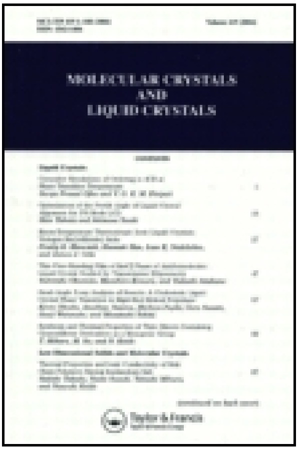

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PDLC Building and Automotive Glazing Applications

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PDLC Building and Automotive Glazing Applications

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The paper describes the state of the art of the PDLC, the main producers in the world differentiated by European, USA and Japan situation as in know how as in manufacturing as in applications, the Italian situation with Isoclima (SPS) and SNIA activities is also mentioned.

The PDLC market situation is still quite low due to the high cost and even due to technical performances which, in a simple word, are still mainly confined on building architectural internal ambient. Only in Japan, some architectural situations concern even external building applications.

A tentative innovative application on vehicle field for switchable sunvisors and blind persian switchable panels on lateral and backlite windows, are also part of the experimental work described in the paper.

Finally, to overcome patent, performance and reverse mode behavior, a strong tentative by Isoclima with innovative principles are also propedeutically described to show the strong willing of Isoclima to be at highest level in the field of PDLC as a switchable glazing. Unfortunately, the intrinsic weakness of the market to use PDLC technology is still a real limit even after the innovative Isoclima's patents. In fact, other switchable technologies, like the EC (electrochromic), SPS (suspended particle dispersion) and, recently, cholesteric LC, seem coming soon. So, the present work has suggested to develop in Isoclima (SPS) further new PDLC technologies, like the reverse mode, in collaboration with Chemical Department of Calabria University (Italy). The recent successful results in Isoclima (SPS) show the necessity to be industrially developed with worldwide interested partners.

Keywords: PDLC; Building; Automotive applications; New PDLC reverse mode

State of the art

The worldwide state of the art consists on the present patent situation and the main PDLC film manufacturing producers and building glazing manufacturers. All the useful information are described as following:

Patent: **Fergason – Raichem Co.** (USA) NCAP patent, still strong worldwide and enough to infringe the phase separation Kent State (USA) patents and the many others following.

USA: **3M** producing film "Viracon" (recently not anymore) to be applied in Viracon windows.
Polytronix producing film "Polyvision" even in color – Fig.1

Japan: **UMU** (Company of Nippon Sheet Glass Group) producing film and applications – Fig.2 and 3 – even on external ambient – Fig.4.

Europe: **Saint Gobain-Saint Roch** (3M or UMU film) manufacturing "Privalite" only building window. The performances exhibited by the Saint Roch PDLC product are shown in Table 1.
Isoclima: Only Italian market applications with also some prototype glazing in automotive (Fig.5 and 6).
Snia: Producing PDLC film with own process and characteristics shown in Table 2.

The summarized description points out:

- the main patent is still strongly at the hands of Raichem;

- the PDLC film producers at industrial level, are now only UMU (Japan) and Polytronix (USA). SNIA (Italy) has recently started to produce a small production to be tested. In order to have the specifications of the producing PDLC, Fig. 1 for Polytronix and Table 1 for SNIA, show their typical characteristics which do not differ from those of UMU;

- the switchable PDLC manufacturing windows for building, are Saint Gobain-Saint Roch in Europe (See the characteristics in Table 2), UMU in Japan and Viracon in USA.
  The main typical building applications of the switchable PDLC glazing are realized by UMU (Nippon Sheet Glass) as are shown in

Office Space (Fig.2), in House (Fig.3) and in External building (Fig.4).
Isoclima seems the only worldwide Company who has developed prototype of PDLC glazing for automotive applications in cars (Fig.5) and in trucks (Fig.6).
On the sunvisor of the trucks'windshield can be noticed the possibility of two alternative switchable zone requested by the trucks drivers. The performances of the glazing are described in a confidential Fiat-Iveco's report. But it can be pointed out that the PDLC glazing seems not completely satisfactory from the cost/benefit ratio to be industrially applied. One of the main task to be achieved is the reverse mode performances as Isoclima started to develop by a recent R&D in collaboration with Chemical Department of Calabria University obtaining significant positive results necessary to be industrially developed with interested partners willing to entry the automotive market with PDLC reverse mode glazing.

TABLE 1: SNIA'S PDLC CHARACTERISTICS

Capacitive impedance: 800 Ω/50Hz quite stable with temperature (capacitive factor quite strong).

- transparency "on" similar to Polytronix
- transparency "off" a little longer than Polytronix
- adhesion with metallized coating internal at the sandwich lower than polytronix
- the characteristics are shown in Table 2 where V (volt): voltage in sinusoidal current 50Hz; I (mA) electrical current; P (VA/m^2): electrical power/m^2; TL: light transmission (illuminant A); Haze %.

V [V]	I [mA]	P [VA/m^2]	T.L.	HAZE %
10	9		56.8	14.01
20	21.8		66.9	"
30	35		72.8	"
40	48	4	74.3	9.02
50	61	6.3	74.9	6.75
60	75	9.4	75.3	5.71
70	87	12.5	75.6	5.11
80	100	16.6	75.9	4.74
85	107	18.8	75.9	4.56
90	113	21	76.1	4.47
100	127	27	76.2	4.28

For voltage over 70 volt, the haze is lower than the haze of Polytronics but can create some inconvenient at voltage over 80 volt.

TABLE 2: Saint Gobain – Saint Roch PDLC "Privalite" performance

	SINGLE GLASS		DOUBLE GLASS	
	on	**off**	**on**	**off**
LT (transmission)	**75%**	**74%**	**67%**	**66%**
LR (reflection)	**19%**	**18%**	**23%**	**22%**
Solar factor	**---**	**---**	**59%**	**59%**
Haze	**6.5%**	**94%**	**6.5%**	**94%**

Thermal conductivity of double glass in the range of 2.8 down to 1.3 W/m^2k.

APPLICATIONS

Automobile— POLYVISION™ is used as privacy glass on windows, including bullet proof windows. POLYVISION™ is utilized as a single source switching element for tail lights as well as for turn signals.

Banks — POLYVISION™ is utilized in teller windows and automated teller areas to insure privacy before and after business hours.

Home Construction — POLYVISION™ is utilized on skylights to control lighting as well as on windows for privacy, thereby minimizing or eliminating the use of blinds.

Hospitals— POLYVISION™ is utilized in newborn units to control visual inspection of newborns with ease.

Office Building Construction—
POLYVISION™ is utilized for privacy in conference rooms when needed without compromising interior design concepts.

Outdoor Advertising — POLYVISION™ replaces standard light bulb applications to maximize visual appeal. POLYVISION™ allows multiple advertisements for a single advertiser. POLYVISION™ is especially attractive when utilized for advertising at outdoor sporting events.

POLYVISION™ SPECIFICATIONS

Standard Glass Colors:
Clear, Bronze, or Gray tints.

Thickness:
Glass ranges 8 mm to 98 mm or
.31 inches to 3.86 inches
Film is .015 inches

Size:
Flexible to a maxium of 40" x 98" or
1.016M x 2.484M

Environmental:
Storage — -40C to 100C or -40F to 212F
Operation — -10C to 65C or 14F to 149F

Electrical:
Drive Voltage — 60 volts A.C.
Amperage — less than 250 mA per sqm
Power — approx. 20 Watts per sqm

Response Time:
Ambiant (20C) — 50 milliseconds

Optical:
Transparency — Over 70%
Viewing Angle — 140 degrees

POLYTRONIX, INC.

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Tel: (214) 238-7045
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Telex: 3259808
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Ask your Polytronix Representative about how you can maximize your design capabilities, cost effectively!

Fig. 1: PDLC characteristics of Polytronix film

Fig. 2: UMU building applications in office space of PDLC glazing. See Color Plate I at the back of this issue.

Fig. 3: UMU building applications in house of PDLC glazing. See Color Plate II at the back of this issue.

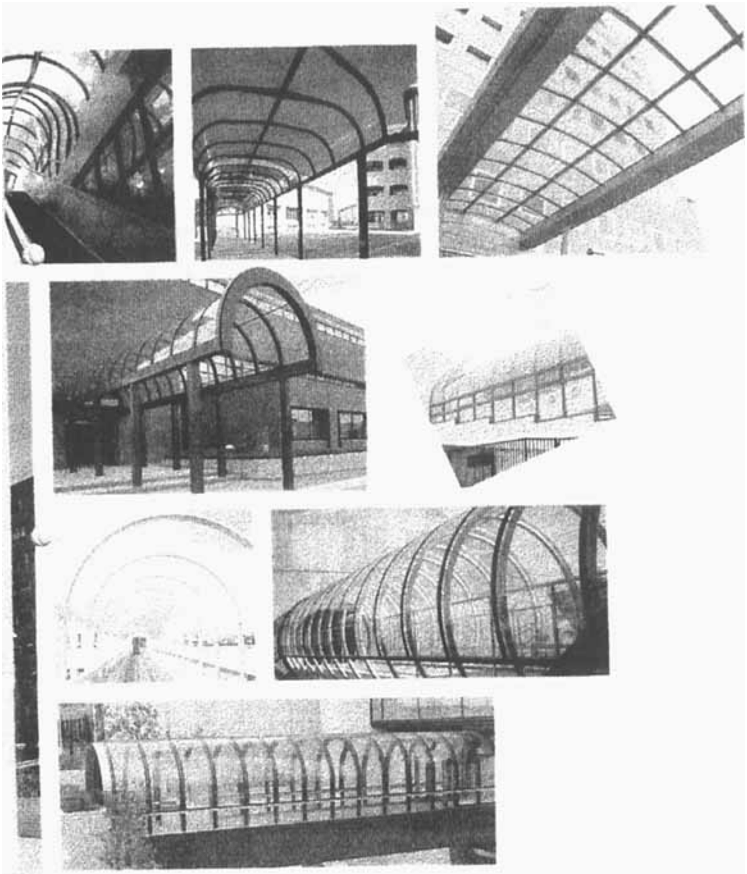


Fig. 4: External building applications of the UMU-PDLC film. See Color Plate III at the back of this issue.

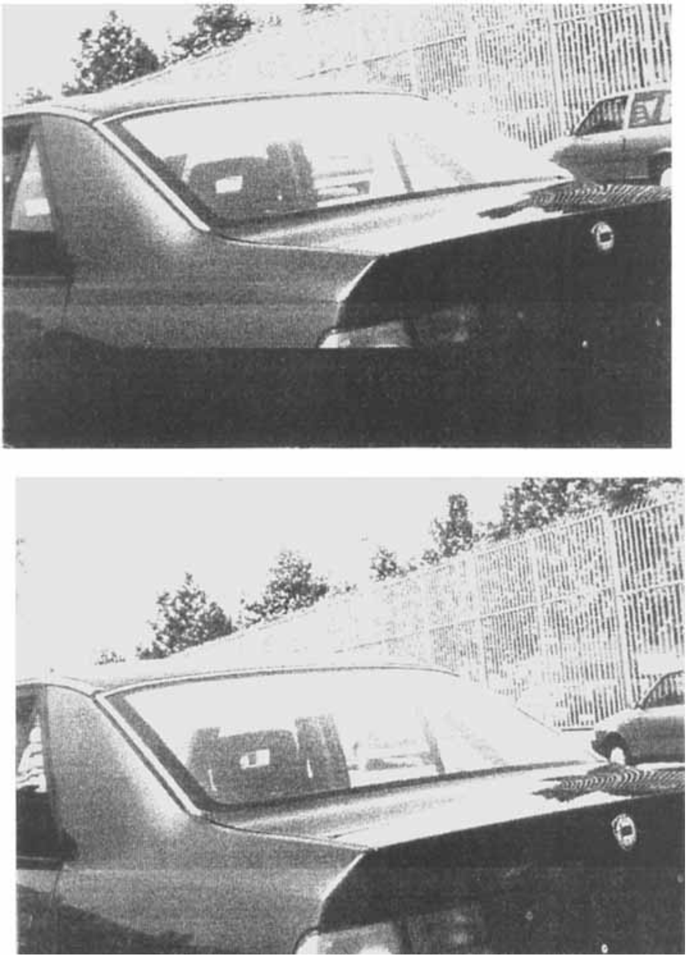


Fig. 5: Isoclima sunvisors by PDLC on FIAT cars

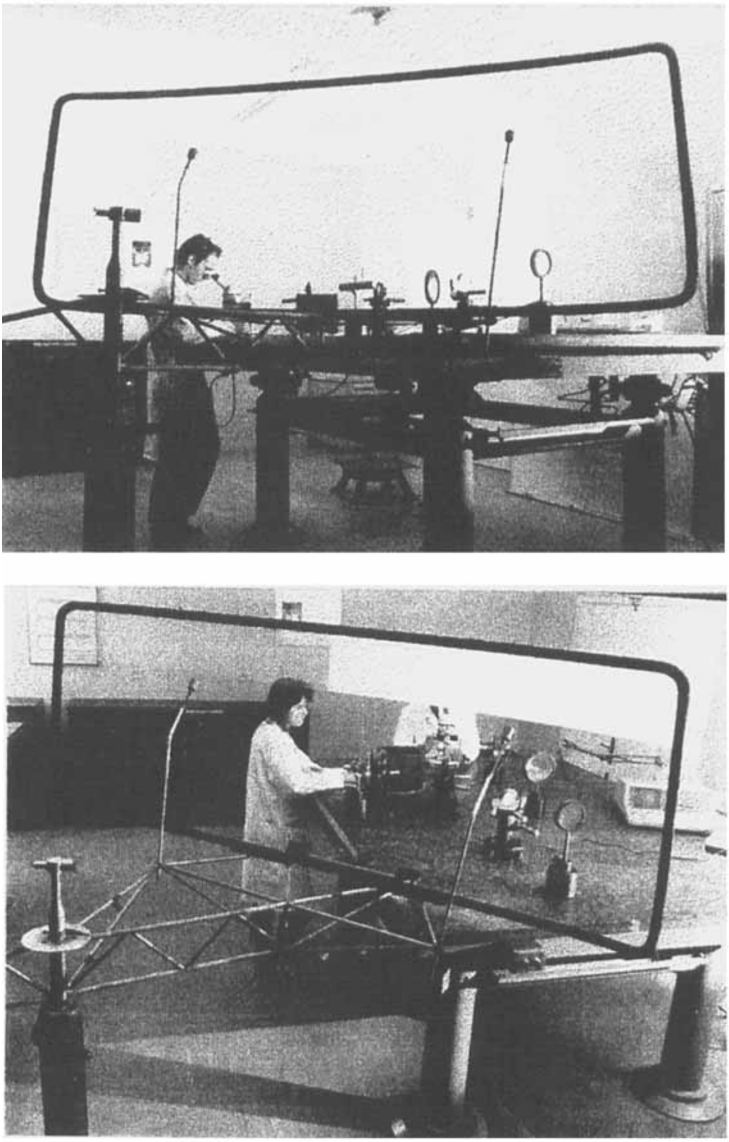


Fig. 6: Isoclima blind shutter with PDLC film on the FIAT-IVECO trucks. See Color Plate IV at the back of this issue.

GENERAL PERFORMANCES

The general performances of a normal PDLC can be summarized by three main parameters as a function of the voltage V (volt) and the frequency Hz (hertz) of the electrical power supply:

- Tt = parallel light component transmission (transverse);
- Tp = perpendicular light component transmission (perpendicular to the panel surface of PDLC)
- H = haze, % of the ratio between direct light component transmission and total light transmission composed by direct and scattered light.

Fig. 7a, 7b can be taken as a prototype of PDLC performances

Fig. 8 shows the differences at the state on/off light transmission vs voltage with 50 Hz frequency (top) and of light transmission vs frequency. We can see that the light transmission changes particularly with frequency for three different kinds of PDLC: Polytronics, UMU, 3M seems to be better. And so, the PDLC especially for UMU is now quite improved.

Fig. 9 shows the performances of UMU film with the most recent samples. Note the slightly difference between the total transmission of the states on and off which defines the PDLC not to be a solar control technology but only a switchable technology.

Fig. 10 shows the capacitive impedance Z in ohm of the PDLC like a pure capacitor. So, the impedance can be taken as a parameter relative to the stability in function of frequency: higher is the impedance higher is the stability, thus the level of impedance shown on Fig.10 confirms the instabilities experimental verified among UMU, 3M and Polytronix PDLC applications.

A part general performances, the experimental limitations of the PDLC verified in 10 years Isoclima's experience, will be treated on the following paragraph.

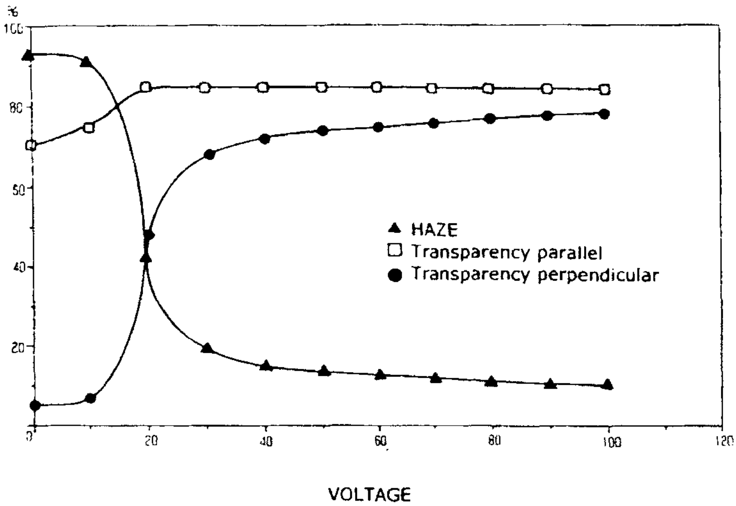


Fig. 7a: Typical % Transmission, parallel or perpendicular on haze as a function of voltage (at frequency of 50Hz) electrical field.

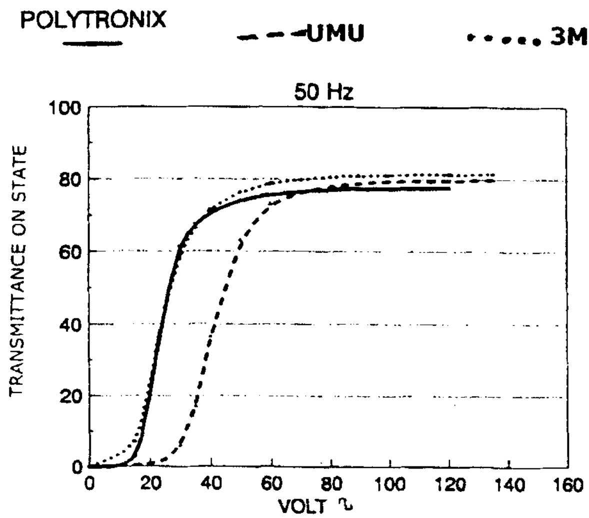


Fig. 7b: Typical % transmission (perpendicular) as a function of electrical voltage for PDLC film manufactured by Polytronix, NSG (UMU), 3M.

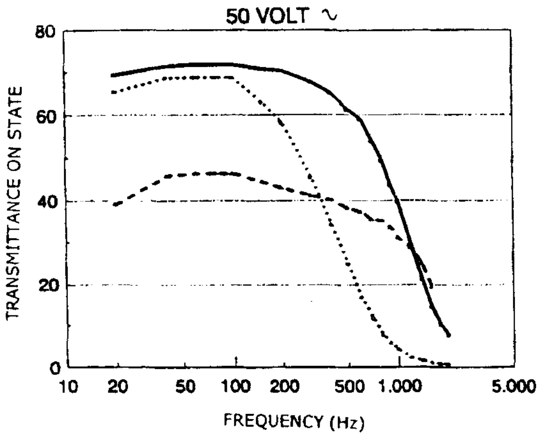
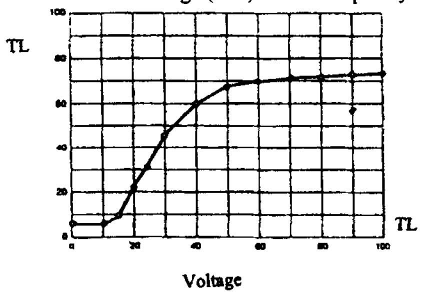


Fig. 8: Polytronics, UMU and 3M comparison of PDLC. Transmittance as a function of voltage (rms) and of frequency. – Polytronix, ---- UMU, ... 3M



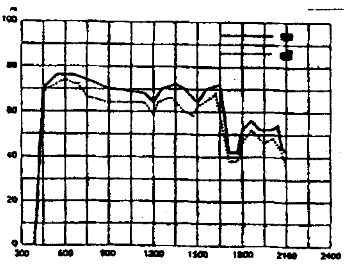
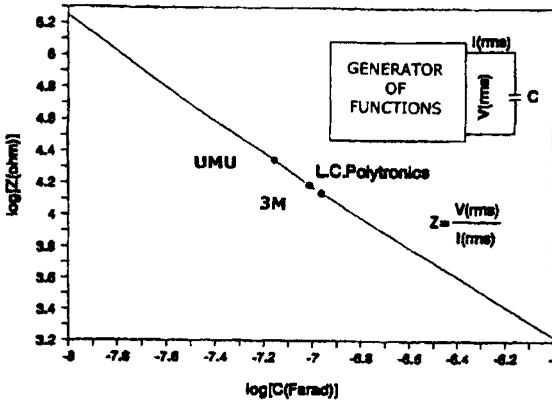


Fig. 9: Performances of UMU. The total transmission (Tt+Tp) differs slightly in state off and on (less than 10%) which affects also the energy transmission for the two states. This performance defines the PDLC not a solar control film technologically useful.



Frequency 100 Hz - sinusoidal wave
Z = capacitive impedence
Temperature 20°C

Film L.C. UMU	5.39 μF/m2
Film L.C. 3M	8.38 μF/m2
Film L.C. Polytronics	7.62 μF/m2

Fig. 10: Comparison of log impedance Z as a function of log capacity for Polytronix, UMU and 3M samples.

LIMITATIONS OF THE PRESENT PDLC

Direct mode: The situation of transparency only in the presence of electrical field, creates a lot of limitations in applications mainly in the automotive applications due to safety reasons even for privacy but also for external. So, any application seems to be confined to internal building.

Haze too high: (>4%) even for colored PDLC which limits any applications except where, like privacy, the transparency is not important as a function of angle of vision. The scattering light of an angle more than 60° is nearly the same of the off state.

UV Deterioration: Especially when it is exposed to solar rays. This again is limiting the external applications.

The presence of high percentage of LC creates two problems: The high percentage of LC increases strongly its cost. The second point has been experimented several time: as the PDLC behaves like a capacitors, the high % of LC and especially their monomers (radicals) reduces its impedance, increasing the electrical current (joule effect) and thus the temperature during the on state application for a long time.
Further at temperature higher that 60°C the diffused light at state on similar to the state off.

The adhesion: The adhesion with the metallized surfaces of PET is practically near to zero. So, any structural glazing has to be avoided for delamination problems. Any tentative has so far created optical problems or chemical incompatibility (See adhesion values in Table 3 and Table 4).

Quite a lot of LC in PDLC: Practically more than 30% of LC in PDLC does not contribute to the electro optical properties of the system.

A very low chemical compatibility with pigments: To get different colors it is difficult due to find compatible pigments.

High cost: Due also to the high percentage of LC and limited kind of LC compatible with the dispersed polymers.

Adhesion

The adhesion between the external PET surfaces of the PDLC film and the PVB or PU glass adhesives has been tested recently in Isoclima. In order to understand better, the author describes in the following table the peeling test performances obtained in a dynamometer TC 100 in order to know the adhesion between the glass and the adhesives PET surfaces after the lamination process with primer or not primer at the interface (See Table 3 and Table 4).

TABLE 3: PEELING ADHESION AT THE INTERFACE OF PVB OR PU AT GLASS INTERFACE AFTER THE LAMINATION PROCESS

INTERLAYER	PRIMER	PEEL FORCE (Pli) (pound / linear inch)
PU S123 (Sierracin)	No	13
PU S123 (Sierracin)	Fx 155	50
PU S123 (Sierracin)	Fx 177	60
PE 399 (PU Polymer)	Fx 155	36
PVB Dupont	No	24
PVB Dupont	Fx 155	35
PVB Dupont	Fx 177	40
PVB Monsanto	No	17
PVB Monsanto	Fx 155	25
PVB Monsanto	Fx 177	30

The choice of PE 399 by Polymar (Morton) is due to the fact that the lamination is done at 105°C which does not deteriorate the LC of the PDLC and also shows the softer strain-stress mechanical behavior.

Notice the higher adhesion with primers (manufactured by Isoclima) and the higher adhesion of PU in comparison with PVB with the primer as well. For the adhesion of PVB and PU with the external PET surface of PDLC the following data have been found. It is important to note the great differences between the peel force quite high at glass-adhesive interface and its low value at PET adhesives interface.

TABLE 4: ADHESION AT INTERFACE BETWEEN PET SURFACE AND PVB AND PU AFTER LAMINATION PROCESS.

INTERLAYER	PRIMER	PEEL FORCE (Pli)
PU S123 (Sierracin)	No	4-5
PU S123 (Sierracin)	Fx 177190	17*
PE 399 (Morton)	No	2-3
PE 399 (Morton)	Fx 155190	13-20
PVB Dupont	No	0
PVB Dupont	Fx 155	0

* It is necessary to take into consideration that the PU with the primer at room temperature is 35 Pli but when the temperature is increased in operation (50°C) is reduced nearly 50% (to 17) and this is the value of the peeling which has to be considered.

It is important to take into consideration that the good resistance to delamination at the interface of PET PVB or PU seems experimentally reliable when the value of Pli is around 16 but it is necessary to know its possible degradation with temperatures as is the case of PU with primer at the PET interface.
The main problem of delamination occurs with PVB/PET interface when the peeling can be only 3 Pli with special primer but worst situation is the delamination possible occurring at internal interface of the PDLC cell-metallized surface of PET where the value of peeling seems nearly zero. To be precise the adhesion at interface between the PDLC material cell and the metallized PET film. Only recently, the Polytronix has increased the value of peeling at this interface up to 3Pli (difficult to measure).
Among the sample of NSG and 3M the lower peeling value at metallized PET surface and PDLC cell is the sample of SNIA (the value is really zero).

So, in conclusion, the best adhesion between the external PET surface of the PDLC cell and the glass adhesive are obtained with primer and PU.
The adhesion between the internal metallized surface of the PDLC cell can be considered one of the main limit to use the present PDLC in structural glazing.

RECENT R&D ON PDLC REVERSE MODE IN ISOCLIMA

The limitations mentioned above, have tried to be overcome at Isoclima Spa by a project approaching the PDLC "reverse mode" with a fundamental contribute and experience of Chemical Department of Calabria University in Cosenza (Italy).
The project has investigated the "reverse mode" PDLC technologies in two ways:

1. orientation of dielectrive negative LC with a magnetic field and nearly simultaneous polymer matrix solidification by UV light activating a cross-link structural thermodynamical transition. The principles and results are described in a patent which belongs to Isoclima.
   Unfortunately, to be industrially successful, the magnetic field has to be simply lower than 3 Tesla in order to get a technology at massive level. It is certainly known that the magnetic field over 3 Tesla needs special magnetic technologies (involving superconductor application materials) which are extremely expensive and difficult to control.
   As a consequence, either the LC manufactures will find new LC mixtures with higher magnetic susceptibility or the technology will remain in stand by, until the market should be ready to pay more the reverse mode PDLC with performances equivalent to the present PDLC not reverse mode.
   Meanwhile the Isoclima development has contribute to find new concepts at Chemical Department of Calabria University which recently has achieved a new approach to a reverse mode PDLC which can be considered the natural and logistical evolved step of the previous PDLC: to main evolution concerning the transition to reverse mode PDLC, is that the dispersion of LC phase in the polymer matrix is not anymore in droplets but homogeneously dispersed in a special polymer matrix. The new PDLC shows also not a gel morphology but only an homogeneous dispersion.
   The samples are ready to be investigated at Isoclima.

This technology can be interesting for display as well: low LC content (less than 40%), high contrast, good dyes compatibility and the convenience to overcome strongly the Fergason-Raychem patent.
All results are easily available on the horizon of the reverse mode PDLC technology in the same line but with better performances than the equivalent tentative mentioned in [1], [2].
Isoclima is ready to discuss with a partner about these technologies which certainly are worth to be developed at industrial level.

2. The second tentative of reverse mode technologies for displays, to overcome the necessity of polarization, has been made by a 100% dielectric negative LC which are oriented by a special poliimmide film coating the two electrodes of the metallized PET film.
Through the Isoclima experimental work the special fracture of the polyimmidic coating has been found essential to orient suitably the LC in the way to obtain an higher transmittance (more than 60%) and quite low haze (less than 4%). The compatibility with a coloring pigment is a further advantage of this innovative technology which is also patented by Isoclima and it is available to be disclosed to an interested partner willing to furtherly develop it.

CONCLUSION

The mentioned technical limitations of the PDLC technologies have so far contributed, in addition to the high cost, to confine their applications in a quite small market, mainly in the interior building architecture. But new technologies especially the "reverse mode" with liquid crystals with negative dielectric constant can give new driving force to the use of PDLC film with better performances and lower cost, in competition with other coming switchable technologies like EC. The Isoclima know how in the "reverse mode" innovative PDLC technologies, has been patented and is certainly available to be industrially developed with interested partner of glazing and also display applications. The new technologies are an evolutive step to technically improve the PDLC and certainly worth to approach to enlarge the market.

Acknowledgements
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