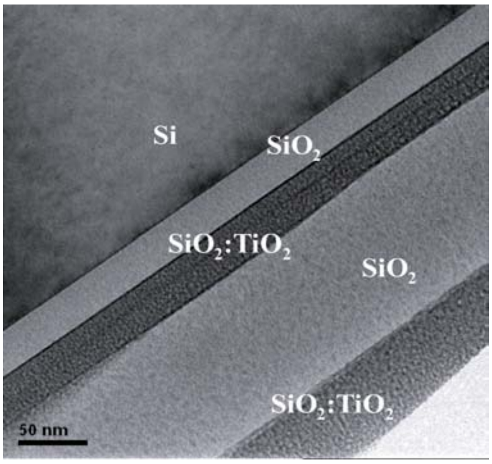


Fig.2: Transmission electron microscopy of a cross section of a $Ti_{0.5}Si_{0.5}O_2$//SiO_2 multilayer stack (bright field). The nanocomposite $TiSiO_2$ layers appear in dark grey, while the homogeneous SiO_2 layers appear in light grey.

1.2 Porous silicon dioxide

Previous simulations [3] have shown that the availability of low refractive index materials favors a higher solar transmission for the same value of visible reflectance. Among common sol-gel materials (mostly oxides, formed during annealing in air), silicon dioxide exhibits the lowest refractive index of approximately 1.47.

One way to decrease the refractive index of silicon dioxide is to introduce voids into the coating structure. By adding organic macromolecules to sol-gel precursor solutions, xerogel films can be created which contain nanometric organic regions. In the subsequent annealing step, the organic macromolecules can be oxidized, thereby leaving behind nanometric pores.

Ellipsometric data as measured from a nanoporous SiO_2 film deposited on a preoxidized silicon substrate are displayed in Fig.3(a). In the three-dimensional diagrams, the ellipsometric quantities tan(psi) and cos(delta) are plotted as a function of the wavelength and the angle of reflection. The analysis of these data is based on the fit of a Cauchy-type dispersion relation and yields the precise film thickness of the thermal silicon oxide (27 nm) and of the porous sol-gel film (152 nm), as well as the dispersion relation $n(\lambda)$ [see Fig.3(b)]. Using the Bruggeman effective medium theory, a pore volume fraction of 30 % is estimated from the low refractive index values (approximately 1.32 at 600 nm).

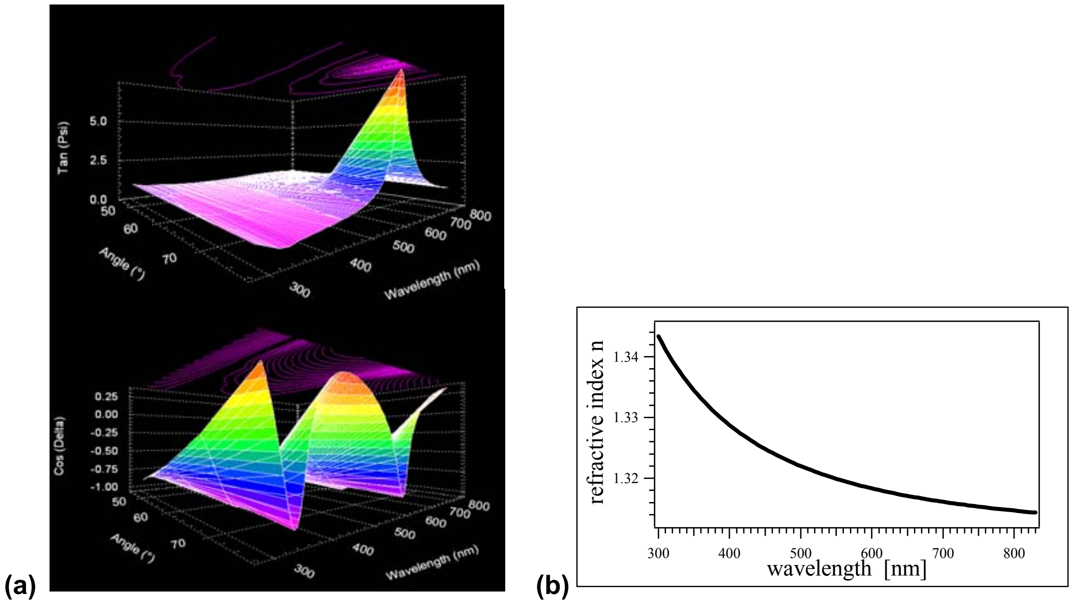


Fig.3: Ellipsometric determination of the refractive index n(λ) of nanoporous silicon dioxide.
(a) Measured data for the ellipsometric quantities tan(psi) and cos(delta)
(b) Refractive index n(λ), as inferred by the numerical analysis of the experimental data. A pore volume fraction of 30 % is estimated from the low refractive index values.

1.3 Fluoride/oxide nanocomposite thin films

Magnesium fluoride MgF_2 is one of the rare thin film materials exhibiting a refractive index lower than that of SiO_2. Its application is restricted though by its lower hardness and eventually occurring adhesion problems. Aiming at superior film properties and at a tunable refractive index, a novel nanocomposite material has been found previously by mixing fluorides and oxides (see SFOE report "Feasibility study on the sol-gel deposition of nanostructured materials based on oxides and fluorides for coatings on solar collector glazing", Oct. 2005).

The film morphology is illustrated by Fig. 4. The TEM images have been obtained from a cleaved corner of a Mg-F-Si-O film sandwiched between two SiO_2 layers. While in bright field the nanostructure is barely visible [Fig.4(a)], the dark field image shown in Fig.4(b) exhibits clearly bright spots in the region of the Mg-F-Si-O film. These features are a typical signature of a nanocomposite material. Further investigations will be necessary to clarify the exact nature of the nanostructure.

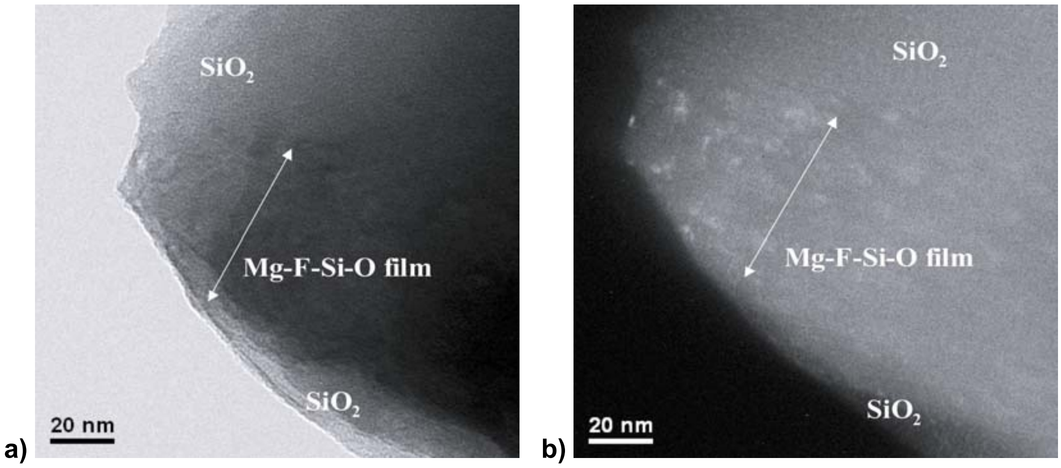


Fig.4: Transmission electron microscopy of a cleaved corner of a nanocomposite Mg-F-Si-O film sandwiched between two SiO_2 layers.
(a) Bright field image: the nanostructure is barely visible
(b) Dark field image: the bright spots are a typical signature of a nanocomposite material

Fig. 5(a) shows ellipsometric data as measured from a Mg-F-Si-O//SiO_2 tandem layer deposited by two sol-gel dip-coating cycles on a silicon substrate. The numerical analysis of the tan(psi) and cos(delta) spectra yields film thicknesses of 138 nm and 130 nm for the SiO_2 and Mg-F-Si-O layers, respectively.

Remarkably low refractive index values are found [see Fig.3(b)]. The observed range from 1.255 to 1.270 is extremely interesting for single-layered anti-reflection coatings on solar collector glazing, as well as for multilayered colored coatings with a high solar transmission.

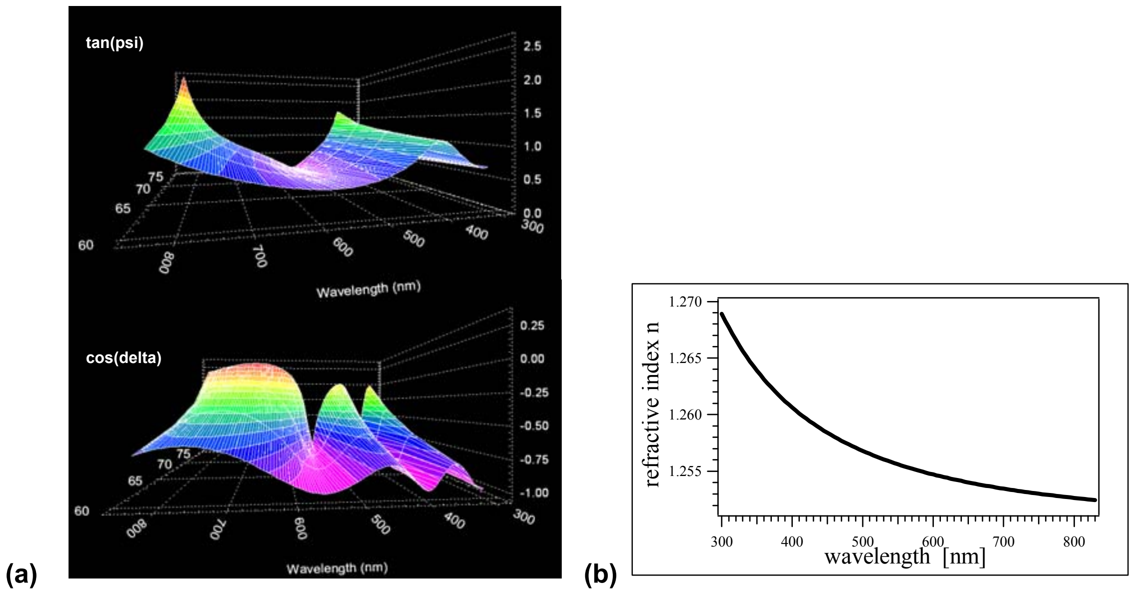


Fig.5: Ellipsometric determination of the refractive index n(λ) of nanocomposite Mg-F-Si-O films.
(a) Measured data for the ellipsometric quantities tan(psi) and cos(delta)
(b) Refractive index n(λ), as inferred by the numerical analysis of the experimental data. Remarkably low refractive index values are found.

2. Sol-gel deposition of nanostructured thin films on A4 - sized substrates

The tunable refractive index of nanocomposite materials provides a large degree of freedom for an optimization of the coatings. By mixing e.g. silicon oxide (n ≈ 1.47) and titanium oxide (for sol-gel films n ≈ 2.2) any intermediate refractive index can be achieved, opening manifold possibilities for multilayer design.

SiO_2 and $Ti_{0.3}Si_{0.7}O_2$ were chosen as low and high index materials, respectively, and the withdrawal speeds in the dip-coating process were adapted to yield the desired film thicknesses. By cycling dip-coating and thermal annealing, colored multilayers have been deposited on A4 - sized glass panes with a low iron content (thickness 4 mm, solar transmission 89.4%). Photographs of two colored samples (brownish and light blue) are shown in Fig.6(a). The homogeneity and quality of the coatings are satisfying. The solar transmittance of the blue sample is diminished by only 1.4 percent points with respect to the uncoated substrate, while the decrease in solar transmittance amounts acceptable 3.4 percent points for the brownish sample. The corresponding spectra of normal transmittance are displayed in Fig.6(b). The data yield a visible reflectance of 14 % and 12.6 % for the blue and brownish sample, respectively. First visual tests with the “Demo-Box” showed that a slightly higher visible reflectance might be desired. An increase in visible reflectance should be possible even without lowering the solar transmittance by application of nanostructured low refractive index materials (nanoporous SiO_2 and novel quaternary Mg-F-Si-O films).

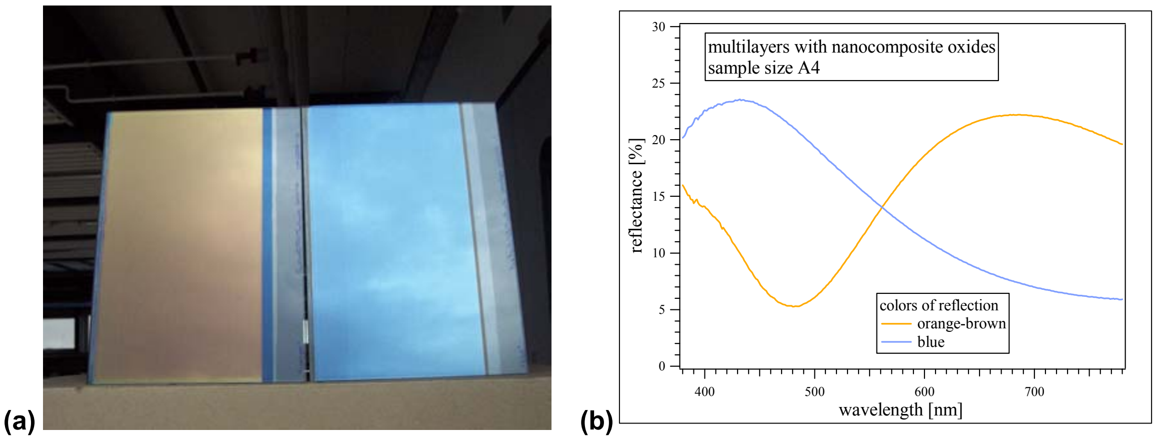


Fig.6: Sol-gel deposition of nanocomposite oxide coatings on A4 - sized substrates.
(a) Photograph of glass panes coated with colored multilayer stacks. The loss in solar transmittance due to the colored coating amounts to only 1.4 percentage points (blue sample) and 3.4 percentage points (brownish sample).
(b) Spectra of normal transmittance. The data yield a visible reflectance of 14.0 % and 12.6 % for the blue and brownish sample, respectively.

3. Film hardening by UV-curing

For the industrial production of multilayers by the sol-gel process, UV-curing shall replace the thermal annealing step needed after the deposition of each individual layer. Film hardening by UV exposure will result in speeding up the process and saving energy, thereby reducing costs significantly.

3.1 Establishing the experimental infrastructure

A special UVC radiation source has been designed and built. Two UVC discharge tubes are mounted in a suitable housing in order to irradiate the substrate from both sides [Fig7(a)]. The electrical power of each tube emitting at a wavelength of 254 nm amounts to 15W, the irradiation in the vicinity of the entrance slit is in the order of 8 mW/cm^2. The source is attached to the dip-coater, which guarantees a continuous displacement of the substrate [Fig.7(b)]. The assembly is placed into the laminar flux chapel [for a photograph see Fig.7(c)], which has been thoroughly equipped with UV-absorbing panes and a safety interlock. Outside the likewise screened chapel, the level of UVC radiation is below the detection threshold of the UV-radiometer (4 μW/cm^2).

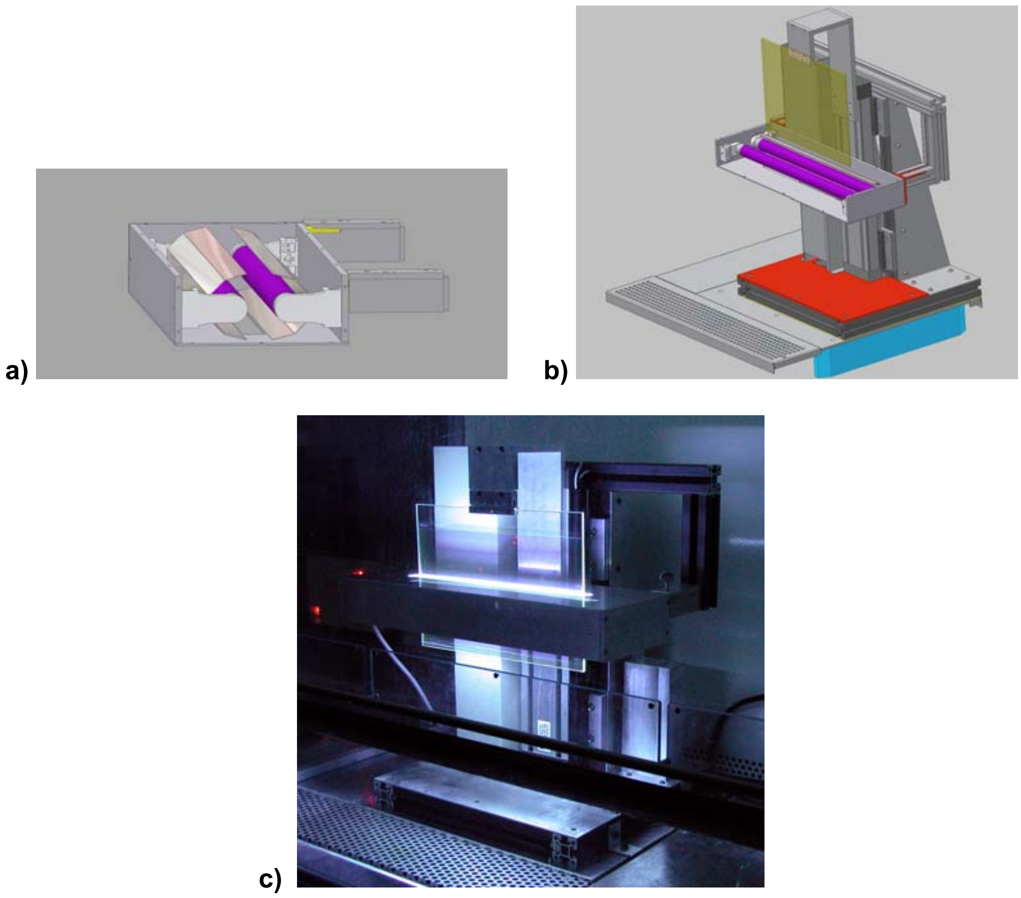


Fig.7: Set-up for film hardening by UV-curing
(a) Schematic drawing of the UVC radiation source (principal emission wavelength 254 nm)
(b) The source is attached to the dip-coater which guarantees a continuous displacement of the substrate
(c) Photograph of the dip-coater equipped with the UVC radiation source. The assembly is placed in a laminar flux chapel which has been equipped with UV-screens.

3.2 Photosensitization of the used precursor solutions

A literature research has clarified the methods of photosensitization of the used precursor solutions. Certain functional groups have to be attached either to the precursor molecules or to the surface of previously formed nanoparticles. By introducing a photoinitiator, a UV-induced photopolymerization can be achieved, allowing the likewise hardened Xerogel film to be resistant towards dissolution in the next precursor solution. First experiments have been performed, but the used solutions still need to be improved.

4. Preparation of the prototype fabrication of colored collector glazing on the industrial scale by magnetron sputtering (substrate size 1.90 m x 3 m)

An industrial partner for the fabrication of prototype collector glazing on the industrial scale has been found. The company GLAS TRÖSCH has agreed to prepare prototype coatings on panes of solar glass with the dimensions of 1.90 m x 3 m by magnetron sputtering. The possibilities and boundary conditions of the existing equipment have been discussed with Fabian Zwick, GLAS TRÖSCH. In a first attempt, the colored multilayers will be based on homogenous silicon and titanium dioxides. Computer simulations of the envisaged multilayer designs have been performed using refractive index data on sputtered films. After optimization, promising combinations of film thicknesses have been identified. Predicted values for the solar transmittance, the visible reflectance, and the color coordinates are summarized in TABLE 1. For a visible reflectance of approximately 20 %, indicating a sufficiently strong reflection, a solar transmission of 84 % will be possible. Especially the light blue colors are rather stable with respect to a variation of the angle of reflection.

The production of first prototype glazing is scheduled for mid/end December. First tests on the industrial production line have already shown encouraging results.

layer										
1	2	3								
t(TiO2) [nm]	t(SiO2) [nm]	t(TiO2) [nm]	L	a	b	u'	v'	Rvis [%]	Tsol [%]	
20	120	20	51.7	-1.9	-22.4	0.18	0.41	19.9	84.1	light blue
25	110	25	57.2	-3.7	-22.2	0.17	0.41	25.1	80.8	light blue
20	210	20	51.6	10.4	21.2	0.24	0.5	19.8	83.3	orange-brown

Table 1: Multilayer design by computer simulations. For promising combinations of layer thicknesses, the table summarizes the predicted values for the CIE color coordinates L, a, b, u', v', the visible reflectance R_{vis}, and the solar transmittance T_{sol}.

5. Architectural integration of the novel colored solar collectors

With the extra funding provided by EPFL-LESO-PB (see letter "demande de prolongation" of April 2006), we are now able to study the possible implementations of the new glazing. Using the collector model "Demo-Box" (see Fig.8) we have been able to demonstrate visually the features of the developed coatings. Combining the colored interference filter with a diffusing surface or interface has been proven to be extremely helpful in order to achieve the desired masking level in all conditions. Several possible partners have been contacted and visited, namely AGENA, CLIPSOL and SCHWEIZER for collector and façade manufacturers, and GLAS TRÖSCH for the glass coating industry. Several architects were also interviewed and showed a great interest in this technology (Hestness, Rejenka, Müller…). Regarding the potential market for this technology, a study on the use of glass as a façade cladding on opaque and transparent parts has been conducted, showing a major trend towards this application in recent buildings.

Fig.8: Demonstration collector "Demo-Box". The collector model allows to visualize the effect of the colored reflection hiding ondulations and sothering traces of the black selective absorber. The effect is especially impressing when the colored coating is combined with a diffusing surface or interface.

Dissemination/industry contacts

- Presentation of a model collector with the dimensions 20 cm x 30 cm (the "Demo-Box") to possible industrial partners (AGENA, CLIPSOL, SCHWEIZER, ...) and to architects (Hestness, Rejenka, Müller, ...)
- Collaboration with GLAS TRÖSCH on the prototype production of the novel collector glazing
- Discussions with CENTROSOLAR GLAS GmbH, Germany (former FLABEG) concerning the prototype fabrication of the novel collector glazing by sol-gel dip-coating
- a new CTI project on sol-gel deposition of nanostructured selective solar absorber coatings is in preparation and negotiation with the Swiss solar collector manufacturer ENERGIE SOLAIRE SA is ongoing

National Collaboration

A close collaboration exists with the research group of Prof. Peter Oelhafen, Institute of Physics, University of Basel. Jamila Boudaden provided the refractive index data of sputtered oxides for the simulation of the prototype coatings. The collaboration can be characterized as cooperative and productive.

Within EPFL, the project benefits from the accessibility to electron microscopes and to the facilities of TEM sample preparation at the Interdepartmental Center of Electron Microscopy CIME. Especially mentioned should be the excellent technical and scientific support by Guido Milanesi, Danièle Laub, Dr. Aïcha Hessler, Dr. Marco Cantoni, Fabienne Bobard, and Prof. Philippe-André Buffat.

The research group of Prof. Libero Zuppiroli (LOMM at EPFL) offered us access to their new ellipsometer. We appreciate especially the spirit of scientific collaboration in this group and the discussions with the collaborators Michel Schär, Dr. Rolando Ferrini, and Dr. Olivier Nicolet.

International Collaboration

- Current European project *SOLABS*,

Partners from France, Spain, Slovenia, Germany and Switzerland. Even though the topics of glazed and unglazed thermal solar collectors are clearly separated, synergies emerge especially regarding architectural aspects.

Name of Project:

"Development of unglazed solar absorbers (resorting to coloured selective coatings in steel material) for building facades, and integration into heating systems"

EU project number: NNE5-2001-00963

- Collaboration with Polymer Competence Centre PCCL, University of Leoben, Austria,

Theory and modelling of thin film optics, group Dr. Dieter Gruber

- Invited keynote lecture at the ESF exploratory workshop on carbon based nanostructured thin films in Gdansk, Poland, with participants from Austria, Belgium, the Czech Republic, France, Germany, Greece, Italy, Lithuania, Poland, Portugal, the Slovak Republic, Slovenia, Sweden, Switzerland, and Turkey.

A new European network on nanostructured thin films is envisaged by the workshop participants.

Evaluation 2006 and Outlook 2007

Achievements made in 2006 concern various aspects of the project: the nanostructure of the deposited thin films is directly imaged by transmission electron microscopy, the refractive index of advanced low n materials is measured accurately by ellipsometry, nanostructured films are deposited on the intermediate size scale (A4), the equipment for film hardening by UV curing has been built, first tests of the prototype fabrication on the industrial scale have been performed, and work on the architectural integration has been started.

Project goals accomplished in 2006 :

1. Structural and optical characterization of advanced nanocomposite/nanoporous materials

Evidence for the nanocomposite structure of our $Ti_{1-x}Si_xO_2$ single- and multilayered coatings and quaternary Mg-F-Si-O films has been found by transmission electron microscopy. The gained knowledge on the nanostructure will be very useful for the optimization of the coating properties.

Precise ellipsometric measurements have confirmed that very low refractive indices can be achieved for nanoporous SiO_2 and novel quaternary Mg-F-Si-O films. The accurate data on the refractive index will allow reliable simulations of multilayer stacks.

2. Sol-gel deposition of nanostructured thin films on A4 - sized substrates

The fabrication of nanocomposite SiO_2:TiO_2 films has been demonstrated by sol-gel dip-coating of A4 - sized glass panes. The nanostructure is hereby formed in a self-organized process during thermal annealing.

The coloration of the glass panes implies only small energy losses which are easily acceptable for the solar thermal application (1.4 and 3.4 percent points for the blue and brownish sample respectively). The achieved solar transmittance is clearly higher for the SiO_2//$Ti_{0.3}Si_{0.7}O_2$ multilayers than for the SiO_2//TiO_2 multilayers deposited on A4 glass panes in 2005. The visible reflectance of the SiO_2//$Ti_{0.3}Si_{0.7}O_2$ multilayers amounts to 14.0 % and 12.6 %. First visual tests with the “Demo-Box” showed that for the application a slightly higher visible reflectance might be desired. An increase in visible reflectance should be possible even without lowering the solar transmittance by application of nanostructured low refractive index materials (nanoporous SiO_2 and novel quaternary Mg-F-Si-O films).

3. Film hardening by UV-curing

The experimental infrastructure for UV-curing has been established. A literature research has clarified the methods of photosensitization of the used precursor solutions. First experiments have been performed, but the used solutions still need to be improved.

4. Preparation of the prototype fabrication of colored collector glazing on the industrial scale by magnetron sputtering (substrate size 1.90 m x 3 m)

An industrial partner for the prototype fabrication of colored collector glazing has been found. The possibilities of the production facilities for thin film deposition have been discussed. For a first attempt of industrial scale production, adapted multilayer designs have been proposed. First tests on the industrial production line have shown encouraging results.

5. Architectural integration of the novel colored solar collectors

The model collector “Demo-Box” has been presented to facade manufacturers (AGENA, CLIPSOL, SCHWEIZER, ...) and to architects (Hestness, Rejenka, Müller, ...). Possible ways of implementation of the novel colored solar collectors/solar facades have been studied.

Topics for 2007 :

- complementary investigations of nanostructure (high resolution transmission electron microscopy HTEM, phase identification by X-ray diffraction)
- database of precise optical constants from ellipsometry for reliable multilayer simulation
- deposition of low refractive index materials (porous SiO_2 and Mg-F-Si-O) by dip-coating on A4 scale
- mechanical and aging properties of low refractive index films (porous SiO_2 and Mg-F-Si-O)
- demonstration of film hardening by UV-curing
- production of prototype glazing on the industrial scale
- web survey on user’s wishes
- design and implementation of the novel solar collectors/solar facades

Publications 2006

A. Schüler, D. Dutta, E. de Chambrier, G. De Temmerman, P. Oelhafen, C. Roecker , J.-L. Scartezzini, ***Sol-gel deposition and optical characterization of multilayered $SiO_2/Ti_{1-x}Si_xO_2$ coatings on solar collector glasses,*** Solar Energy Materials & Solar Cells 90, 2894 (2006)

A. Schüler, D. Dutta, H. Chelawat, E. De Chambrier, C. Roecker, J.-L. Scartezzini, ***Nanostructured low refractive index materials on solar collector glazing,*** EUROSUN 2006 Proceedings, June 2006, Glasgow, UK

A. Schüler, D. Dutta, H. Chelawat, E. De Chambrier, C. Roecker, J.-L. Scartezzini, ***Nanostructured low refractive index materials containing the elements Si, O, Mg, and F for coatings on solar collector glazing,*** submitted to Solar Energy Materials & Solar Cells

A. Schüler, M. Python, M. Valle del Olmo, E. de Chambrier, ***Quantum dot containing nanocomposite thin films for photoluminescent solar concentrators,*** submitted to Solar Energy

M.-C. Munari Probst, C. Roecker, ***Towards an improved architectural quality of building integrated solar thermal systems,*** submitted to Solar Energy

J. Wellstein, ***Viele bunte Kollektoren,*** Erneuerbare Energien 11.12.2006, 7263 / 22, 1772

Oral Presentations 2006

E. De Chambrier, ***Nanostructured low refractive index materials on solar collector glazing,*** EUROSUN 2006, June 2006, Glasgow, UK

A. Schüler, ***Quantum dots in photovoltaic solar energy conversion*****,** From Solid State to Biophysics III, June 2006, Cavtat, Croatia

A. Schüler, ***Optical properties of metal-doped carbon-based nanocomposite thin films, invited keynote lecture***, ESF workshop on Carbon-Based Nanostructured Composite Films, September 2006, Gdansk, Poland

C. Roecker, M.-C. Munari Probst, **Capteurs solaires colorés et intégration architecturale,** October 2006, symposium ER 06, Yverdon

O. Bouvard, ***Couches minces sélectives pour capteurs solaires thermiques,*** June 2006, Université Montpellier II, Institut Universitaire Technologique de Nîmes, France

C. Galande, ***Synthesis of photoluminescent nanocomposite thin films for solar collectors,*** September 2006, IIT Kanpur, India

A. Kostro, ***PhotonSim - Développement d'un outil pour la simulation de concentrateurs solaires par tracé de rayons selon la méthode de Monte-Carlo,*** July 2006, EPFL, Lausanne

M. Valle del Olmo, ***Characterization of external quantum yield and lateral energy losses in photoluminescent Quantum Dot solar concentrators,*** July 2006, EPFL, Lausanne

PhD work in progress

Estelle de Chambrier, tentative title of PhD thesis : ***Matériaux diélectriques nanostructurés pour vitrages colorés sur capteurs solaires thermiques***

Master's theses (related topics)

Andre Kostro, ***Photonsim: development of a Monte Carlo ray tracing software for the simulation of photoluminescent solar concentrators***

Miguel Valle del Olmo, ***Characterization of external quantum yield and lateral energy losses in photoluminescent solar concentrators***

Visiting Students

Olivia Bouvard, Université Montpellier II, Institut Universitaire Technologique de Nîmes, ***Couches minces sélectives pour capteurs solaires thermiques***

Charudatta Galande, IIT Kanpur, India, ***Synthesis of photoluminescent nanocomposite thin films for solar collectors***

Architectural aspects

Maria-Cristina Munari Probst

Technical support

Pierre Loesch, LESO

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