

THERMAL DAMAGE IN LUMINESCENT SOLAR CONCENTRATORS (LSC) FOR PHOTOVOLTAIC SYSTEMS

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Summary

The temperature dependence of the optical efficiency of luminescent solar concentrators (LSC) has been studied. It has been found that in the range room temperature (RT) - 100 °C an important thermal degradation is produced.

The damage depends not only on the temperature but also on the nature of the dye and can reach values as high as 37% in the case of RhB.

The damage is partially recovered when the LSC is cooled to RT.

Résumé

Nous avons étudié la dépendance de l'efficacité optique avec la température pour des Concentrateurs Solaires Luminescents (LSC). On a trouvé une dégradation thermique importante dans une gamme de la température normale (RT) à 100 °C.

Il semble que le dommage ne dépend pas seulement de la température mais aussi de la nature du colorant et qu'il peut atteindre jusqu'à 37% pour la RhB.

Le dommage a une récupération partielle quand le LSC est refroidi jusqu'à la température normale.

Introduction

A new type of solar concentrator, the so-called luminescent solar concentrator (LSC), has been recently proposed [1, 2]. It consists of a highly

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transparent material, usually Polymethyl Methacrylate (PMMA), containing luminescent centres that convert part of the solar spectrum into a wavelength emission better matched to the spectral response of a photovoltaic cell. The transparent material behaves as a light pipe, trapping and transmitting the luminescent emission toward the cell and making a high concentration factor possible. These effects allow a substantial reduction in the photovoltaic material area and consequently lead to lower cost photovoltaic converters.

This particular type of concentrator operates without sun tracking and can work efficiently with diffuse light.

The idea involved in the LSC is very promising, but it has, at the present time, a number of drawbacks, of which the more important is the degradation. Goetzberger *et al.* [3] have reported, for a prototype LSC, that the efficiency decreases by 50% after about one year of utilization. This damage to the LSC, as well as to dyes in solution, has been attributed [4] to optical bleaching. However, more experimental data are needed on the influence of different factors such as light intensity, irradiation wavelength, nature of the dye, host material, etc. Particularly, there is no information concerning the possibility of thermal damage, which could be important because during exposure to solar radiation the LSC can reach temperatures well above room temperature, mainly on sunny days.

In this paper the temperature dependence of the absorption and emission bands in the range 20 - 100 °C has been studied for three different dyes in PMMA.

It has been observed that both the absorption and emission bands rapidly decrease when the LSC is warmed above RT. This thermal damage obviously implies a reduction in the efficiency of the LSC. The decrease depends both on temperature and on the particular dye considered, and for the temperature range studied in this work it lies between 10 and 40%.

Experimental

PMMA doped with Rhodamine B (RhB), Rhodamine 6G (Rh6G), and Fluorescein (F) has been supplied by PLEXI, S.A. Samples of this material $10 \times 10 \times 1 \text{ mm}^3$ in size were cut from the original plates.

A Cary-17 spectrophotometer was used for the absorption measurements. Due to the fact that the luminescence efficiency of the dyes is very high, it was considered necessary to check that the absorption spectra measurements are not disturbed by the fluorescence.

As the luminescent emission is diffuse, at variance with the collimated beam of the spectrometer, the perturbation can be minimized by using several mirrors inside the measurement chamber. Absorption data obtained with this experimental equipment and standard measurements give the same result. In fact, this could be expected due to the light pipe effect in the LSC which concentrates the fluorescence mainly at the edges of the sample.

The temperature variation was achieved by placing the sample in a furnace which can be accommodated in the sample chamber.

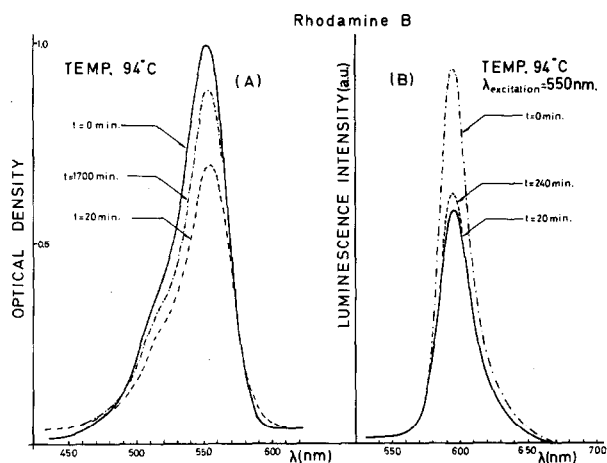


Fig. 1. Time dependence of the optical absorption (A) and luminescence (B) (excitation wavelength $\lambda = 550$ nm), at 94 °C, of a sample of PMMA doped with RhB.

The same furnace and spectrometer — now working in single beam function — have been used to obtain the emission bands. A Silvana lamp with a high intensity Bausch and Lomb monochromator were used for excitation.

Experimental results and discussion

Figure 1 shows the time dependence of absorption (A) and emission (B) bands in PMMA doped with Rhodamine B at 94 °C. The corresponding bands at RT are also given for comparison purposes. The position and half-width of the band remain constant, but large intensity changes appear with time of treatment. For short times the intensity decreases, and after reaching a plateau a new increase is found. In accordance with this behaviour, the assignment of these effects to a single dependence of the optical transition with temperature should be discounted.

In order to determine whether these thermal effects are associated with dichroism, the absorption and luminescence bands have been obtained with polarized light. In each case no difference was found.

The possible effect of thermal annealing of the residual stress has also been checked, using samples previously strained, without detecting any difference from as-received samples.

Figure 2 shows the time dependence of the absorption band of RhB for three different temperatures. It can be seen that for every curve there is an initial decrease and, after a plateau, a partial recovery from the thermal damage. Similar behaviour has been found in luminescence experiments.

The decrease and recovery levels, as well as the time required to reach them, are temperature dependent, suggesting that the damage is connected with a thermally activated process.

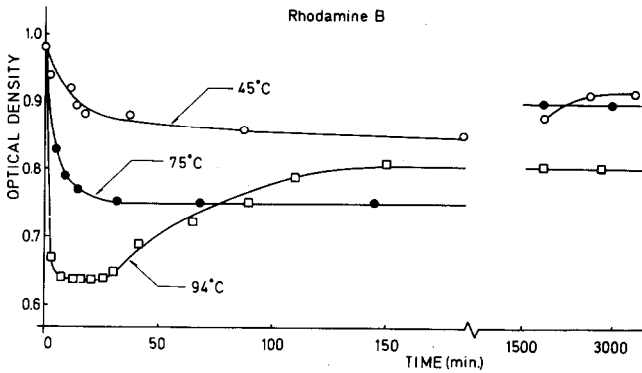


Fig. 2. Time dependence of the absorption peak for RhB for samples stored at different temperatures.

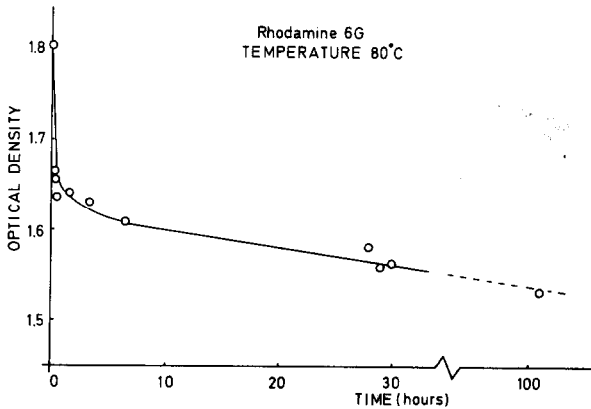


Fig. 3. Time dependence of the absorption peak for Rh6G stored at 80 °C.

Figure 3 shows the thermal damage to PMMA doped with Rh6G. In this case the rate of change is much slower, reaching 14% in 100 h.

For fluorescein-doped PMMA the behaviour is very similar, but in this case the observed change is less than 10%.

It is expected that under operating conditions the LSC will be subjected to thermal cycles following the daily oscillations. These conditions have been simulated, as shown in Fig. 4, for a maximum temperature of 74 °C in order to enhance the thermal effects on the absorption bands. The samples were heated up to 74 °C and slowly cooled to RT after being maintained for 10 min at the maximum temperature.

We must point out that when the sample is cooled to RT a partial recovery of the thermal bleaching occurs. This recovery decreases with successive cycles.

The experimental data are insufficient to explain the origin of the thermal damage observed. Nevertheless, it is well known [5] that at tempera-

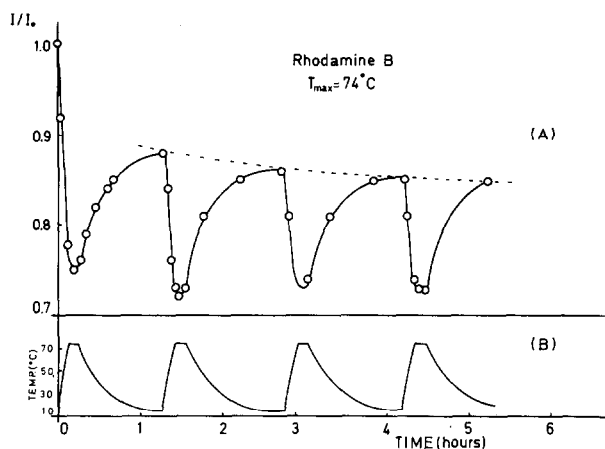


Fig. 4. Effect of thermal cycles on the absorption band of RhB (A) together with the temperature variations (B).

tures lower than the glass transition point ($\sim 100^\circ\text{C}$), the molecular chains of PMMA begin to move. Hence, it is possible to conjecture that these movements can facilitate changes in the dye position in the host material, and also give rise to the aggregation of these molecules. Dimer and trimer formation has been observed in several solutions and changes in the efficiency of the absorption and luminescence bands have been attributed to these aggregates [6 - 8].

This possibility implies changes in the thermal damage for different concentrations of dyes. In considering the role of concentration in thermal bleaching, it is necessary to determine the origin of the damage and also the ideal dye concentration for LSC devices.

Regardless of its origin, we conclude that for temperatures in the range $20 - 100^\circ\text{C}$ the LSC suffers an important thermal degradation and, consequently, a decrease in the efficiency of conversion of the solar spectrum.

Finally, in view of the present results, it is necessary to be careful to avoid the superposition of thermal degradation in optical damage measurements.

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