

Optical Materials Technology for Energy Efficiency and Solar Energy Conversion IV

Carl M. Lampert
Chairman/Editor

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Optical Materials Technology for Energy Efficiency and Solar Energy Conversion IV

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**OPTICAL MATERIALS TECHNOLOGY FOR ENERGY EFFICIENCY
AND SOLAR ENERGY CONVERSION IV**

Volume 562

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Carl M. Lampert
Lawrence Berkeley Laboratory

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Session 6—General Topics, Deposition Theory, and Instrumentation
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INTRODUCTION

Advanced optical materials make it possible to increase energy efficiency for building components and solar energy conversion, among other applications. This conference provided a focus for interrelated aspects of optical materials covering theory, analysis, research, and development. The papers contained within represent work done by universities, industry, and national and international research institutions.

The conference was divided into seven sessions:

- Session 1. Optical Switching Materials
- Session 2. Concentrator and Reflector Materials
- Session 3. Heat Mirrors and Spectral Splitting Filters
- Session 4. Photoelectrochemical and Photovoltaic Materials
- Session 5. Solar Absorbers
- Session 6. General Topics: Deposition Theory and Instrumentation
- Session 7. International Forum

One of the most popular sessions was optical switching films (session 1). Developments in thermochromic, photochromic, electrochromic, and liquid crystal materials were presented for use in architectural and possibly automotive applications. New materials included electrochromic nickel oxide and photochromic plastic based on spirooxazine derivatives.

In the second session, the potential of holographic films for solar concentration and selective filtering was introduced. Still much more work needs to be done in this area for solar energy. These studies were followed by developments in the stability of silvered polymers and glasses for reflectors.

The third session reported on a new heat mirror (transparent conductor) material based on cadmium indate. The theoretical knowledge of scattering effects was extended for indium oxide and non-homogeneous gold films. Included in this session were the design and use of spectral splitting filters for cogeneration.

Session four contained experiments on photoelectrochemical electrodes for hydrogen generation and revealed some practical results on double surface solar cells.

Solar absorbers were covered in session five. Discussions were confined to new transition metal alloys and high temperature absorbers for central solar receivers.

In the last technical session, general topics were discussed including novel radiative heat pumps, evacuated glazings, sol-gel films and a high temperature integrating spheres.

Finally, a special International Forum discussed the technical needs in the energy related coatings industry and building sciences.

The proceedings serves as a timely companion to the SPIE proceedings Vol. 324 of January 1982, Vol. 428 of August 1983, and Vol. 502 of August 1984, all dealing with optical materials technology for solar energy and energy efficiency.

Carl M. Lampert
Lawrence Berkeley Laboratory

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**OPTICAL MATERIALS TECHNOLOGY FOR ENERGY EFFICIENCY
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Volume 562

Session 1

Optical Switching Materials

Chairman

Carl M. Lampert

Lawrence Berkeley Laboratory

Thermochromic materials research for optical switching films

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Abstract

A dual-ion-beam-sputtering (DIBS) deposition system is used to deposit doped vanadium dioxide ($V_{1-x}M_xO_2$), where M is a dopant that decreases the transition temperature (T_t) from that of stoichiometric VO_2 . The objective is to synthesize a material that will passively switch between a heat-transmitting and a heat-reflecting-state at specific design temperatures. The technique is reactive ion beam sputtering of vanadium and a dopant (separate beams) in a well controlled atmosphere of Ar with a partial pressure of O_2 . The films are deposited at elevated temperature ($>700K$) onto glass and sapphire substrates for spectrophotometric evaluation above and below T_t .

The longer range goals of this research are to develop the material for: (1) thin film application to building glazings and (2) pigments for opaque wall coatings. The glazings will transmit and the walls will absorb solar energy when the $V_{1-x}M_xO_2$ temperature (T) is low ($T < T_t$). At $T > T_t$, both glazings and walls will reflect the solar infrared.

Introduction

Over the past several years there has been a great deal of interest in the application of chromogenic materials for energy control in buildings¹⁻⁴. The greatest interest in thermochromic materials has been in the transition metal oxides. Some of these materials exhibit discontinuous changes in electrical conductivity of up to eight orders of magnitude, with attendant changes in their infrared transmittances. Honeywell conducted a study of electrochromic and thermochromic materials for solar energy applications, with emphasis on niobium and vanadium oxides⁵. Of the materials that exhibit significant switching, the vanadium dioxide (VO_2) transition temperature ($T_t \sim 68^\circ$) is closest to the range that is useful for solar energy control in buildings, as shown in Figure 1⁶. The dark vertical band in Figure 1 is at the temperature range of interest ($\sim 20^\circ C$ to $30^\circ C$).

Several investigators have doped VO_2 as a means of gaining an understanding of the transition mechanism. Some dopants increase T_t while others decrease T_t , as reported by J.B. Goodenough⁷. Some materials with large temperature effects are shown in Table 1. Tungsten (W) doping decreases T_t the most on a "per atomic percent" basis, followed by molybdenum (Mo), tantalum (Ta) and niobium (Nb). Horlin, Niklewski and Nygren⁸ measured the electrical switching characteristics of $V_{1-x}W_xO_2$ for $x = 0.000, 0.006, 0.038$ and 0.052 (see Figure 2). Note that the switching ratio changes quickly for a low

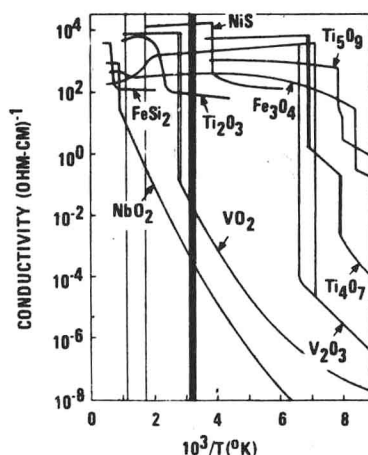


Figure 1. Conductivity vs. reciprocal temperature for several transition metal compounds⁶.

Table 1. Transition Temperature vs. Composition for Doped VO_2 ($V_{1-x}M_xO_2$)

M	$dT_t/dx(^{\circ}K/at\ \% M)$	x for $T_t = 310^{\circ}K$	σ/σ_0 at T_t
Nb	~ -8	0.04	< 10
Ta	-5 to -10		
Mo	~ -12	0.025	100+
W	-21	~ 0.014	~ 100
	~ -28	~ 0.010	

doping level and that T_t moves only slightly. With additional doping, the switching ratio changes more slowly. For $x = 0.006$, T_t occurs at 50°C and for $x = 0.038$, T_t occurs at -30°C . Thus it appears that with W doping at a level of a little less than two atomic percent ($x \leq 0.02$) the transition temperature will be in the best range for passive solar building applications. However, the relationship between x and T_t is not the only important consideration. There might be optical characteristics that favor a dopant other than tungsten, even though the switching range might be smaller.

Experimental approach

The approach to select a dopant and a doping level was to deposit thin films on glass substrates and measure their spectral transmittances (T_λ) and reflectances (R_λ) at $T < T_t$ and at $T > T_t$. Reactive dual-ion-beam-sputtering (DIBS) was chosen as the film deposition technique for the following reasons.

- o Honeywell has considerable experience with reactively sputtered VO_2 , some of that experience being reactive ion beam sputtering.
- o Ion beam sputtering is highly controllable.
- o Ion beam sputtering is convenient for doping studies (concurrent deposition of two materials independently controlled).
- o Spectral (R_λ and T_λ) measurements give rapid feedback about optical performance, making many iterations possible in a relatively short time.

A schematic diagram of a single gun ion beam sputtering system is shown in Figure 3.

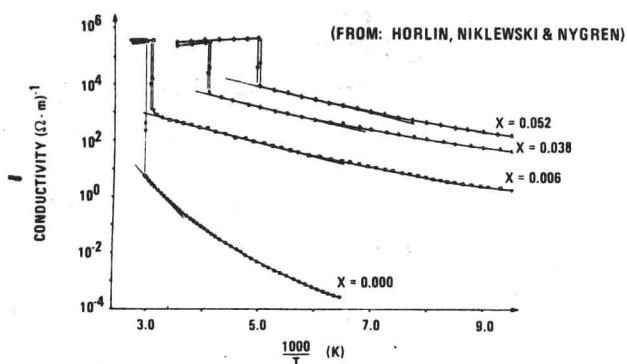


Figure 2. Electrical conductivity of tungsten-doped VO_2 ($\text{V}_{1-x}\text{W}_x\text{O}_2$)⁸.

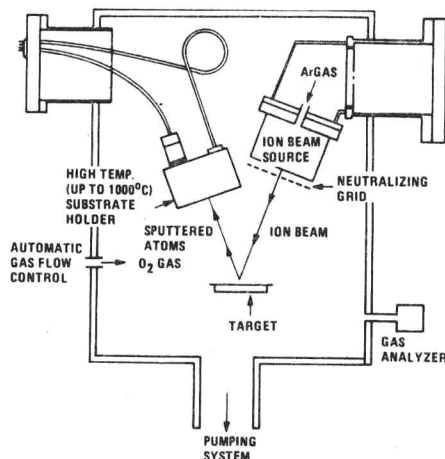


Figure 3. Ion beam sputtering system.

This system with a 2.5 cm, Kaufman-type ion gun, and automatic gas flow control equipment, was the system with which we started the program. We added a one-cm ion gun alongside the larger gun and modified the target holder to hold two targets side by side.

The argon ion beam from the 2.5-cm gun (1.3 keV and 60 mA) bombards the vanadium target, coating the substrate placed in a sputter-up arrangement as shown in Figure 3. Oxygen is metered into the chamber as a controlled percentage of the argon sputtering gas. When the combination of oxygen partial pressure and vanadium deposition rate is correct, the growing film is stoichiometric VO_2 . Also, if the combination of film growth rate and substrate temperature is correct, the film will have a high degree of crystallinity, which is needed for good switching.

The second ion beam gun (1-cm diameter) is used to sputter the doping target simultaneously with the main vanadium source. The problems we have had with this new ion beam gun (doping gun) have driven us to find an alternative method for doping. We first attempted to place tungsten (W) wire on the surface of the V target so they would be sputtered simultaneously. The results were not satisfactory, giving doping levels higher than the range of interest for solar applications (T_t too low). W wire was then placed across the ion beam immediately outside of the accelerator grid, in the position of the ion gun beam neutralizer filament. W is sputtered from the wire, deposited on the V target and

resputtered with the V. This has the drawback that we cannot estimate the doping levels from simple geometry so that we will have to determine those levels by independent measurement. However, it does allow us to obtain optical performance measurements on appropriately doped samples and we will continue to use this technique until the doping gun is functioning properly.

Experimental results

The deposition of VO_2 was optimized before any doping experiments were attempted. An example of the spectral transmittance (T_λ) above and below T_t for a 300 nm thick VO_2 coating on Corning 7059 glass is shown in Figure 4. Note that the switched state ($T > T_t$) transmittance is very low at wavelengths longer than 1 μm . It is also interesting to note that the coating transmits in the visible spectrum in both the unswitched and switched states.

The switched and unswitched spectral transmittances for a 100 nm VO_2 film on Corning 7059 glass are shown in Figure 5. Note that the peak transmittances in the visible

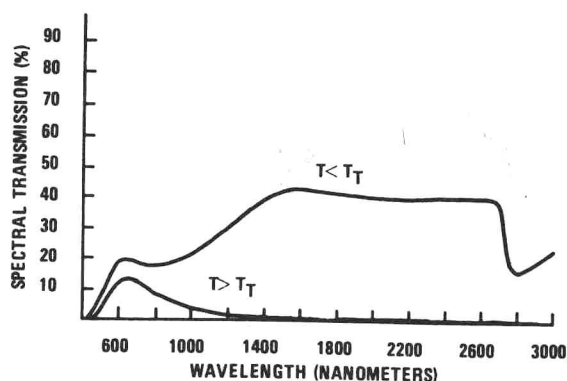


Figure 4. Spectral transmittance of 300 nm VO_2 film on glass above and below T_t .

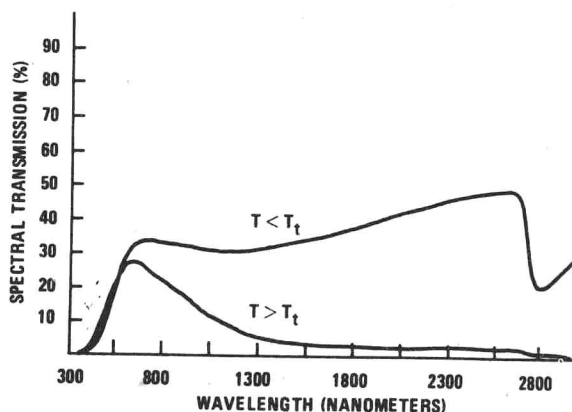


Figure 5. Spectral transmittance of 100 nm VO_2 film on glass above and below T_t .

spectrum are roughly twice as high as those for the 300 nm films. The cutoff of the short wave visible gives these films a light amber color. However, also note that this thinner VO_2 film is not nearly as effective at rejecting the solar IR. It should be pointed out that all these spectral transmittance measurements are on samples without antireflection (AR) coatings. Unswitched VO_2 has an index of refraction (n) of slightly less than 2. Thus, there is approximately a 10-percent loss at the VO_2 -to-air interface giving a total of ~15-percent transmittance reduction because of interface reflectances.

The electrical switching characteristic for the 100 nm undoped sample discussed above is shown in Figure 6. We are not sure why the transition occurs well below the normal 68°C . Also shown is the electrical switching characteristic for a W-doped film of approximately 85 nm thickness. The transition temperature is at least 30°C lower in the W-doped sample. However, the transition is too gradual for good solar performance. This is evident in its spectral transmittance characteristics at -40°C , 24°C and 50°C as shown in Figure 7. This same type of gradual transition occurs in undoped VO_2 films that are not sufficiently crystalline. Also, note that the transitions for W-doped VO_2 single crystals shown in Figure 2 are sharp. Therefore, it's possible that we have not yet achieved the necessary long-range order in our W-doped films.

Conclusions

The following conclusions can be drawn from the experimental results to date:

- o The transition temperature of VO_2 thin films can be reduced by doping the films with W.
- o W-doped VO_2 thin films (~100 nm thick) have good visible transmittance.
- o The sharpness of the transition has to be improved for passive solar temperature control of buildings.

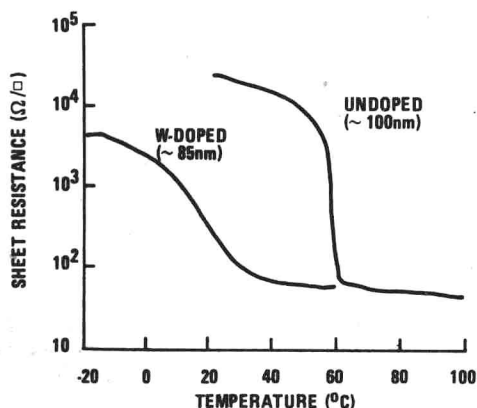


Figure 6. Electrical switching characteristics for undoped and tungsten-doped VO₂ thin films.

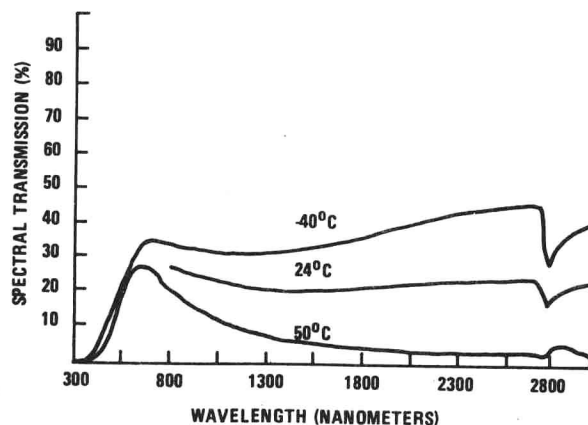


Figure 7. Spectral transmittance of 85 nm W-doped VO₂ film on glass at three temperatures.

Acknowledgements

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Photochromic performance of spiroindolinonaphthoxazines in plastics

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Abstract

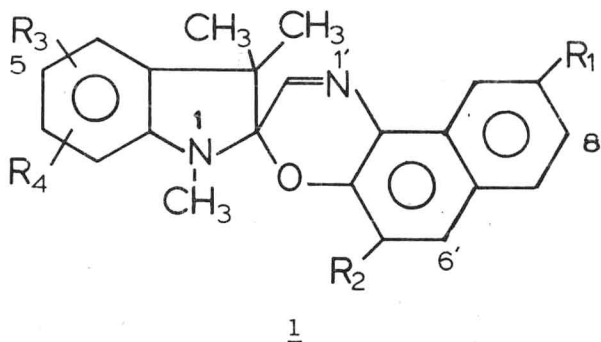
Spiroindolinonaphthoxazine compounds exhibit good photochromic effect and excellent light fatigue resistance in organic solvents as well as in plastics. Further improvement in the light fatigue resistance can be achieved by organo-nickel light stabilizers without impairing the photocolorability of the photochromic compound. The photochromic performance of a spiroindolinonaphthoxazine derivative in CAB including darkening and fading kinetics, temperature dependence, and fatigue characteristics is presented in detail.

Introduction

There are numerous potential applications such as personal protections, data displays, camouflage, decoration and passive solar uses for photochromic materials. The requirements on the photochromic materials for each application are different and need to be tailored individually. However, there is a basic common requirement for all applications on the photochromic materials. Namely, the materials should have durability in use.

A wide variety of materials, including both inorganic and organic compounds, have been reported to show photochromic effect.¹ However, none, except photochromic glasses, have been found to have wide scale industrial applications. One of the prime reasons for this lack of industrial applications for photochromic materials, particularly organic photochromic compounds, is their durability. Almost all organic compounds lose their photochromic ability easily upon exposure to sunlight. This lack of durability to sunlight irradiation is called light fatigue.

Among the hundreds, if not thousands, known organic photochromic compounds, there exists a unique class of compounds which shows excellent light fatigue resistance. This class of compounds is called spiroindolinonaphthoxazine (or abbreviated as spirooxazine, Scheme 1).



The chemical structure of spirooxazine is closely related to the widely investigated spiropyrans. The only difference in the chemical structure between spiropyran and spirooxazine is that the $c=c$ bond in the pyran ring is replaced by a $c=n$ bond in the case of oxazine.

Because of their excellent light fatigue resistance, many applications for photochromic materials which require moderate durability of one to several years become reality. In the past five years, American Optical Corporation introduced the PHOTOLITE lens, solar ink, and other products made from these photochromic compounds to the market. Recently, we found that the excellent light fatigue resistance of 1 can be further improved by organo-nickel light stabilizers.² In this paper, we shall discuss the performance of some derivatives of 1 in different plastics, the relative effectiveness of nickel-complex light stabilizers on the improvement of the light fatigue resistance of 1 as well as the concentration effect of the nickel complexes.

Experimental

Materials

The derivatives of **1** were synthesized and purified by a procedure reported earlier.³ The intermediates were synthesized by Fischer indole synthesis method.⁴

Pellets of cellulose acetate butyrate (CAB) were supplied by Eastman Chemical. The polyurethane (DP-10391) used was supplied by Conap, Inc. and for epoxy samples Emerson & Cuming Eccogel 1365-35 was used. Organonickel light stabilizers were available from commercial sources such as Ferro Corp., American Cyanamid, and Ciba-Geigy. They were used as received.

Sample preparation. The samples for evaluating the substituent effect and the effect of organonickel light stabilizers were prepared by dissolving 2 weight percent (per resin) of the specified derivative of **1** and CAB in methylene chloride. A CAB sheet was cast from the methylene chloride with the aid of a doctor blade. For polyurethane and epoxy samples, **1** was mixed with the monomer components and cured the resulting monomer mixture in an oven according to the instructions specified by the resin manufacturers.

Spectroscopic and Fadeometer measurements. The photocolability of the samples was measured on a Cary 14 spectrophotometer equipped with an apparatus which allowed the Cary spectrophotometer to record the activated spectrum of the sample while the sample was activated by an external Hg lamp. The UV intensity on the surface of the sample was monitored by a J-221 UV intensity meter manufactured by Ultraviolet Products, Inc. and was corresponding to 3.1-3.2 mW/cm² of the sunlight exposure.

For temperature dependence studies, the sample was placed in a cell whose temperature was controlled by passing a stream of temperature regulated N₂ gas. This minimized the heating of the sample by the Hg lamp used for activation.

A Fadeometer manufactured by Atlas Electric Device was used for accelerated fatigue testing. The samples were subjected to 20-hour cycle exposure and the photocolability was monitored after each exposure.

Results and discussion

Substituent effects on the photochromic performance in cellulose acetate butyrate (CAB)

As in the case of spiropyrans, a dilute solution of derivatives of **1** in ethanol is colorless and becomes intensely blue when irradiated by a UV light source or by sunlight. The blue color of the solution disappears rapidly once the light source is removed. This process can be repeated almost indefinitely. The photophysical properties of a derivative of **1** ($R_1=R_2=R_3=R_4=H$) in solution have been reported.³

For practical applications, a solid photochromic material is more useful than a liquid. Thus, we have made most of our investigation on the photochromic performance of **1** in plastic hosts. For the convenience of easy laboratory manipulations, CAB was chosen as the plastic host for evaluation. A number of derivatives of **1** have been screened for their photochromic behavior such as initial visual transmittance and photocolability. The results are tabulated in Table 1.

Table 1. Photocolability of Spirooxazine Derivatives in CAB*

	$R_1=R_2=H$		$R_1=CH_3O$		$R_2=CH_3O$	
	V.T.(%)	ΔA^{**}	V.T.(%)	ΔA	V.T.(%)	ΔA
R_3 and/or $R_4=H$	88	0.9	87	1.4	67	1.8
5-Cl	89	0.9	89	1.1	79	1.4
5-methyl	87	1.4	86	1.8	46	2.1
6-methyl	88	1.1	86	1.8		
4(and 6), 5-dimethyl	83	1.4	78	2.6		
4,7-dimethyl	85	1.3	78	2.2		

* The thickness of the CAB films was 5.5 to 6.0 mils.

** ΔA denotes the change in the absorbance, before and after UV irradiation, at 610 nm which is the peak position of the absorption band of the activated form.

The number of derivatives of **1** tested is limited, but the data strongly indicates that an alkyl or alkoxy substitution improves the photocolability considerably. In addition, a methoxy substitution at the 5' position increases the initial visual transmittance drastically. This is due to shifting the thermal equilibration between the unactivated and activated forms towards the activated form by the methoxy substituent at the 5' position.

Improvement of light fatigue resistance by organo-nickel light stabilizers. In view of the similarity in the chemical structure between the spiropyrans and spirooxazines, it was surprising to find that the photochromic durability of spirooxazines is exceptionally better than that of spiropyrans. For instance, the quantum yield of photodecomposition of a derivative ($R_1=R_2-R_3-R_4=H$) of 1 in ethanol irradiated by 366 nm of a Hg lamp is 2×10^{-4} which is about 10^3 smaller than most spiropyrans.²

Even with this exceptional light fatigue resistance, the photochromic durability of a photochromic material made from 1 is still not sufficient for most applications. In the course of investigation on the mechanism of photodecomposition and methods for improving the light fatigue resistance, we have found that organonickel light stabilizers can increase the light fatigue resistance of 1 by several folds. Although conventional UV light stabilizers such as Cyasorb UV 24 and Tinuvin P can improve the light fatigue resistance somewhat they effectively screen off the UV light needed for activating the photochromic effect and thus, reduce the photocolorability of the photochromic material. In contrast, the organonickel light stabilizers do not interfere with the photochromic action since they do not absorb in the 300-400 nm region. This noninterference is very important in the practical applications to achieve maximum photochromic reaction by utilizing all the available light intensity. The relative effectiveness of different organonickel light stabilizers in improving the light fatigue resistance of a derivative of 1 is presented in Table 2. For UV-Chek AM-205, it has been found that a minimum of 2.5 wt % (per resin) is needed to provide the maximum achievable light fatigue resistance. No further improvement was observed when the concentration of the light stabilizer was increased. A steady decrease in the light fatigue resistance was detected as the concentration was decreased below 2.5 wt %.

Table 2. Effectiveness of Organonickel Light Stabilizers

	Residual Photocolorability*	Reduction in Initial Photocolorability**
Control	0	0
Cyasorb UV 9	18	8
Cyasorb UV 24	24	17
Tinuvin P	16	25
Cyasorb UV 1084	68	0
Irgastab 2002	54	0
Rylex NBC	47	0
UV-Chek AM-105	33	0
UV-Chek AM-205	63	0

* In percent, after five (5) 20-hour cycles of Fadeometer exposure.

** Due to screening effect.

Performance in CAB. We have taken a step further from the laboratory manipulation to factory production. We are able to produce flat goggle lenses from CAB by injection molding. This provides us a method to produce photochromic CAB sheets or lenses at a cost economically feasible for many applications.

The flat sheet has a thickness of 1.5 mm and is slightly bluish before sunlight exposure. The initial visual transmittance of the sheet is 82% and can be darkened to an intense blue with 23% V.T. at 20°C by a 100 W Hg lamp with UV intensity equivalent to a bright sunny day. The photochromic response of the sheet is fast. It will become fully darkened and bleach 50% in less than 1 minute. It will revert completely to the clear state in about 15 minutes. The photochromic darkening and fading curves are displayed in Figure 1. In Figure 2, the transmission spectra before and after activation are given.

In addition, we have investigated the temperature dependence of the darkenability of the photochromic CAB sheet. As indicated in Figure 3, the degree of darkening of the sheet depends strongly on the temperature. Below 20°C, the increase in visual transmittance as the temperature increases is much more significant than at lower temperatures. Thus, for instance, the visual transmittance of the sheet after fully darkened is 58% at 35°C.

The photochromic CAB sheet also shows good light fatigue resistance. After 5 and 10 cycles of 20-hour Fadeometer exposure, the residue photocolorability is, respectively, 57% and 46% of the original value.

Performance in other plastics. Because spirooxazine is an organic compound, it is compatible with many polymeric materials. Besides CAB, we are able to obtain good results in acrylics, epoxies, polyurethanes, and PVC. The performance of 1 in these plastics, in general, follows the trends in CAB.

Conclusions

In conclusion, photochromic materials made from spirooxazines, particularly with an organonickel light stabilizer, have excellent light fatigue resistance which expands the scope of applications for these photochromic materials. Due to this excellent light fatigue resistance, the possibility of using these materials for passive solar uses is not far from reality. At present, we feel that an inexpensive sun shade or drape with 1 to 2 years' use life to control the lighting in a building is not beyond the reach.

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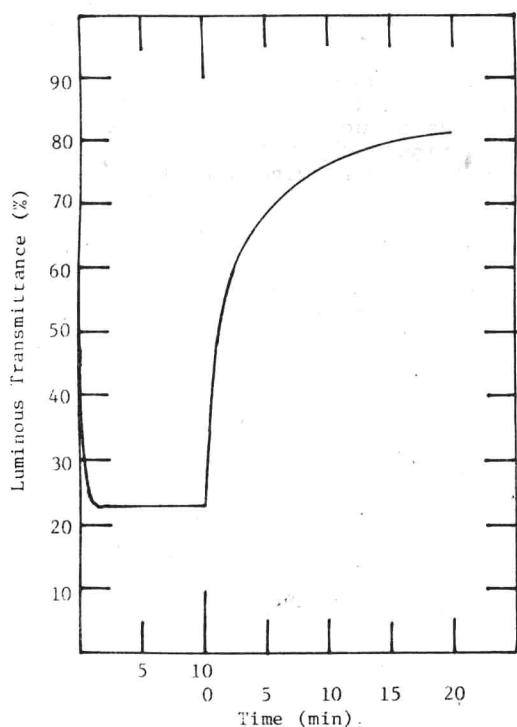


Figure 1. Darkening and fading curves of photochromic CAB sheet at 20°C

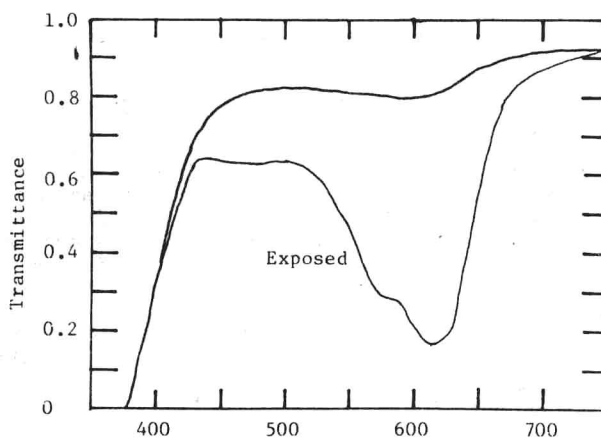


Figure 2. Transmission spectrum of photochromic CAB sheet before and after UV exposure

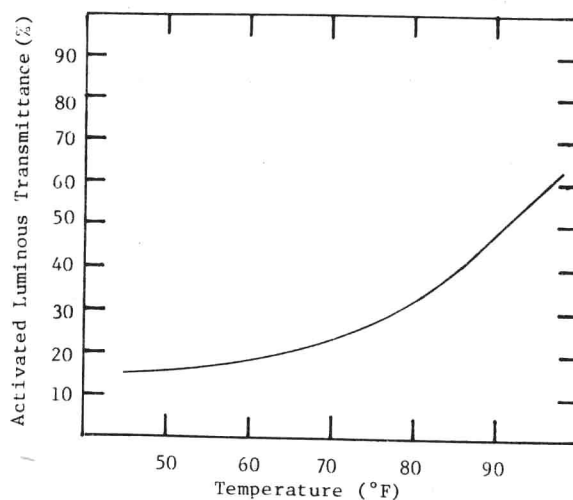


Figure 3. Temperature dependence of photocolorability of photochromic CAB sheet

Liquid crystal window to control the solar energy

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Abstract

Liquid crystal window has been considered as an optical shutter to control the solar energy. Investigation of various types of liquid crystal cells show that the phase change guest host (PCGH) type would be better to fabricate large size LC-cell. PCGH-cell with black dye has anomalous transmission dip near the threshold voltage for incoherent light in the range of 400 to 500nm. The anomalous dip is shown to come from scattering of incident light by the voltage induced inhomogeneities created during the phase transformation. 6 μ m thick 12.5cm x 12.5 cm LC-window has been fabricated using PCGH-LC mixture. The transmittance of the window could be controlled to an accuracy of less than 1% using IBM-PC computer.

Introduction

Most of the modern electronic passive displays incorporate liquid crystal (LC) mixtures because of their useful electro-optic properties and low power and voltage requirements¹. In addition being used as a display element, LC cell can also be used as a light shutter to control the solar energy in the visible range of the spectrum. Various multilayer optical thin film coatings are being considered for "smart" windows to control the solar energy². Ideally a solar energy window should have large controllability of transmittance in a specified range of wavelengths. In order to see the applicability and the feasibility of LC window as a controller of solar energy, we have fabricated a large number of test cells using the three most commonly used types, dynamic scattering, twisted nematic and guest-host, of LC mixtures. Some of the transmittance measurements as a function of the wavelength have previously been presented³. In addition to presenting additional transmission measurements of the test cells, we have fabricated 12.5 cm x 12.5 cm LC window to see its effectiveness as a light shutter to control the solar energy.

In the dynamic scattering mode^{4,5}, observable only in the negative anisotropic nematics, the cell is clear in the off-state (no voltage applied to the cell), and turns into frosty appearance in the on-state (for voltages above the threshold). Since the dynamic scattering cells do not require any polarizers, these cells are easy to fabricate. However, their power dissipation is rather high, and high voltages are needed to obtain reasonable transmission controllability (TC), the maximum percentage of controllable transmission.

The twisted nematic type⁶ is the most commonly used material for displays because of its low power requirements and high contrast ratios. The use of crossed polarizers require in the twisted nematic cells reduces considerably the transmittance, which is usually less than 50% of the incident light. The viewing angle of the twisted nematics is very narrow.

In the guest-host type^{7,8} the pleochroic dye molecules (guest), 1 to 5% in concentration, follow the nematic molecules (host) whose orientation can be manipulated with the externally applied electric field. The optical absorption of a pleochroic dye molecule depends on its orientation with respect to the polarization vector of the incident light. Strong absorption in the transmitted light is observed when the long axes of the dye molecules are parallel to the polarization vector. In the phase-change guest-host (PCGH) mode^{9,10}, cholesteric to nematic or vice versa phase transformation occurs at the threshold voltage. PCGH-cells do not require any polarizers, and have the advantage of selective absorption over specific wavelengths by properly choosing the dye type.

Transmission Measurements

Fabrication of 2 cm x 2 cm test cells, measurement techniques and the types of liquid crystal mixtures used have previously been described³. Transmission versus voltage curves of a 9 μ m thick dynamic scattering cell obtained at $\lambda = 458$ nm are shown in Fig. 1. For the transmission measurements, the photo-detector had an effective detecting area of 1 cm² without any aperture in front of it. From Fig.1, we can see that the transmission of the cell is about 81% below the threshold and decreases gradually above that. Reduction in transmission above the threshold voltage can be obtained either by placing an aperture or moving the detector away from the cell. This behavior is expected from a dynamic scattering liquid crystal mixture, because of the forward scattering by the micro-sized birefringent regions created by the electric field. The incident collimated beam (1.2 mm in