Project no. NMP3-CT-2003-505664

NANOEFFECTS

Nanocomposites with High Colouration Efficiency for Electrochromic Smart Plastic Devices

Specific Targeted Research Project

FP 6 Thematic priority 3: Nanotechnologies and nanosciences, knowledge-based multifunctional materials and new production processes and devices (NMP)

Final Activity Report

Period covered: from Apr 1, 2004 to September 30, 2007

Date of preparation: December 20, 2007

Start date of project: Apr 1, 2004

Duration: 42 months

Fraunhofer-Institut Silicatforschung (ISC)
Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V.

Revision [draft]

1. PROJECT EXECUTION

A three-year Specific Targeted Research Project (2004-2007) Funded by the European Commission Under the Sixth Framework Programme, Priority 3 NMP

- **Summary description of project objectives**

Electrochromic devices (ECD) are smart devices that are able to undergo electrochemically reversible colour changes and allow a deliberate power-triggered reduction of light transmittance whenever needed. Though ECDs based upon inorganic oxides or organic dyes show good performance, there are still major disadvantages obstructive to a broader exploitation, despite more than 30 years of gradual research and optimisation efforts. Above all, it is the extremely high cost of the state-of-the-art technologies (1500 €/pair of electrochromic sunglasses, 800 €/m^2 electrochromic window). A second drawback is the lack of a technology for all-plastic ECDs that are desirable for many applications for reasons of flexibility, weight and impact resistance.

The Specific Targeted Research Project NANOEFFECTS (2004-2007), funded by the European Commission under the Sixth Framework Programme, Priority 3 NMP, was expected to realise a breakthrough to overcome the limitations of existing ECDs by utilizing a new wet-chemical approach based on Chemical Nanotechnology.

The general project objective was the development of novel electrochromic nanocomposites and transparent conductive oxides (TCO) as well as prototypes of flexible all-plastic ECDs, prepared therefrom. Electro-active materials with high colouration efficiency such as heterocycle-based conductive polymers played a crucial role in the development. Compared to the state-of-the-art the novel technology was anticipated to show substantial benefits in terms of cost-effectiveness, processing, response time and environmental aspects. It was expected that multisectoral interest for different industrial branches would be created. The application primary aimed at was smart eyewear with high added value. Other potential user groups (automotive, textile, display and domestic appliance industry) have been identified.

- **Contractors involved**

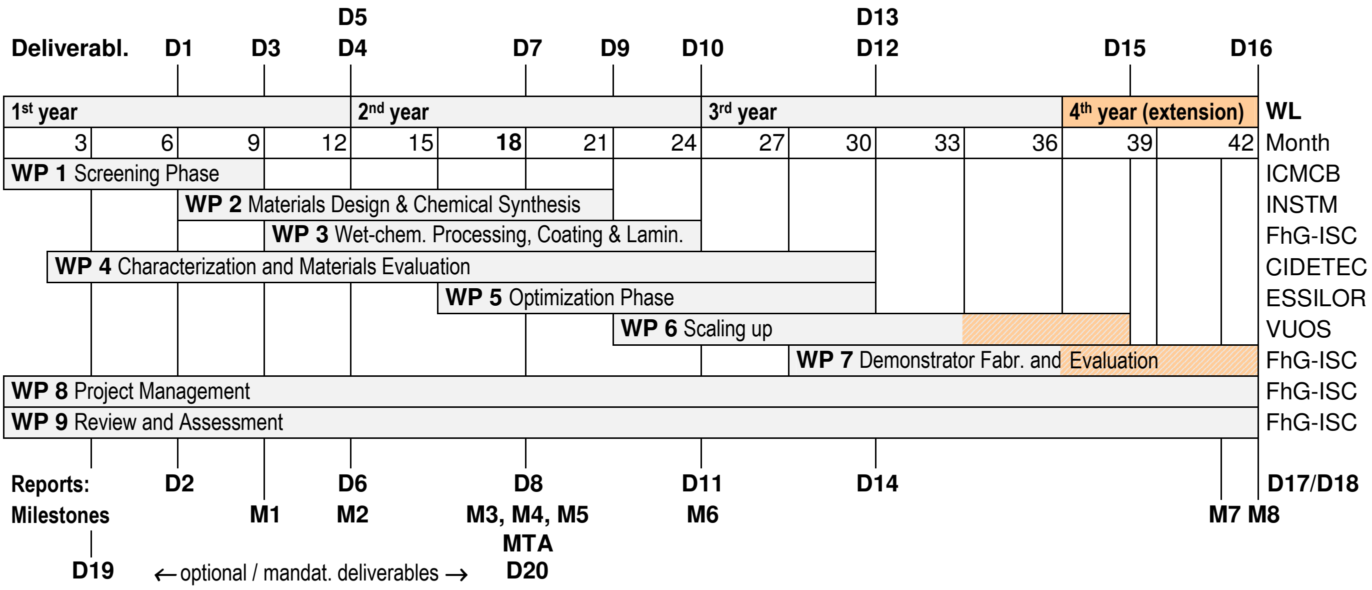
Partic. Role*	**Partic. No.**	**Participant name**	**Participant short name**	**Country**
CO	1	Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V. c/o Fraunhofer-Institut Silicatforschung	**FhG-ISC**	D
CR	2	Centro de Tecnologías Electroquímicas	**CIDETEC**	E
CR	3	Consorzio Interuniversitario Nazionale per la Scienza e Tecnologia dei Materiali c/o Department Materials Science, University Milano-Bicocca	**INSTM**	I
CR	4	Vyzkumny ustav organickych syntez a.s.	**VUOS**	CZ
CR	5	Essilor International	**ESSILOR**	F
CR	6	CNRS - Institut de Chimie de la Matière Condensée de Bordeaux	**ICMCB**	F
CR	7	Institut de Recherche d'Hydro-Québec	**IREQ**	CND
CR	8	Fabrica Española de Confecciones s.a.	**FECSA**	E
CR	9	Functional Coatings Group, Universidade do Minho	**GRF**	PT
CR	*10*	*VACMINHO Ltd. (end date of participation June 30, 2005)*		
CR	11	Solvionic S.A.	**SOLVIO**	F
CR	12	Maser Microelectronica S.L.	**MASER**	E
CR	13	SOLEMS S.A. (*start date of participation July 1, 2005*)	**SOLEMS**	F

*CO: Co-ordinator, CR: Contractor

- **Work performed, methodology and end results**

The work plan was broken down into nine work packages (WP 1 – WP 9). WPs 1 through 6 were linked to RTD activities. WP 7 was linked to activities of type "Demonstration", while WPs 8 and 9 were related to Management tasks. Clearly defined Deliverables were assigned to the WPs. The main project output is innovative plastic ECDs. Eight Milestones (M1 – M8) towards this development were defined, comprising 1st and 2nd generation coating materials and product-like demonstrators including their validation.

The schedule of the work plan is schematically presented in the following Gantt chart (D: Deliverable, M: Milestone, WL: Work package Leader). A total of 565 person-months was deployed.



WP 1 – SCREENING PHASE (RTD activity)

The envisaged ECD technology ought to be compatible with plastic substrates and consist of electrochromic nanocomposite and complementary colouring ion storage layers, contacted by transparent conducting oxide films with an ion-conducting electrolyte in between. The architecture of such a device is shown in Figure 1.

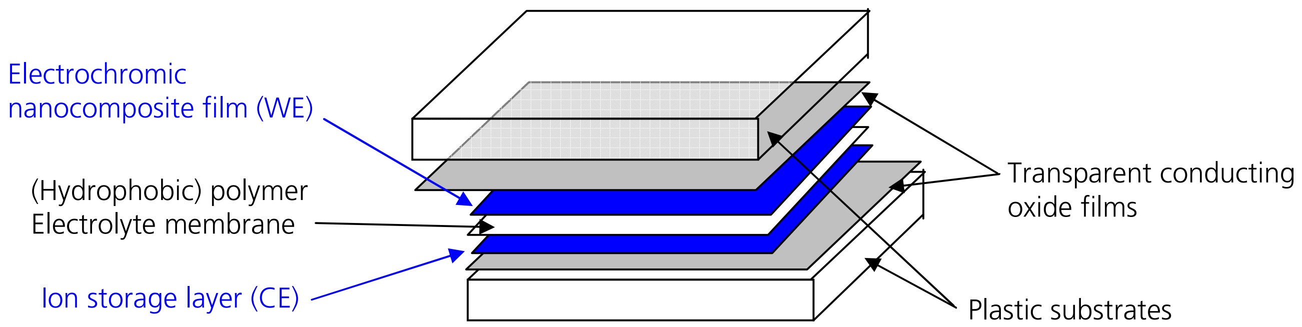


Figure 1. Schematic view of a nanocomposite based electrochromic plastic device. WE: Working, CE: Counter electrode.

In the beginning of the project, a large variety of polymerogenic heterocyclic compounds from commercial sources and conductive polymers (CP) prepared therefrom, as well as available transparent conductive oxides (TCO) and polymer electrolytes were screened in terms of their electrochemical and optical properties. Polysiloxane binder materials and chemical processing aids were studied with regard to their suitability to improve processability, support film formation and assure good adhesion. Customer requirement specifications were compiled by all industrial end-users for prospective products, summarising all technical and aesthetic requirements for a commercialisation.

The highly stable Poly(3,4-ethylene dioxythiophene)s (PEDOT, Figure 2) emerged to be the most promising CP type for applications where switching from a highly transmittive state to a darkened state is required. Different processing options were explored: a) the use of polymer dispersions prepared by a micro emulsion technique (formulated with dispersants and binders; Route i), and b) in-situ oxidative polymerisation (ISP, performed on the substrate to be coated; Route ii). Colouration efficiencies up to $\eta = 1500\ cm^2/C$ were achieved. A commercially available plastic foil coated with tin-doped indium oxide (ITO, T-MOx® 40/175 µm) showed limited chemical stability but promising low sheet resistance (40 Ω/sq.), a high transparency in the visible (T = 91 %) and good adhesion upon bending.

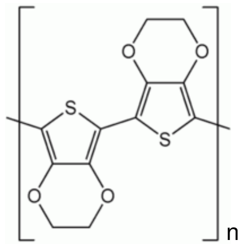


Figure 2. Molecular structure of PEDOT.

Degree to which the objectives were reached: Deliverables D1 (Experimental set-ups for characterisation) and D3 (Selection and screening results / WP 1 report) were delivered in due time. D2 was merged in the 1st periodic activity report, i.e. D6. Milestone M1 [High colouration efficiency polymers (= PEDOTs) and suitable host materials identified, precursors selected] was met.

WP 2 – MATERIALS DESIGN & CHEMICAL SYNTHESIS (RTD activity)

Based on the findings made in the screening phase a novel type of substituted 3,4-ethylene dioxythiophene was synthesized. The monomers were suitable for in-situ chemical polymerisation (Route ii) to attain the target of thin films with high electrochromic contrasts, high cycling stability, and in particular, a virtually colourless oxidised state, which is of utmost importance for ophthalmic applications. The electrochromic properties of the materials developed were superior to polymers derived from commercially available monomers. Trials to use Route i to polymerise the new (water insoluble) monomers by means of micro emulsion techniques were only conditionally effective but highly conductive polymers could be obtained from water soluble monomers. The need for colour modifiers (CM) to correct the blue colour of the neutral polymers was identified. A molecular concept was developed and validated by colour mixing experiments.

Strategies were developed to deposit TCO on plastics and systems with encouraging property profiles were identified (e.g., a film based on SnO_2 with a sheet resistance of $R_s = 25$ Ω/sq., a transparency of T ~ 86 % in the visible at a thickness of d = 1010 nm).

A preparation method for hydrophobic polymer electrolyte membranes based on ionic liquids and Li salts was developed. From structure-property relationships (ionic conductivity vs. transparency vs. adhesive properties etc.) the best trade-offs with respect to the set requirements were selected. Very high ionic conductivities (up to 10^{-3} S/cm at room temperature could be achieved). Figure 3 shows a slightly less conductive but fully transparent and spin-coatable adhesive electrolyte membrane that has been used to laminate two fluorine-doped tin oxide coated glass sheets. Appropriate UV stabilisation concepts for electrolytes and electrochromic devices were also suggested at this stage.

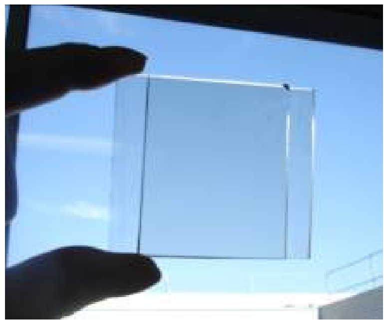


Figure 3. Ion conducting polymer membrane (developed by ICMCB and SOLVIO) between FTO glass sheets.

Degree to which the objectives were reached: Deliverables D4 (Synthesis routes for precursors), D5 (1st generation coating sols/coated plastics), D6 (Progress Report), and D9 (Modified synthesis routes for optimum performance / WP 2 report) were delivered in due time. Milestone M2 (Decision on most promising synthesis & processing routes) was met: Coatings with suitable intrinsic conductivity and electrochromic properties were prepared (= Criteria M2). Decision on the most promising processing routes was taken. The ISP of thiophenes was preferred for those applications where high transparency and a colourless state are mandatory, i.e., ophthalmic lenses (Route ii). The dispersion route (Route i) was considered to be useful for the electroconductive equipment of textiles and for the application of large substrates, e.g., by means of spray coating.

Parallel to the synthetic work in WP 2 in this work package mainly elementary work was performed on how nanoparticulate dispersions (Route i) or monomers (Route ii) can be processed to films with good optical quality, and how TCO can most favourably be applied to plastics. The sol-gel technique was successfully employed to enable wet-chemical processability, enhance the stability of dispersions, and ensure durable adhesion on clean TCO surfaces. The dual nature of the chosen wet-chemical processing method is demonstrated in Figure 4. Route i and ii films were applied to relevant substrates. In order to perform the chemical polymerization in a controlled manner and avoid overoxidation, different moderator bases retarding the polymerisation kinetics by reducing the oxidant's reactivity were evaluated and the most effective ones selected for further optimisation.

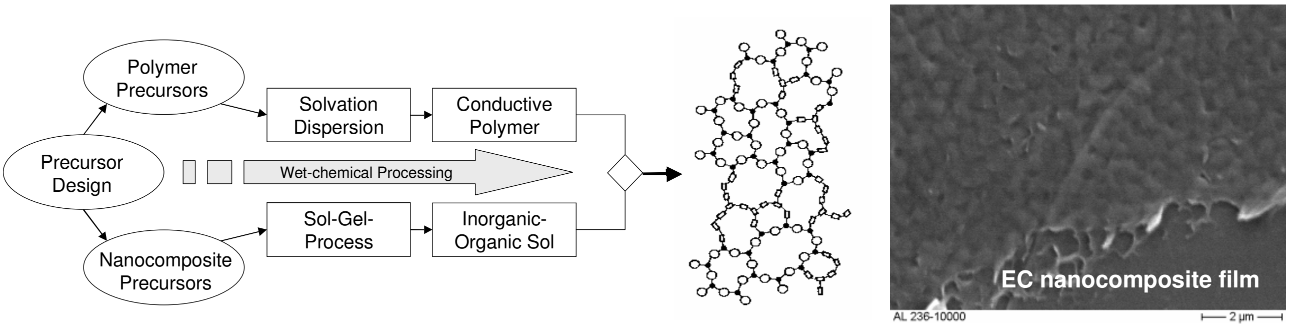


Figure 4. Dual wet-chemical processing of electrochromic (EC) nanocomposite films. Left. Schematic view of the processing; Right: Hybrid polymer structure comprising branched polysiloxane (circles and dots) and linear organic polymer moieties (rectangles; idealised depiction), and SEM micrograph of a selected film prepared from a new monomer developed by Univ. Milano-Bicocca/INSTM.

With the help of hybrid nanocomposite binders, homogeneous CP sols were formulated and used to prepare conductive films on fabrics (< 10^3 Ω/sq.). The room temperature (max. 40 °C) deposition of ITO on ophthalmic plastics by DC magnetron sputtering from ITO targets was successful.

<u>Degree to which the objectives were reached:</u> Deliverables D7 (Midterm Assessment - Validation test results on 1st generation electrochromic plastics), D10 (2nd generation coating sols and coated plastics / WP 3 report), and D11 (Progress Report, 2nd PAR) were delivered in due time. The criteria set for the Midterm Assessment Milestones M3 (Validated, nanocomposite coated electrochromic plastics), M4 (TCO equipped plastic lenses), and M5 (Feasibility assessed for electrochromic equipment of textiles) were met, as shown in Table 1.

Table 1. Midterm assessment criteria and values actually achieved.

Midterm Assessment Criteria	Achievements
• High colouration efficiency proved (η > 120 cm^2/C)	→ η = 600 to 1500 cm^2/C
• Durable adhesion of polymer (B5 acc. to ASTM D 3359) to TCO-coated substrates	→ B5 (excellent)
• Cycle lifetime of ≥ 10^3	→ 10^3 cycles (*)
• Durable adhesion of TCO (B5 acc. to ASTM D 3359) to relevant ophthalmic plastics	→ B5 (excellent)
• Sufficient conductivity of TCO	→ 60 Ω/sq. (good)
• Textiles: appropriate implementation (printing, lamination)	→ Fixation of a flexible device between two fabric layers

(*) in liquid electrolyte under ambient conditions

The Midterm Report (Deliverable D8) with a more detailed comparison of the results obtained and the milestone criteria set was submitted to the European Commission on January 10, 2006.

WP 4 - CHARACTERISATION AND MATERIALS EVALUATION (RTD activity)

Accompanying the synthesis and coating deposition work all relevant systems have been characterised continuously and comprehensively by state-of-the-art analytical techniques. In particular, the following methods were employed:

- NMR-spectroscopy to follow reactions and determine the purity of educts and products;
- Full (spectro)electrochemical characterisation (oxidation potentials, cyclovoltammetry, cycling) of films (open three-electrode setup) and devices;
- SEM, EDX, Raman spectroscopy, and AFM to characterise microstructure and topology as well as to determine the chemical composition of films and surfaces;
- Impedance spectroscopy, UV-Vis spectrometry, viscosimetry, Raman spectroscopy to reveal structure-property-relationships in polymer electrolytes;
- 4-Point measurement of sheet resistances, optionally as a function of temperature;
- Flexural bending tests to investigate the cracking behaviour of brittle films on plastic substrates;
- Accelerated weathering techniques to assess photochemical and moisture stability of films and devices;
- Use of clean and dry room facilities and glove boxes for film preparation and device assembly;
- Electrical testing.

Figure 5 exemplifies an electrochemical cycling test performed on an electrochromic polymer film deposited on PET-ITO sheet by in-situ polymerisation.

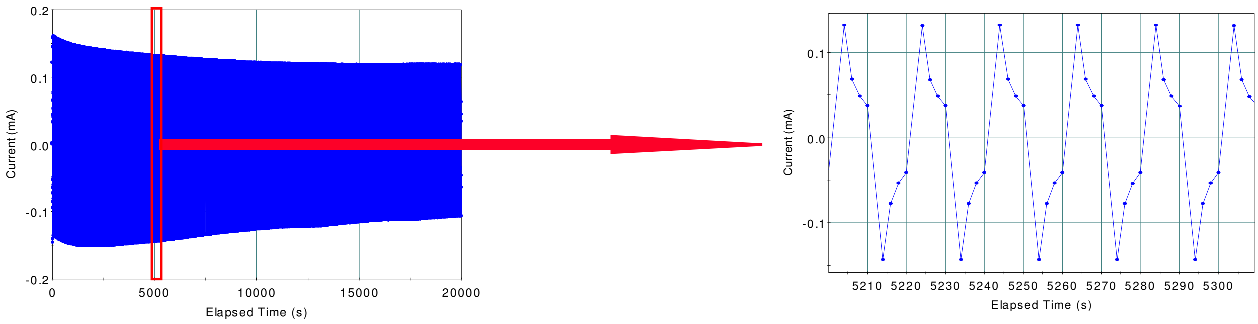


Figure 5. Assessment of the electrochemical stability of a selected nanocomposite film by means of potential cycling. NIR-visible spectra (not shown) were measured at -1.0 V and 1.0 V before and after 1000 redox cycles (10 s each). Electrolyte: 0.1 M $LiClO_4$ in propylene carbonate (open cell).

Degree to which the objectives were reached: Deliverable D12 (Validation test results on 2nd generation electrochromic plastics / WP 4 report) was delivered in due time. The main objective of this WP, i.e., the comprehensive characterisation and electro-optical, thermal and mechanical performance evaluation of ECD system components, was achieved. The results provided a strong basis for the further development, which set the stage for identifying the most promising materials and components.

WP 5 – OPTIMISATION PHASE (RTD activity)

In WP 5 the main emphasis was laid on the optimisation of the single ECD components with regard to the technical and aesthetic requirements, and their assembly to flawlessly running, full devices. Joint optimisation efforts have yielded 2nd generation materials (Milestone M6) and 1st generation electrochromic devices (Deliverable D13) with improved performance in each particular sub-area of the project (TCO, electrochromic films, and electrolytes). The response times for the electrochromic films achieved at that stage of the project were in the range of 2-20 seconds (stability validated by means of electrochemical cycling, see above). Towards the end of the optimisation phase high performance coatings [electrochromic nanocomposite films with high transparency in their bleached state (T = 90 % at 550 nm, no residual blue hue)] and materials [highly conductive, stable polymer electrolytes with adhesive properties ($\sigma \sim 10^{-4}$ S/cm at 25 °C)] were available to enter into the projected scaling-up (WP 6) and demonstrator fabrication activities (WP 7).

The deposition of highly conductive TCO on ophthalmic plastics (50-60 Ω/sq. / $T_v \sim 88$ %) was transferred to curved substrates. During the optimisation phase, the cracking tendency of ITO-plastic compounds could significantly be reduced (Figure 6, left / middle) and the adhesion improved. A ultrasonic sample cleaning process (Figure 6, right) was implemented (→ spin-off result).

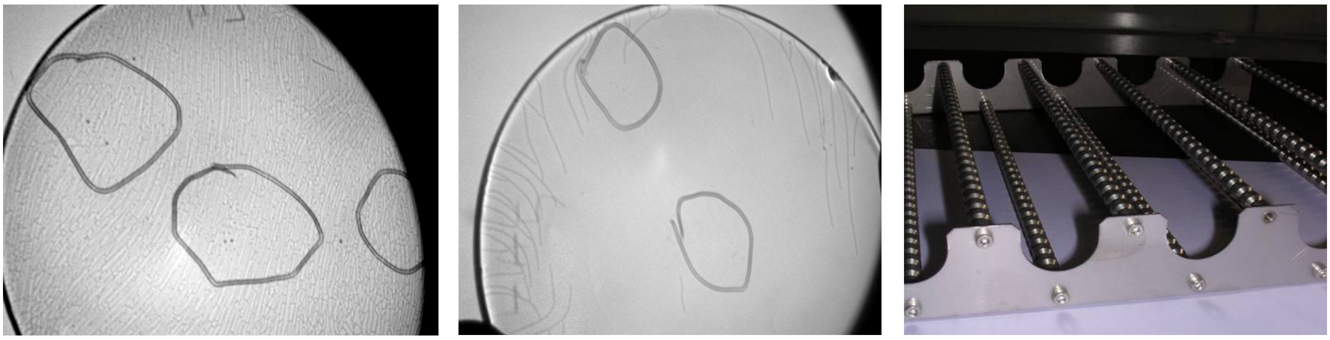


Figure 6. Cracking upon annealing an ITO coated ophthalmic lens. Left picture: Initial situation, many small cracks; Middle picture: Few large cracks; Right picture: Principle of sample baskets for ultrasonic cleaning.

The attempts to fine-tune the hue in the darkened state by means of colour modifiers (see section WP 2) were conditionally effective. The CM structure could be improved such that an orange-pink coloured dye with a colourless oxidised state was obtained. Chemical syntheses were optimised in terms of raw materials consumption, preparative conditions and environmental / occupational protection.

Degree to which the objectives were reached: WP 5 was successfully finished, all WP objectives were reached. Deliverable D14 was merged in the 2nd periodic activity report, i.e. D11. Milestone M6 (2nd generation sols and coated plastics → Decision about final synthesis and processing routes) was met: Joint optimisation efforts resulted in 2nd generation coatings with improved performance and a 1st generation device, where these have been integrated. The criteria set by the consortium for M6 in the Description of Work (Annex I) were essentially fulfilled:

- Curved & flat samples 25 cm^2 & 100 cm^2 in size, respectively, spin-coated and assembled to ECDs.
- Response times in the range of 2-20 s for complete devices depending on configuration and size.
- 1st generation all-plastic devices (D13 = 1st generation electrochromic devices / WP 5 report, Figure 7) comprising the optimised coating compositions survived more than 10^4 cycles of continuous switching with only a slight drop in performance.

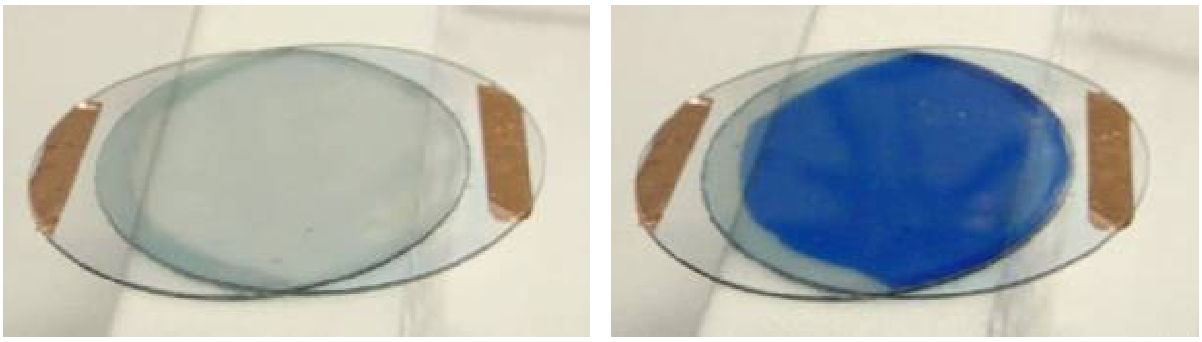


Figure 7. 1st generation electrochromic device comprising optimised electrochromic polymer (INSTM, VUOS, ISC) and Prussian Blue type compositions (ICMCB) deposited on TCO coated ophthalmic plastic lenses (SOLEMS, ESSILOR), laminated with solid polymer electrolyte (IREQ). Left: Bleached state; Right: Darkened state.

WP 6 - SCALING-UP (RTD activity)

Subsequent to the selection and optimisation of the most promising system components scaling up activities were to be deployed. This comprised the scaling-up of the syntheses of starting compounds and precursors as well as the quest for methods to prepare large area coatings/membranes (electrochromic films, TCO films, electrolytes).

- Chemical scaling up work was performed for a number of 3,4-ethylene dioxythiophene derivatives chosen on the basis of previously obtained results. After validation of the lab procedures in WP 5 the multi-step syntheses were scaled up to 50 l glass vessels (Figure 8). 350 g batches of pure final product were prepared affirming that the syntheses are viable and robust enough for production on a pilot plant scale.

Figure 8. 50 l vessel for the synthesis of EDOT derivatives.

- The kinetics of the polymerisation reaction for 3,4-ethylene dioxythiophenes was retarded to a point where processing at room temperature (superseding cooling) and the use of large scale coating application techniques became possible. Thin defect-free polythiophene-polysiloxane films were prepared on substrates up to a size of 15 x 20 cm^2 by means of the doctor blade technique.
- High optical/mechanical quality and even larger sizes (30 x 30 cm^2) were achieved for electrodeposited Prussian Blue (PB) type films, being a suitable ion storage material. Neither the electrochromic polymer coating nor the PB films did crack upon bending but the usually high brittleness of TCO films was considered to require further optimisation. Fragmentation and stress-strain modelling experiments were performed to find a feasible solution (conditionally effective).
- For the scaled-up production of solid polymer electrolyte (SPE) membranes specially designed electrolyte mixtures were processed by means of pilot coating machinery. The technology employed is capable of accurately controlling the thickness and homogeneity of the SPE and can be used in dry (and inert gas) environments to avoid deterioration by oxygen and moisture.
- Appropriate tools for ophthalmic lens cleaning and coating were implemented. By the end of WP 6 the processes were operational for preparing high performance TCO films on low-index plastics (both flat and curved). The potential throughput of the established reactive magnetron-sputtering machine is 1000 units per day for lenses 65 mm in diameter.

<u>Degree to which the objectives were reached:</u> WP 6 was successfully finished; All WP tasks were elaborated on according to the plan and the objectives were reached. Deliverable D15 (Scaled up production of precursors) was duly delivered: Joint efforts resulted in an effective knowledge transfer from the materials developers to those partners that scaled-up the procedures. The scaling up work performed in WP 6 was a necessary prerequisite in order to demonstrate that the processes are industrially viable (up to a pilot plant level as far as the precursor production is concerned), and to manage the fabrication of demonstrators (WP 7).

WP 7 DEMONSTRATOR FABRICATION AND EVALUATION (Demonstration activity)

WP 7 served to fabricate product-like 2^{nd} generation devices (demonstrators) with excellent lifetime and optical performance. Several designs were evaluated, among them curved lens-on-lens devices, rectangular flat lens-on-lens devices with sputtered metal edges, and flexible foil-on-foil devices. In terms of the electrolyte membrane two options (a physically drying hydrophobic system and a more hydrophilic, cross-linked SPE) were pursued.

The optical performance data of a flat lens-on-lens device (configuration: plastic-ITO / electrochromic nanocomposite / SPE / PB type material / ITO-plastic) are exemplified in the following:

- Transmittance:
  - Bleached state: T_b = 79 % at 620 nm (= wavelength of maximum absorption)
  - Darkened state: T_d = 19 % at 620 nm
  - Electrochromic contrast: ΔT = 60 % at 620 nm
- Colour coordinates:[1]
  - Bleached state: L* = 84,52, a* = -2.16, b* = 1.49 (colourless)
  - Darkened state: L* = 55.61, a* = -8.01, b* = -36.34 (dark blue)
- Response times:
  - Colouring to 50 % (90 %) of maximum absorbance: 14 s (31 s)
  - Bleaching to 50 % (10 %) of maximum absorbance: 9 s (13 s)

In extended cycling tests performed under ambient conditions, high operational stability could be confirmed for the lens-based devices (Figure 9). A total loss in the optical contrast in the order of only 20-30 % after 86.000 cycles and a pronounced memory effect were noticed (Figure 11). Periodic testing of large-sized foil-on-foil devices (Figure 10) employing electrical control units and testing sets/protocols used in the automotive business revealed those configurations complying best with automotive requirements. Assets and drawbacks were identified.

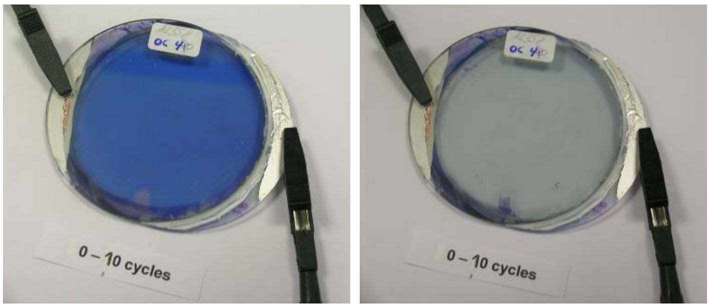


Figure 9. 2nd generation ECD (lens-on-lens configuration). Left picture: coloured state; right picture: bleached state.

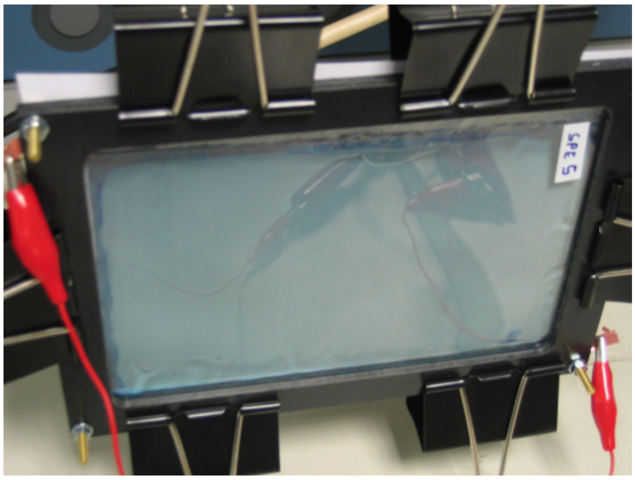


Figure 10. Large-sized 2nd generation ECD (foil-on-foil configuration).

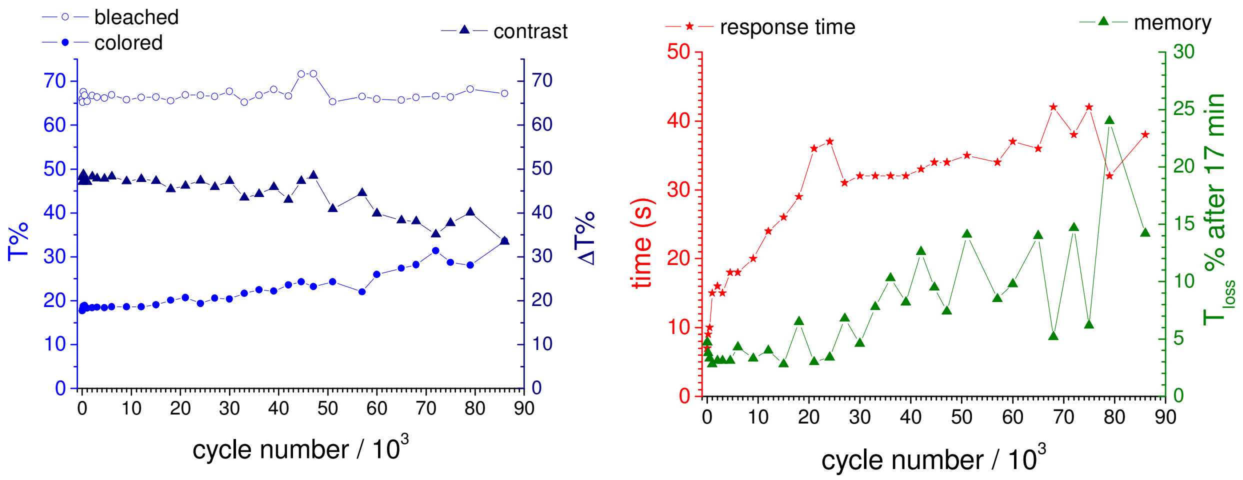


Figure 11. Cycling performance of a 2nd generation electrochromic device as depicted in Figure 9 (switching cycle: 1.1 V for 30 s, –1.0 V for 60 s, 1.1 V for 60 s, –1.0 V for 30 s). Left graph: Coloured and bleached state transmittance and optical contrast (bright, medium and dark blue curves, respectively); Right graph: Response time and memory at open circuit potential (red and green curves, respectively).

[1] According to the CIE-Lab colorimetry system. L*: Luminance, a* = red-green co-ordinate, b* = blue-yellow co-ordinate.

Besides the achievements towards high performance electrochromic plastic devices a considerable number of large size textile demonstrators (30 x 21 cm^2, different types of fabrics, e.g. polyamide, polyester) were equipped with conducting polymer nanocomposite coatings by means of a lab padding machine (→ spin-off result). As can be seen from Table 2 all finishings significantly improved the electronic dissipation characteristics of the fabrics and clearly complied with the requirements set for anti-static textiles (10^9 – 10^6 Ohm/sq). As revealed by the colour and sheet resistance deviations occurring upon washing, a remarkable durability could be stated. Moreover, the nanocomposite films surprisingly improved the tear strength of the textile substrates by up to 60 (warp) and 150 % (weft).

Table 2. Colour, mechanical and electrical dissipation properties of textile demonstrators. Coating: Polythiophene nanocomposites; Substrate: Plain polyamide fabric #694. The AL codes designate different formulations.

Nanocomposite film type	**uncoated**	**AL/503**	**AL/504**	**AL/505**	**AL/520**
Colour coordinates (After washing, 5 cycles 40 °C)					
L* (luminance)	90,69	65,34 (74,03)	71,70 (81,71)	71,26 (76,8)	71,91(76,39)
a* (red-green coordinate)	-0,43	2,02 (2,73)	2,54 (3,41)	2,47 (2,88)	2,53 (2,90)
b* (yellow-blue coordinate)	0,63	-16,29 (-14,67)	-15,07 (-12,43)	-15,76 (-14,43)	-15,82 (-14,41)
Tensile strength (ISO 13934-1)					
Warp	67 daN	67 daN	71 daN	72,2 daN	72,1 daN
Weft	45,3 daN	49,3 daN	48 daN	49,9 daN	48,7 daN
Tear strength (ISO 13937-1)					
Warp	21,14 N	53,3 N	39,5 N	31,4 N	33,2 N
Weft	15,70 N	38,9 N	33,2 N	32,0 N	30,1 N
Electronic dissipation (EN 1149-1) (After washing, 5 cycles 40 °C)	$>10^{12}$ (n/a) [Ohm/sq.]	$<10^5$ ($<10^8$) [Ohm/sq.]	$<10^9$ ($>10^{11}$) [Ohm/sq.]	$<10^8$ ($<10^8$) [Ohm/sq.]	$<10^9$ ($<10^9$) [Ohm/sq.]

- **Relation of the achievements of the project to the state-of-the-art**

The core of the achievements is a novel conducting polymer-polysiloxane nanocomposite coating with outstanding electro-optical properties that changes its optical absorption properties within seconds with a high electrochromic contrast upon the application of a small electric voltage. The colouration efficiency of this material is usually higher than 600 cm^2/C. In comparison with the state of the art material tungsten oxide (40 cm^2/C) this means that conductivity and charge density requirements are drastically lowered, thus resulting in higher stability and lower energy consumption. The electrochromic layer preparation comprises only wet-chemical, cost- and energy-efficient environmentally friendly processing steps, which may present a strong advantage against coatings prepared via state-of-the-art physical deposition processes (e.g. for tungsten oxide). Eventually, the electrochromic films are virtually colourless and highly transparent in their bleached states, which is of utmost importance for use in the ophthalmic sector.

Integrated in plastic devices along with suitable transparent electrodes, ion-conducting polymer electrolytes and Prussian blue type ion storage layers, swift, highly reversible and strong colour changes with an optical density change of 0.8 can be attained. The colour change takes place within seconds upon the application of a potential of approx. 1 V. Literature known obstacles such as poor adhesion of polymer layers on transparent conductors (e.g. ITO) were solved by employment of organosilane chemistry. The use of ionic liquids and corresponding lithium salts in polymer electrolyte preparations resulted in improvements in terms of optical, thermal and electrical properties going beyond the state-of-the-art. Moreover, novel TCO-plastic pairings not existing before were explored for use in electrochromic devices.

The novel ECD technology may constitute a breakthrough in smart shading technology by overcoming common limitations of state-of-the-art technology, such as slow response times, low cycling stability, low colouration efficiency, and incompatibility with lightweight impact resistant plastic substrates. It can be considered for a multitude of uses and applications where the degree of visible or infrared light transmittance is desired to be controlled for reasons of safety, comfort and energy saving.

- **Impact of the project on its industry or research sector**

  Large diverse markets are identifiable for electrochromic products, provided a lost-cost technology is available. With regard to these potential markets, the project has important economic development perspectives. The number of jobs involved in the potential businesses is estimated to be >100.000 in Europe.

  According to the end user partner ESSILOR (holds the major position in ophthalmic glasses development and production in Europe and in the world, 215 million corrective lenses/year) the development may contribute to overcome limitations existing for transmission tuneable lenses, provided thin plastic glasses switching from colourless to a neutral colour can be produced in high-throughput production. Eye-wear and safety goggles represent important markets worldwide (ophthalmic glasses: approx. 10 billion € (850 million lenses per year), sunglasses: close to 100 million €, plus specialty protection glasses). Demands for efficient light transmission tuneable lenses exist. ECDs may be used to realise real smart lenses working under any conditions.

  The focus on a thin flexible polymer-based product will also open up good perspectives with respect to retrofitting and a number of niche applications. The market for upgrading existing (vehicle) windows is much larger than the market for new ones. European automobile makers produce approx. 15 million vehicles per year (worldwide annual production approx. 52 million). The automotive industry represents a large market for smart shading devices including sunroofs, visors, and windows.

  The work shall be continued in a successor project attributed to up-scaling and technology matters (FP7 Large scale integrated project INNOSHADE, under contract negotiation). The textile-related work in NANOEFFECTS will enter into a follow-up activity on protective functional textiles (European research proposal under preparation).

- **Co-ordinator contact details and reference to the project website**

  Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V.
  Hansastrasse 27 C, 80686 München, Germany
  Website http://www.fraunhofer.de

  Authorised scientific contact persons:

  Dr. Gerhard Schottner
  Phone +49-(0)931-4100-627, Fax -698
  E-mail gerhard.schottner@isc.fraunhofer.de

  Dr. Uwe Posset
  Phone +49-(0)931-4100-638, Fax -698
  E-mail uwe.posset@isc.fraunhofer.de

  Postal address: Fraunhofer-Institut Silicatforschung (ISC), Neunerplatz 2, D-97082 Würzburg, Germany

  Project Website: http://www.nanoeffects.eu, http://www.nanoeffects.org, http://www.nanoeffects.de

2. DISSEMINATION AND USE

- Overview table - Dissemination of Knowledge (selected entries, technical meetings and workshops omitted)

Planned / actual Dates	**Type**	**Type of audience**	**Countries addressed**	**Size of audience**	**Partner responsi-ble / involved**
04-2004	*Workshop [a]*	*Industry/Research*	*D*	*30*	*FhG-ISC*
08-2004	*Project website launch [b]*	*General public*	*Internat.*	*unlimited*	*FhG-ISC*
08-2004	*Link from ISC website*	*Interested parties*	*Internat.*	*unlimited*	*FhG-ISC*
10-2004	*Press release [c]*	*Industry/Research*	*E*	*unlimited*	*CIDETEC*
01-2005	*Press release [d]*	*Industry/Research*	*Internat.*	*unlimited*	*CIDETEC*
04-2005	*Conference [e]*	*Research*	*USA*	*300*	*GRF*
05-2005	*Poster [f]*	*Pupils (age 12-18)*	*F*	*200*	*ICMCB*
09-2005	*Seminar [g]*	*PhD students*	*I*	*30*	*FhG-ISC, INSTM*
09-2005	*Conference [h]*	*Research*	*Internat.*	*100*	*CIDETEC*
09-2005	*Conference [i]*	*Research*	*CZ*	*2000*	*ICMCB, SOLVIO*
10-2005	*Conference [j]*	*Research*	*USA*	*250*	*ICMCB, IREQ*
11-2005	*Conference [k]*	*Research*	*USA*	*unlimited*	*ICMCB*
01/2005-12/2005	***Publications [l]***	*Research*	*Internat.*	*unlimited*	*CIDETEC*
05-2006	*Conference [m]*	*Research*	*Internat.*	*3000*	*ICMCB, SOLVIO*
09-2006	*Conference [n]*	*Research*	*Internat.*	*300 directly, unlimited via proceedings*	*6 partners*
09-2006	*Conference [o]*	*Research*	*I*	*300*	*INSTM, FhG-ISC*
10-2006	*Discussions during con-ference [p]*	*Research, Industry*	*Internat.*	*100*	*FhG-ISC, VUOS*
11-2006	*Journal [q]*	*General*	*F*	*unlimited*	*ICMCB*
11-2006	*Seminar [r]*	*Industry, academia*	*CZ, South Korea, Japan*	*85*	*VUOS*
01/2006-12/2006	***Publications** [s]*	*Research*	*Internat.*	*unlimited*	*CIDETEC, ICMCB*
05-2007	*Seminar [u]*	*Research*	*Canada*	*150*	*FhG-ISC, IREQ*
05-2007	*Seminar [v]*	*Industry, academia*	*CZ, South Korea, Japan*	*40*	*VUOS*
07-2007	*Conference [w]*	*Academia*	*F*	*unknown*	*ICMCB*
09-2007	*Conference [x]*	*Research*	*Internat.*	*200*	*CIDETEC*
09-2007	*Forum [y]*	*General*	*Internat.*	*unlimited*	*GRF / Univ. Minho*
01/2007-12/2007	***Publications** [z]*	*Research*	*Internat.*	*unlimited*	*ICMCB, CIDETEC*
Pld. 2008	*Publication [aa]*	*Public, Parliament*	*Internat.*	*unlimited*	*FhG-ISC, EC*
Pld. 2008	***Publications** [ab]*	*Research*	*Internat.*	*unlimited*	*UniMIB / INSTM, FhG-ISC, ICMCB, SOLEMS, ESSILOR*

[a] Workshop "From Molecular Precursors to Smart Materials" held at FhG-ISC in co-operation with the Society of German Chemists (GDCh). Dealing with mechanical and optical actor materials (amongst them electrochromes). The NANOEFFECTS project was introduced (2004).

[b] www.nanoeffects.eu, www.nanoeffects.org, www.nanoeffects.de

[c] Bulletin Adimendun Materialak: This bulletin is issued by Basque research centres involved in a joint project called Actimat. In October 2004 the NANOEFFECTS project was mentioned.

[d] Bulletin CIDETEC: Distributed among CIDETEC's (potential) clients in order to inform them about available technology and projects. The bulletin is sent by ordinary mail and accessible through CIDETEC's web page. The bulletin has national and international impact.

[e] Conference Talk "Characterisation of ITO sputtered coatings on glass and plastic substrates prepared at room temperature", V. Teixeira et al., 48th Annual SVC Technical Conference, Denver, USA.

[f] Poster on electrochromism on the occasion of the "Year of Physics" in France.

[g] Seminar talk for PhD students (Dottorado di Ricerca in scienza dei Materiali), Universita degli Studi di Milano-Bicocca, September 2005.

[h] Spanish network based on photovoltaic, electro-optic, and electronic devices hold in Benicassim (Spain) in September 2005.

[i] Conference Talk "Non-Hydrolytic Ionic Liquid Based Gel Polymer Electrolytes for Flexible Electrochromic Devices", I. Litas, S. Duluard, G. Campet, F. Mauvy, F. Malbosc, M.-H. Delville, EUROMAT, Prague/Czech Republic, 2005.

[j] Conference Talk "Ionic Liquid for Electrochromic Devices Under European Community Program", K. Zaghib, M.-H. Delville, A. Guerfi, I. Litas, P. Charest, G. Campet, 208th Meeting of the Electrochemical Society, Session O1 - ELECTROCHROMICS FOR ENERGY EFFICIENCY, chaired *inter alia* by K. Zaghib (IREQ), Los Angeles/USA, 2005.

[k] Conference Talks at the MRS Conference, Boston/USA 2005: "Electrochromic devices based on hydrophobic ionic liquids"; (ii) "Electrochemical behaviour of tungsten oxide and Prussian blue films in various electrolytic media including ionic liquids", M.-H. Delville, G. Campet, S. Duluard, I. Litas, H. Jung.

[l] Publications in peer-reviewed scientific journals (2005):
- "Variable optical attenuator made by using new electrochromic devices", R. Vergaz, D. Barrios, J. M. Sanchez-Pena, C. Vazquez, C. Pozo-Gonzalo, D. Mecerreyes, J. A. Pomposo, Proceedings of SPIE-The International Society for Optical Engineering (2005), 5840, 389-396.
- "New organic dispersions of conducting polymers using polymeric ionic liquids as stabilizers", R. Marcilla, E. Ochoteco, C. Pozo-Gonzalo, H. Grande, J. A. Pomposo, D. Mecerreyes, Macromolecular Rapid Communications (2005), 26(14), 1122-1126.

[m] Conference talks (T) and poster presentation (P) at the Symposia *Battery and Energy Technology Joint Session* (i, iii) and *Electrode Materials and Processes for Energy Conversion and Storage* (ii) of the 209th Meeting of The Electrochemical Society; Denver, Colorado May 7-12, 2006:
- (i) "Non-Hydrolytic Ionic Liquid Based Gel Polymer Electrolytes for Flexible Electrochromic Devices", M. H. Delville, I. Litas, S. Duluard, G. Campet, F. Mauvy, and F. Malbosc (T);
- (ii) "Nanohybrid Materials Based on Transition Metal Oxides and Conducting Polymers: Toward the Modification of Electrochemical Properties", M.-H. Delville, G. Campet, H. Jung, J. Choy, V. Murugan (T);

- (iii) "Electrochromic Behaviour of Tungsten Oxide (WO_3), poly-3,4-Ethylene dioxythiophene (PEDOT) and Prussian Blue (PB) Films in Ionic Liquid Based Electrolyte and Study of Complete Devices", M. H. Delville, S. Duluard, I. Litas, H. Jung, G. Campet (P).

[n] Poster presentations (P) and conference talk (T) at the 7th International Meeting on Electrochromism (IME 7); September 3-7, 2006, Kadir Has University, Istanbul, Turkey:
- "Electro-optical analysis of PEDOT symmetrical electrochromic devices", R. Vergaz, D. Barrios, JMS Pena, C. Marcos, C. Pozo (P; CIDETEC);
- "Ionic Liquid Based Liquid and Polymer Electrolytes: Electrochromic Behaviour of PEDOT and Prussian Blue Films and Complete Devices", S. Duluard, I. Litas, H. Jung, G. Campet, M.-H. Delville (T; ICMCB);
- "Flexible Electrochromic Devices Based on Non Hydrolytic Ionic Liquid Gel Polymer Electrolytes", M.-H. Delville, S. Duluard, I. Litas, G. Campet, F. Malbosc (P; ICMCB, SOLVIO);
- "Electrochemical and Spectroelectrochemical Investigation of Complementary Electrochromic Devices Based on Oxidatively Polymerised 3,4-Ethylene Dioxythiophenes and Electrochemically Deposited Prussian Blue", A. Celik, S. Duluard, M.-H. Delville, G. Campet, A. Labouret, U. Posset, G. Schottner (P; ICMCB, SOLEMS, FhG-ISC);
- "Recent Advances in Electrochromic Plastic Devices", C. Pozo-Gonzalo, D. Mecerreyes, R. Marcilla, J. A. Pomposo, E. Ochoteco, M. Salsamendi (P; CIDETEC);
- "Mechanistic Study of the Poly(3,4-Ethylene Dioxythiophene) Redox Process", R. Ruffo, A. Celik, U. Posset, C. M. Mari, G. Schottner (P; INSTM/Univ. Milano-Bicocca, FhG-ISC);
- "Single-Doped and Co-Doped SnO_2 Transparent Thin Film Electrodes", I. Saadeddin, B. Pecquenard, J. P. Manaud, H. S. Hilal, G. Campet (P; ICMCB);

[o] Conference Contribution "Meccanismo di ossidoriduzione in poli(3,4-etilendiossitiofeni)", R. Ruffo, C. M. Mari, U. Posset, A. Celik, G. Schottner, XXII Congresso Nazionale della Società Chimica Italiana, September 10-15, 2006, Università degli Studi di Firenze, Italy.

[p] XIIth International Seminar on the Technology of Conducting Polymers, Firenze, Italy, October 9-11, 2006.

[q] "Des Matériaux aux mille facettes" (Reportage), Le Journal du CNRS, n° 202, November 2006, p. 6-7.

[r] 3rd International Fine Chemicals & Specialty Seminar, *Chemical Specialties and Functional π–π Systems: R&D Activities at VUOS,* Necas M., Kubac L., Castkova K., Kaja M., Vynuchal J., November 17, 2006; Ulsan, South Korea.

[s] Publications in peer-reviewed scientific journals (2006):
- "Conductivity enhancement in raw polypyrrole and polypyrrole nanoparticle dispersions", J. A. Pomposo, E. Ochoteco, C. Pozo, P.-M. Carrasco, H.-J. Grande, F.-J. Rodriguez, Polymers for Advanced Technologies (2006), 17(1), 26-29. (CIDETEC)
- "Tailor-made polymer electrolytes based upon ionic liquids and their application in all-plastic electrochromic devices", R. Marcilla, F. Alcaide, H. Sardon, J. A. Pomposo, C. Pozo-Gonzalo, D. Mecerreyes, Electrochemistry Communications (2006), 8(3), 482-488. (CIDETEC)
- "Use of polymeric ionic liquids as stabilizers in the synthesis of polypyrrole organic dispersions", R. Marcilla, C. Pozo-Gonzalo, J. Rodriguez, J. A. Alduncin, J. A. Pomposo, D. Mecerreyes, Synthetic Metals (2006), 156 (16-17), 1133-1138. (CIDETEC)
- Simultaneous doping of Zn and Sb in SnO_2 ceramics: Enhancement of electrical conductivity, Saadeddin I., Hilal H. S., Pecquenard B., Marcus J., Mansouri A., Labrugere C., Subramanian M. A. and Campet G.; Solid State Sci. (2006), 8 (1), 7-13. (ICMCB)

[t] *omitted*

[u] Seminar talk 'Nanocomposite-based Electrochromic Smart Plastic Devices with High Colouration Efficiency (NANOEFFECTS) - a Targeted Research Project funded by the European Commission'', May 16, 2007; IREQ, Montreal-Varennes, Canada.

[v] 4th International Fine Chemicals & Specialty Seminar, *Organic Materials for Electronics and Photonics,* May 22, 2007; Prague, Czech Republic.

[w] Poster presentation "Hydrophobic lithium conductive ionic liquid based membrane electrolytes: evidence of the effect of PMMA addition on ionic liquid and lithium interactions by conductivity and vibrational spectroscopies, S. Duluard, J. Grondin, I. Litas, G. Campet, M.-H. Delville, J.-C. Lassègues, Journées SFC 2007, 16-18 July, 2007, Paris, France.

[x] Poster presentation "Nanoengineering of PEDOT thin films for optoelectronic applications", Dobbëlin, M.; Marcilla, R, Pozo-Gonzalo, C.; Salsamendi, M. ; Ochoteco, E.; , Pomposo, JA.; Mecerreyes, D.;.Bolink, H.; *Thin Solid Films for OLEDs and Optoelectronic Applications,* Polonia, 2007.

[y] Link to NANOEFFECTS website established in the PVD Coatings and Vacuum Technology Forum moderated by V. Teixeira, http://tech.groups.yahoo.com/group/PVD_coatings/message/4146.

[z] Publications in peer-reviewed scientific journals (2007):

- "Synthesis and characterization of single- and co-doped SnO_2 thin films for optoelectronic applications", Saadeddin I., Pecquenard B., Manaud J.-P., Decourt R., Labrugère C., Buffeteau T. and Campet G., Appl. Surf. Sci. (2007), 253 (12), 5240-5249. (ICMCB)
- "Influence of Ionic Liquids on the Electrical Conductivity and Morphology of PEDOT:PSS Films", M. Doebbelin, R. Marcilla, M. Salsamendi, C. Pozo-Gonzalo, P. M. Carrasco, J. A. Pomposo, D. Mecerreyes, Chemistry of Materials (2007), 19(9), 2147-2149.

[aa] "Polymer nanocomposite allows for electrochromic eyewear with low power consumption", NMP publication *Smart materials*, European Commission, in press.

[ab] Publications in peer-reviewed scientific journals (2008):

Accepted / in press

- "Mechanistic study of the redox process of an in situ oxidatively polymerised poly(3,4-ethylene dioxythiophene) film", R. Ruffo, A. Celik-Cochet, U. Posset, C. M. Mari, G. Schottner, Solar Energy Materials & Solar Cells (2008), 92(2), 140–145. (INSTM / Univ. Milano-Bicocca, FhG-ISC)
- "Lithium solvation and diffusion in the 1-butyl-3-methylimidazolium bis(trifluoromethane-sulfonyl) imide ionic liquid", S. Duluard, J. Grondin, J.-L. Bruneel, I. Pianet, A. Grélard, G. Campet, M.-H. Delville and J.-C. Lassègues; J. Raman Spectrosc., accepted for publication. (ICMCB, ESSILOR)
- *Electro-optical analysis of PEDOT symmetrical electrochromic devices,* Ricardo Vergaz, David Barrios, J.M.S. Pena, Carlos Marcos, Cristina Pozo and Jose A. Pomposo, Solar Energy Materials & Solar Cells (2008), 92(2), 107-111.
- *All-plastic electrochromic devices based on PEDOT as switchable optical attenuator in the near IR,* Cristina Pozo-Gonzalo, David Mecerreyes, José A. Pomposo, Maitane Salsamendi, Rebeca Marcilla, Hans Grande, Ricardo Vergaz, David Barrios and José M. Sánchez-Pena, Solar Energy Materials & Solar Cells (2008), 92(2), 101-106.

Submitted / planned

- "Lithium solvation in a PMMA membrane plasticized by a lithium conducting ionic liquid based on 1-butyl-3-methylimidazolium bis(trifluoromethane-sulfonyl)imide", S. Duluard, J. Grondin, J.-L. Bruneel, G. Campet, M.-H. Delville and J.-C. Lassègues; Submitted to J. Raman Spectrosc.. (ICMCB, ESSILOR)
- "The effect of aliphatic moderator bases on the in-situ chemical oxidative polymerisation of 3,4-ethylene dioxythiophene", A. Çelik-Cochet, R. Ruffo, C. M. Mari, U. Posset, G. Schottner; in preparation. (FhG-ISC, INSTM / Univ. Milano-Bicocca)
- „Electrochemical and spectro-electrochemical investigation of complementary electrochromic devices based on oxidatively polymerised 3,4-ethylene dioxythiophenes and electrochemically deposited Prussian blue"; A. Celik-Cochet, S. Duluard, M-H. Delville, G. Campet, A. Labouret, U. Posset, G. Schottner, in preparation. (FhG-ISC, ICMCB, SOLEMS)
- IRS study of electrolytes based on $BMIPF_6$ and BMITFSI ionic liquids with LiTFSI lithium salt and PMMA polymer, S. Duluard, I. Litas, G. Campet, M.-H. Delville; in preparation. (ICMCB, ESSILOR)

- Publishable results

Publications

Several conference talks and poster presentations were held on publishable results (see overview table in SECTION A.2 of the PUDK). Written publications were in many cases limited to the abstracts published in the conference proceedings.

After the Midterm meeting (End of October 2005), different consortium partners entered into the preparation of patent applications in order to protect the generated Intellectual Property (confidential; disclosed in SECTION A.1 of the PUDK). At disclosure of the corresponding patent applications, manuscripts are planned to be submitted to peer reviewed journals.

Some of the results presented at the 7th International Meeting on Electrochromism (2006) will be published in a special issue of Solar Energy Materials & Solar Cells in 2008 (Volume 92). The publication of several contributions has been confirmed by the time of writing this report (see item [ab] in previous section, status of all papers: in press, corrected proof, available online).

Besides, a contribution for a NMP brochure on Smart materials to be issued by the European Commission has been prepared. The publication is still pending.

Subsequent to the end of the project, selected results shall be published via the project website, peer-reviewed scientific journals (e.g. Electrochimica Acta) and popular scientific magazines with a wider audience (e.g. Materials Today). The publications are expected to be issued not before the second half of 2008.

Some partners will be attending the 8th International Meeting on Electrochromism (to be held August 2008 in South Korea). Selected project results are planned to be presented (poster presentations, oral contributions). A selection of these presentations will presumably be published in a special issue of a peer-reviewed journal within a scope connected to the subject.

Products and materials / spin-off-results

- Ionic liquids (corresponds to Exploitable result #1 of SECTION A.1 of the PUDK): Production of ionic liquid or molten salts for the chemical industry (catalytic, organic or electrochemical), from small to larger quantities under dry and inert conditions. Ionic liquid compounds are of great importance for green chemistry due to their non-volatility and inflammability, and may enable better selectivity and reactivity in environmentally friendly chemistry. R&D on new multi-functional ionic liquids with regard to catalytic and electrochemical applications. Preparation of solid electrolytes *via* blending with oligomers or polymers.
    - Stage of development: Industrial product.
    - Collaboration offered (manufacturing agreement, licensing).
    - Contact: Dr. Francois Malbosc, SOLVIONIC, Toulouse / France, e-mail: contact@solvionic.com..

- New UV absorbers (corresponds to Exploitable result #3 of SECTION A.1 of the PUDK): New type of effective UV absorbers that can be added to protective coatings or incorporated in mass into the article to be protected. The products are colourless, do not affect the transparency of the coatings and do not migrate in the system. Special silylated species are intended for a use where anti-scratch and UV protective properties are required.
    - Stage of development: Laboratory prototype.
    - Collaboration sought outside the field of electrochromics
    - Contact: Ing. Lubomir Kubac, VUOS a.s., Pardubice / Czech Republic, e-mail: lubomir.kubac@vuos.com.

- Thiophene monomers (partly corresponds to Exploitable result #10 of SECTION A.1 of the PUDK): Functional thiophene monomers for the preparation of conducting polymers. New procedure for the synthesis of 3,4-alkylene dioxythiophene derivatives yielding highly pure final products (patent application CZ, PV 2007-310, pending). Process verified on pilot plant scale, ready for full-scale production. Possible applications besides electrochromic glazings: Electronics/photovoltaics (e.g., hole injection layers), anti-static equipment of plastics, protective clothing, camouflage, sensors.
  - Stage of development: Laboratory prototype.
  - Collaboration sought outside the field of electrochromics
  - Contact: Ing. Lubomir Kubac, VUOS a.s., Pardubice / Czech Republic, e-mail: lubomir.kubac@vuos.com.

- ITO-doped zinc target (partly corresponds to Exploitable result #11 of SECTION A.1 of the PUDK): ITO-doped zinc target for electrochromic windows. The technology is based on collaborative work between IREQ (Hydro Québec) and CNRS-ICMCB. The target can advantageously be employed for the physical vapour deposition of high performance conductive oxide layers for use in electrochromic devices. Further fields of application: displays, functional glazings, solar cells.
  - Stage of development: Laboratory prototype.
  - IPR: IREQ and CNRS-ICMCB have filed a joint patent application.
  - Collaboration offered (contract research, licensing)
  - Contacts: Dr. Guy Campet, CNRS - Institut de Chimie de la Matière Condensée de Bordeaux / France, e-mail: campet@icmcb.u-bordeaux.fr.

- Inorganic-organic hybrid polymers (ORMOCER®s[2]) (tangent to Exploitable results #3, #4 & #5 of SECTION A.1 of the PUDK): Sol-gel derived multifunctional coating materials for versatile use. They are synthesized *via* wet-chemical processing of alkoxy silanes and metal alkoxides at low temperature. Process yields nanoscale polysiloxane clusters bearing functional groups at their periphery that can be subsequently crosslinked by UV irradiation or thermally to form a hybrid interpenetrating network. The nano-sized domains are formed in-situ and trapped by firm covalent bonds endowing the materials with a unique property profile. The properties can be tailored by chemical design and may range between those of glassy inorganic materials and flexible organic polymers. Compounds as described in *Exploitable results 3, 4 & 5* can be incorporated. Hybrid polymers do not show any light scattering and are superior to organic coatings in terms of abrasion resistance and chemical stability. Possible applications: Coatings for mechanical and corrosion protection, films for optical applications (smart or switchable systems), easy-to-clean and self-cleaning surface equipment, anti-static and anti-microbial coatings, textile finishing, binder materials, and many more.
  - Stage of development: Laboratory prototypes and ready-to-apply products.
  - Comprehensive IPR basis: Numerous granted patents; Review publications: G. Schottner, Chem. Mater. 13 (2001) 3422; G. Schottner, K. Rose, U. Posset, J. Sol-Gel Sci. Technol. 27 (2003) 71; G. Schottner, K. Rose, S. Amberg-Schwab, Kunststoffe 94 (2004) 306.
  - Collaboration offered (contract research, licensing)
  - Contact: Dr. Uwe Posset, Fraunhofer Institut für Silicatforschung, Würzburg / Germany, e-mail: uwe.posset@isc.fraunhofer.de.

[2] Trademark of Fraunhofer-Gesellschaft zur Förderung der angewandten Forschung e.V., München.