PUBLISHABLE FINAL TECHNICAL REPORT

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ACRONYM: **SmartWin II**

TITLE: **New Liquid Crystal Smart Windows and Its Production Process**

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Executive publishable summary

This project is an example of applied nanotechnology, namely development of a smart window with three operating mode by means of Polymer Network Liquid Crystal (PNLC).

The main objective is the implementation, owing to the conception and the realisation of a pre-industrial machine, of a smart window:

- with sufficient area glazing to meet the market,
- using a technology which supplies the glazing with three operating modes:
    - a reflective mode limiting the glazing overheating
    - a transparent mode with an excellent transparency
    - a scattering mode having a grey scale,
- for which the operating modes don't require energy consumption and where the transition from one to the other mode is fast (10 ms) thanks to an applied voltage or voltage pulse,
- allowing a high solar factor modulation: a Solar Heat Gain Factor (SHGS) between 0.3 and 0.8.and a high daylight modulation between 0.1 and 0.8.

with a good lifetime.

The outcome of the project was:

Several methods were developed and these allowed improving and realisation a number of lab-scale size (from 2 cm sq. up to 15 cm x 30 cm), active films with three optical states (clear, reflective or scattering state) to three original and complementary directions:

- increased modulation magnitude of the light flux (reflective band broadening up to 240 nm),
- obtain near perfect reflective state and
- having a glazing with only one reflective face.

A concept study – including simulations - of the optimal pattern and shape for SmartWin II windows as well as realisation and scaling-up of switchable patterned glass samples for smart windows.

A market assessment study of smart windows have been carried out and by taking into account e.g. the fenestration markets, functionality and cost of currently available daylight systems, and it shows a very large market potential for this technology.

Conception and realisation of a pre-industrial machine for manufacturing smart windows were obtained. By means of this pre-industrial machine, the sample surface area was progressive increased from lab-scale (approx. 10 cm sq.) up to 60 cm x 80 cm at Mid-Term and up to 68 cm x 120 cm at the end of the project.

Objectives and strategic aspects

The project was organised into four different Work Packages (besides the Management Work Package) and their Tasks (responsible partner acronym in brackets – for full name, see last page):

Work Package 2 – Improvement of new materials
- Task 2.1 – Out-of-equilibrium conditions (CEMES)
- Task 2.2 – Asymmetrical system (LPMC)
- Task 2.3 – Two-frequency addressable LCs (POLYMAGE)

Work Package 3 – Patterning
- Task 3.1 – Definition of optimal pattern (BARTENBACH)
- Task 3.2 – Realisation of patterns (POLYMAGE)

Work Package 4 – Machine for glazing manufacturing
- Task 4.1 – First prototype (DUNA)
- Task 4.2 – Improvement and new types of films (DUNA)

Work Package 5 – Technical evaluation and market assessment
- Task 5.1 – Technical evaluation (CSTB, BYG.DTU and BARTEBBACH)
- Task 5.2 – Market assessment (BARTEBBACH)

The objectives on a Task-by-Task basis are as follows:

<u>Work Package 2 – Improvement of new materials</u>

<u>Task 2.1 Out-of-equilibrium conditions (CEMES)</u>. Improvement of light reflection properties and performances in new Polymer Network Liquid Crystals (PNLCs) by increasing the modulation magnitude of the light flux. By means of different methods, the bandwidth for solar light reflection compared to common chiral liquid crystals (CLCs) should be significantly broadened – almost more than 200 nm – and the modulation of intensity level increased.

<u>Task 2.2 Asymmetrical system (LPMC).</u> All the active films that were made up and used until now are symmetrical active films, but a glazing is in an asymmetrical situation when incorporated into a windowpane and hence it is interesting to have an asymmetrical windowpane as regards light or thermal flux. The objective was the realisation of an asymmetrical layer using different methods. There was expected a strong difference of the reflected light from each of both faces of the resultant film.

<u>Task 2.3 Two-frequency addressable LCs (POLYMAGE).</u> Improvement of light reflection properties and performances in new Polymer Network Liquid Crystals by obtaining quasi-perfect reflective state (i.e. no visible defects at the naked eye). A faster return to the reflective state after switching and a quasi-perfect reflective state will be reached by using a suitable two frequency addressable (TFA) liquid crystal.

Work Package 3 – Patterning

Task 3.1 Definition of optimal pattern (BARTENBACH). Patterning, as the major output from this work package, is a completely new way of manipulating the optical and thermal behaviour of windows, because it is only feasible with this new technology of liquid crystals. The main goal of this task was to define a model pattern system and perform simulations with several varying parameters. Hereby, decision criteria were found and a final pattern was defined.

Task 3.2 Realisation of patterns (POLYMAGE). The realisation of patterns involves the etching of ITO (indium tin oxide) on some specific zones of the glazing in order to electrically control only the remaining ITO areas. In this task, the size and the shape of the surface areas had to be modified as well as the nature of the optical states for each of them.

Work Package 4 – Machine for glazing manufacturing (DUNA)

Task 4.1 First prototype. The machine implements a production process, which will include the key aspects of the film elaboration. At Mid-Term, the machine could allow producing 60 cm x 80 cm glazings devoted to a smart window prototype.

Task 4.2 Improvement and new types of films. Integration in the process of the larger area glazings, i.e. up to 120 cm x 80 cm, and the new type of films.

Work Package 5 – Technical evaluation and market assessment

Task 5.1 Technical evaluation (CSTB, BYG.DTU and BARTENBACH). Detailed characterisation of the luminous and thermal properties of the obtained films respectively windows (obtained in WP 2, 3 and 4) should be made by measurements. The characterisation analysis of each sample acted as feedback for the research in the three other Work Packages.

Task 5.2 Market assessment (BARTENBACH). An assessment of the potential market for liquid crystal windows both on the European level and the World market was carried out. Data from all European countries was collected and cost-benefit analysis performed for different economic scenarios. The integration in the facade and synergy effects of a combination with daylight systems was outlined.

Strategic aspects

The project fulfils the intentions in the **European Research Area (ERA)** - integration of the European research efforts and capacities. The consortium involves research groups and facilities from four different European countries. The **European added value** is the fundamental basis for the achievements within this multi-disciplinary project involving and combining several of the **Research priorities for Europe**: *"Nanotechnologies, intelligent materials and new production processes"* and *"Sustainable development"*. Two of the partners of the consortium are a SME and hence SmartWin II significantly increases the SMEs' research investment and its ability to participate in trans-European high-tech networks as intended in the **ERA**. Furthermore, the project is in direct line with the overall target of the **European White Paper** on Energy for the Future COM(97)599 final (26/11/97); "Promoting of high efficiency windows" is suggested as specific measure to reach the target of a total reduction of the energy consumption in the building sector by 50% in 2010. The application of the SmartWin II technology contributes in two ways; by increasing the use of daylight and hence reducing the use of artificial light as well as reducing the heating and/or cooling loads. Among other contributions to the EU policies can e.g. be mentioned that this technology improves the quality of life and health in terms of better climate and daylight control, which will improve the working conditions for many employees. Also the preserving and/or enhancing the environment policy will benefit from SmartWin II due to that primary fossil energy can partly be replace by solar energy and thus CO_2 reduction is going to be obtained.

Scientific and technical description of the results

Work Package 2 – Improvement of new materials

Task 2.1 – Out-of-equilibrium conditions (CEMES).

Several different 2 cm x 2 cm and 5 cm x 5 cm switchable cells with large reflective band broadening (up to 240 nm) were elaborated. Cells with larger sizes, 10x10 cm^2 were elaborated in collaboration with DUNA.

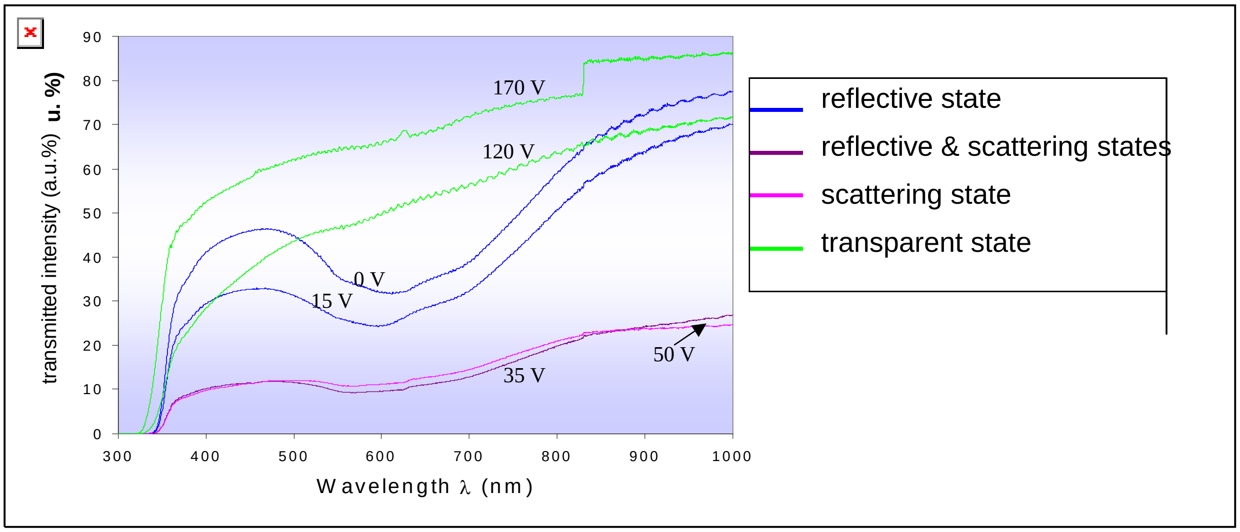


Figure 1. Example of a broadband cell subjected to an electric field: Variation of transmitted light as a function of the wavelength for different voltage values.

Task 2.2 – Asymmetrical system (LPMC).

Different samples with sizes from 2 cm x 2 cm up to 10 cm x 10 cm were made and showed the expected asymmetry: The reflection measurements are different according to the analysed face. The reflection can be controlled by voltage application. The initial state is recovered after voltage application.

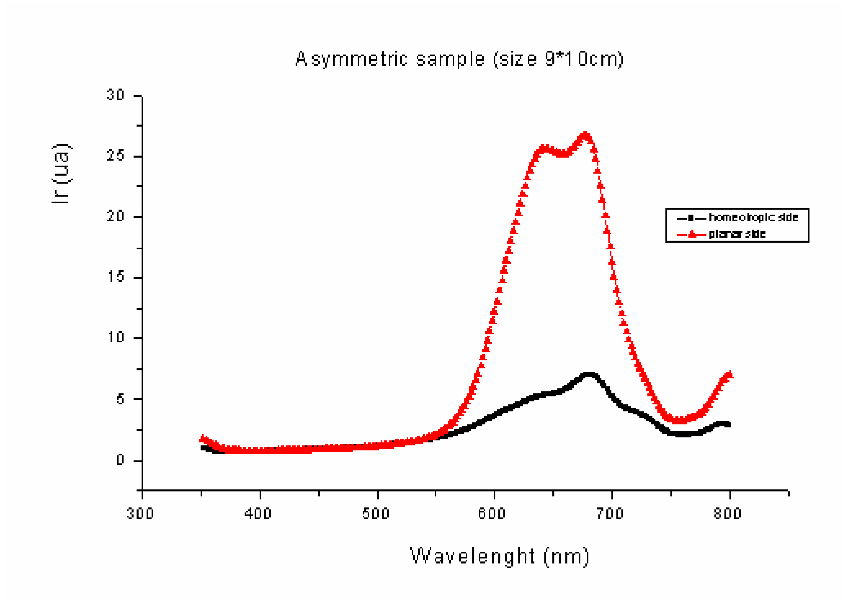


Figure 2. Example of asymmetric cell: Reflection of the planar (red) and homeotropic (black) sides.

Task 2.3 – Two-frequency addressable (TFA) LCs (POLYMAGE).

New films using TFA crystal liquids were successfully elaborated with sizes from 2 cm x 2 cm and up to more than 5 cm x 5 cm, four samples were characterised, which showed no visible defects, a faster return to the reflective state after switching and a quasi-perfect reflective state.

Figure 3a. Sample PM11: reflection view – Off-State.

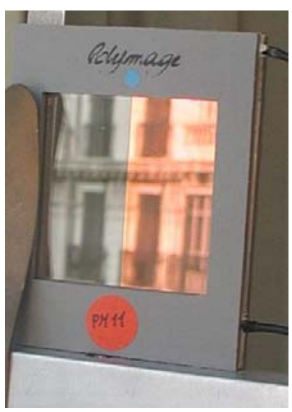


Figure 3b. Sample PM11: reflection view – transparent state.

Figure 3c. Sample PM11: reflection view – immediate return.

Figure 3d. Sample PM11: reflection view – return after U = 47V, f = 14 khz, for one minute.

Work Package 3 – Patterning

Task 3.1 – Definition of optimal pattern (BARTENBACH).

A detailed study was carried by means of simulations. The simulation results, the familiar appearance of horizontal stripes from conventional daylight systems, etc., lead to a final pattern design of five horizontal, individual controllable stripes.

Task 3.2 – Realisation of patterns (POLYMAGE).

Several samples were successfully elaborated with the sizes from 5 cm x 5 cm and up to 15 cm x 30 cm and the number of individually controllable stripes range from two to eight. A process was developed in order to realise the patterns on the samples.

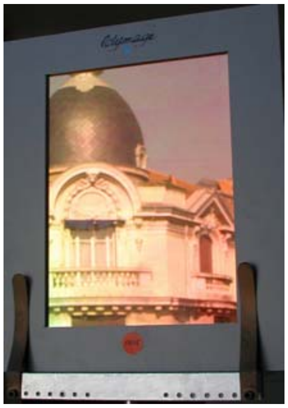


Figure 4a. Sample PM08: reflection view - Off-State.

Figure 4b. Sample PM08: reflection view – voltage stripes 2 and 4.

Figure 4c. Sample PM08: reflection view – voltage all stripes except 3

Figure 4d. Sample PM08: reflection view – voltage all stripes.

Work Package 4 – Machine for glazing manufacturing

Task 4.1 – First prototype (DUNA).

A clean room was made and in there, the equipment for the manufacturing process was developed, tested and installed. Two samples of 60 cm x 80 cm were successfully elaborated on time at Mid-Term.

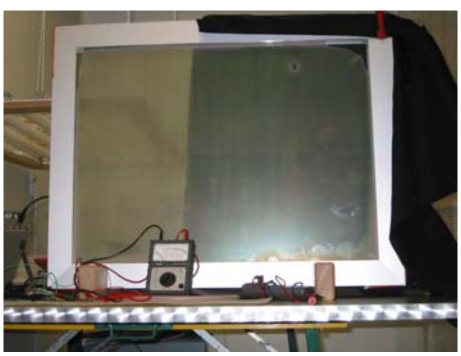
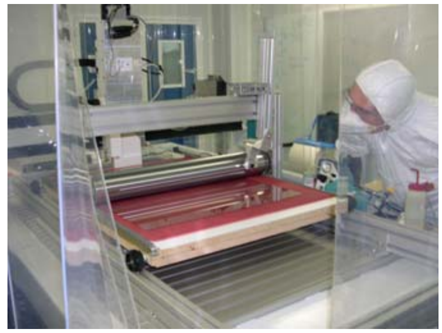


Figure 5. One of the 60 cm x 80 cm LC samples made by DUNA at Mid-Term.

Task 4.2 – Improvement and new types of films (DUNA).

The equipment was modified for larger sample sizes and two samples of 120 cm x 68 cm were elaborated. And the results of Work Packages 3 – Patterning were integrated into the large samples. The complete process is sketched below in figure 6.


1 - Preparation of substrates.


2 - Anchorage layer deposit.


3 - Drying and baking of layers.


4 - Preparation for anchorage layers.


5 - Beads dispensing on closed room –
before cholesteric liquid crystal filling.


6 - Last operation on the sample –
combining thermal treatment and insulation..

Figure 6. Illustration of the SmartWin II process in six steps within the clean room.

Work Package 5 – Technical evaluation and market assessment

Task 5.1 – Technical evaluation (CSTB, BYG.DTU and BARTEBBACH).

The samples from Work package 2, 3 and 4 was characterised optically by means of spectrophotometer and goniospectrometer, and the test results served as guidance for the further research in the above-mentioned Work Packages. Furthermore, preparations were made for an outdoor, test facility for in-situ, dynamic g- and U-value measurements on the large SmartWin II samples. But the samples weren't ready within the timescale of this project.

Task 5.2 – Market assessment (BARTENBACH).

The European and World market for SmartWin II windows have been estimated based on e.g. the fenestration markets, functionality and cost of currently available daylight systems, etc. The last one is indicated below:

Cost dimensions of current available fenestration sytems:

- (super) heat protection glass	€ 50 - 100,-/m^2
- sun protection glass	€ 100 - 200,-/m^2
- simple lamella system	€ 100,-/m^2
- lamella system with daylighting function	€ 200,-/m^2
- daylight system in between insulating glass	€ 300 - 700,-/m^2

SmartWin II would be a switchable combination of all these functions!

Even a conservative estimate gives a very large market potential for SmartWin II windows.

Assessment of Results and Conclusions

Several methods were developed and these allowed improving and realisation a number of lab-scale size (from 2 cm sq. up to 15 cm x 30 cm), active films with three optical states (clear, reflective or scattering state) to three original and complementary directions:

- increased modulation magnitude of the light flux (reflective band broadening up to 240 nm),
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