Study on thermal properties of laminating films of photovoltaic cells

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Abstract

The paper reports a study on thermal properties of laminating films used for the production of photovoltaic cells modules. The main attention is devoted to absorptive (reflective) and emissive properties of various types of films used for the module encapsulation. The main aim of encapsulation is the protection of photovoltaic panel against environmental damage (humidity especially). However, the laminating films have also an influence on the electrical behavior of the whole panel due to various working temperatures of individual photovoltaic cells.

It is generally known that increasing the temperature of photovoltaic cell leads to a decrease of its conversion efficiency. Therefore, the application of laminating films with small absorption, high reflectivity, and good thermal conductivity and with high emissivity on the rear (not illuminated) side causes a decrease of working temperature of photovoltaic panel and thus an increase of produced power. This eventually leads to the shortening of investment recovery time.

Key words: photovoltaic cells, thermal properties of materials, transient pulse method, thermo vision

INTRODUCTION

The absorption of electromagnetic (thermal) radiation was studied with the use of thermocamera Fluke TI55 and by means of the transient pulse method that enables to find out thermal properties of bulk materials (specific heat, thermal diffusivity and thermal conductivity). Thermal properties of defined system of bulk material were measured with and without the application of a laminating film. The surface temperature distribution of the panel was simultaneously monitored by thermocamera Fluke TI 55 during measurements.

EXPERIMENTAL SETUP

Thermocamera measurement

The quantitative study on thermal properties of laminating films was preceded by a preliminary measurement of a photovoltaic panel composed of 8 photovoltaic cells. The individual cells were covered by various laminating films from the rear side (see Fig. 1).

These laminating films types consisted of uni-color ones (white - F03, grey - F04 and black F06) with varying surface finish (mat, glossy), transparent ones (F05, F08, F09) and bi-color ones (blue/white F07, black/white - F02). The black/white laminating film was not placed under any photovoltaic cell.

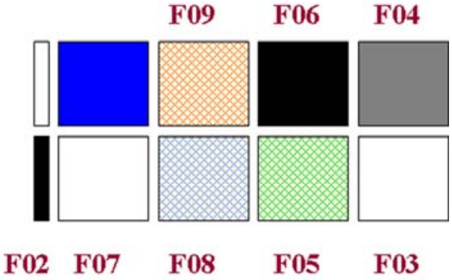

Fig. 1 Settlement of photovoltaic panel

The photovoltaic panel was oriented so that heat dissipation was enabled from the rear side (by conduction, convection and radiation). The steady temperature distribution on this panel after the irradiation by two 500 W bulbs from the distance of 1 m was monitored by the thermocamera Fluke TI 55 and is illustrated in Fig. 2.

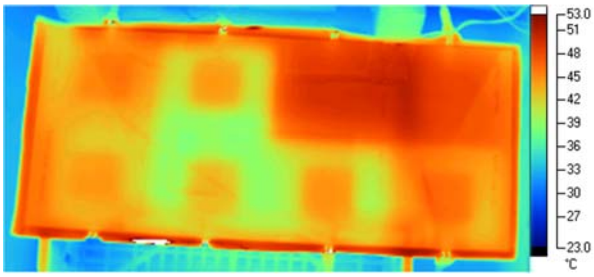

Fig. 2 Thermograph of photovoltaic panel consisting of cells encapsulated in various laminating films

The figure clearly depicts that the worst heat removal is from black and grey laminating film (F06, F04), whose temperature is approx. 50 °C. On the contrary, the best heat removal is from the transparent laminating films (F08, F09 and F05) whose temperature is approximately 35 °C.

Fig. 3 illustrates the situation when two photovoltaic cells were laminated by the same bi-colour laminating film in different orientation. On the left side, the film was placed so that its blue side (wb) is in touch with the photovoltaic cell and the white side is on the the surface. On the contrary, the laminating film orientation is reversed on the right white of the image (bw). It is evident that the temperature of the cell is higher in the second case because the emissivity of the white surface is bigger than the emissivity of the blue surface.

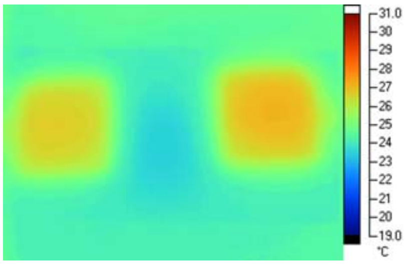

Fig. 3 Thermograph of two photovoltaic cells with different blue and white laminating film orientation (F07): left the white side is facoing out (wb), right vice versa (bw).

Pulse transient method measurement

The experiment setup for measurement by means of transient pulse method is illustrated in **Chyba! Nenalezen zdroj odkazů.** right. Heating caused by the irradiation of the sample (see Fig. 4 left) was simulated by surface thermal source, poly(methylmethacrylate) (PMMA) was used for heat removal from the laminating film (much like during previous experiment). Glass was replaced by PMMA from the frontal side where the temperatute was measured.

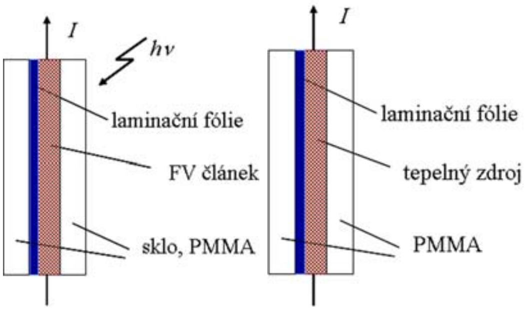

Fig. 4 Arrangement of photovoltaic cell and sample for transient pulse method measurement

The setup of the transient pulse method measurement is illustrated in Fig. 5, [1], [2]. Heating of surface thermal source is caused by defined current pulse. Measurement is usually conducted for various widths of pulses (t_0) and various powers $P = U\,I$. Temperature sampling is carried out by a NiCr-Ni thermocouple (for chosen experiments in combination with the thermocamera).

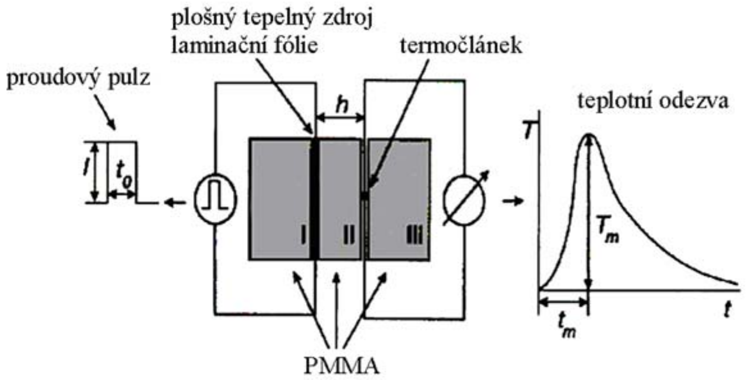

Fig. 5 Principle of measurement by means of pulse transient method

The aim of measurement was to compare thermal parameters of PMMA system without laminating films and with intermediate laminating films. It is possible to judge the suitability of laminating films for the application on photovoltaic panels from changes of thermal parameters (specific heat, thermal conductivity, and thermal diffusivity).

EXPERIMENTAL RESULTS

Measured response recorded by transient pulse method is illustrated in Fig. 6. It is evident from the figure that samples without use of laminating film (PMMA) have bigger maximum response temperature change than samples utilizing the laminating films.

There are negligible differences in the response temperature change of samples utilizing laminating film placed on one or both sides of heat source which is in and contradiction with thermographic record (Fig. 3).

By detailed analysis discussed later we found out that variations in responses really do exist.

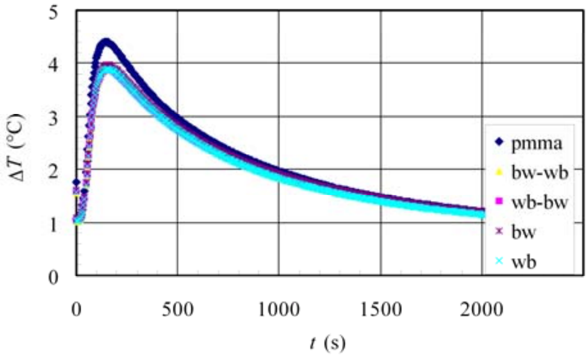

Fig. 6 Transient responses of studied samples: a) without laminating film (PMMA) b) with single blue and white laminating film (F07), see Fig. 4 right (bw, wb) and with two laminating films from both sides (wb-bw, bw-wb)

The dependence of thermal response ΔT on time t upon heat energy input $Q = U\,I\,t_0$ into the sample with thickness h (it equals to the distance of the thermocouple from the heat source) derived by means of the pulse transient method can bed describe by the relation

$$\Delta T = \frac{Q}{c_\mathrm{p}\rho(4\pi\,a\,t)^{(E-D)/2}} \cdot \exp\left(-\frac{h^2}{4a\,t}\right), \tag{1}$$

where a is thermal diffusivity, c_p specific heat and ρ is material density. Parameters D a E are determined by experimental setup: for planar heat source $D = 2$, for heat expanding in three – dimensional space is parameter $E = 3$, [3], [4] and [5]. Thermal conductivity can be determined from these parameters: $\lambda = c_\mathrm{p}\rho\, a$.

From the derivation of dependence of thermal response on the time

$$\frac{\partial \log \Delta T}{\partial \log t} = \left(\frac{D-E}{2} + \frac{h^2}{4at}\right) = 0 \tag{2}$$

it is possible to determine the thermal diffusivity of material being investigated

$$a = \frac{h^2}{2t_\mathrm{m} f_\mathrm{a}} = \frac{h^2}{2(E-D)t_\mathrm{m}}, \tag{3}$$

In this relation, the parameter f_a characterizes setup of experiment, deformation of heat field respectively. This coefficient is for ideal planar setup and heat transfer into the space ($E = 3$, $D = 2$) equal to one.

It is also possible to determine specific thermal capacity

$$c_\mathrm{p} = \frac{Q}{\rho\,\Delta T_\mathrm{m} h^{E-D}} \cdot \left(\frac{E-D}{2\pi\exp(1)}\right)^{(E-D)/2} \tag{4}$$

and thermal conductivity of material under investigation

$$\lambda = \frac{Q}{2(E-D)\Delta T_\mathrm{m} t_\mathrm{m} h^{E-D-2}} \cdot \left(\frac{E-D}{2\pi\exp(1)}\right)^{(E-D)/2} \tag{5}$$

from maximal value of change of temperature $\Delta T_{\mathrm{m}..}$

DISCUSSION

First, the parameters of the system were determined from the measurement of PMMA responses (Fig. 6), i.e. values of the thermal diffusivity, thermal conductivity and specific heat. Results obtained from the measurements of sample with average R = 3 cm and thickness h=6.0 mm correspond to values that are reported in literature: density of material under investigation (PMMA) is: $\rho = 1184$ kg.m^{-3}, thermal diffusivity $a = 1.12 \cdot 10^{-7}$ m^2.s^{-1}, specific heat $c_p = 1450$ J.kg^{-1}.K^{-1} and thermal conductivity $\lambda = 0.193$ W.m^{-1}.K^{-1}.
After inserting the laminating film from one (or both sides), the thermal properties of the system will be different because of different way of heat dissipation.
Maxima of responses will be shifted to lower (or higher values); maximal values will be lower (how it is evident from Fig. 6).
If we analyze these changed characteristics, we will obtain different values of thermal parameters than in the case of PMMA.
By comparing these values with values obtained for PMMA, it is possible to determine changes of heat conductivity and specific thermal capacity of the system. This is illustrated at following figures (Fig. 7 and Fig. 8)

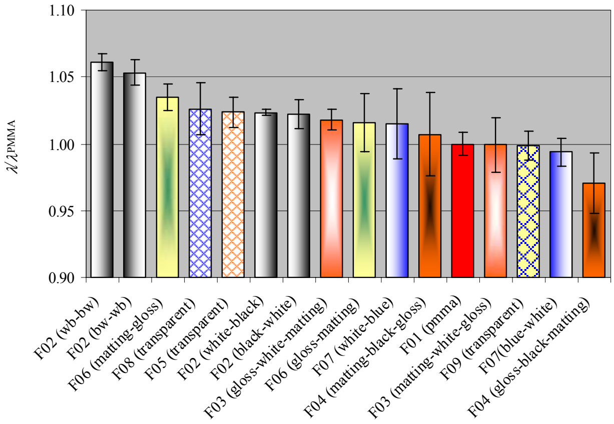

Fig. 7 Relative changes of thermal conducttivity of the system consisting of PMMA and laminating films in view of PMMA itself (F01)

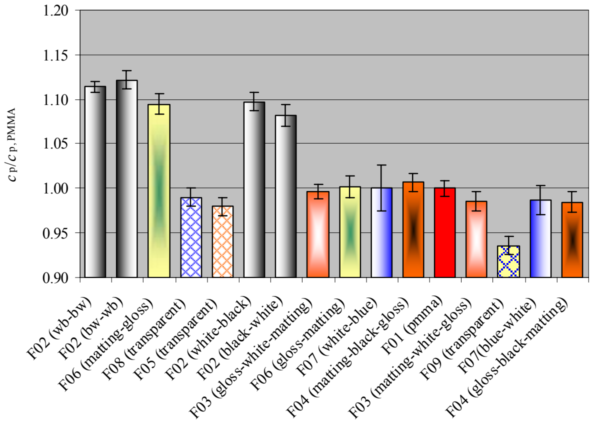

Fig. 8 Relative changes of specific thermal capacity of the system consisting of PMMA and laminating films in view of PMMA itself (F01)

As far as the thermal conductivity is concerned, suitable properties are demonstrated by samples placed left of the sample F01. After their application, these materials caused expansion of samples' thermal conductivity. From the specific heat viewpoint, suitable materials seem to those that caused its reduction.
The most suitable materials are transparent films F02 and F05. Another suitable adept for application to photovoltaic panels is also transparent film F07, which caused a prominent decrease of specific heat whereas the thermal conductivity did not change at all in comparison to PMMA.

CONCLUSIONS

Modified transient pulse method was applied for experimental data evaluation. This method describes general behavior of thermal properties of materials as fractal structures. Dependence of fractal parameter D characterizing non-homogeneous distribution of temperature in material (in E-dimensional space) depending on the distance from heat source and time was determined by using of space-time fractal theory.

Results of theoretical model were verified by measurements of real systems with encapsulated photovoltaic cells. Laminating films suitable both in terms of thermal conductivity (being bigger than conductivity of the system without laminating film - sample F01) and also in terms of specific heat (being smaller than the specific heat of the system without laminating film - sample F01). Transparent laminating films F05, F08, F09 have these properties, as illustrated in Fig. 7 and Fig. 8. Resulting knowledge will lead to optimization of photovoltaic modules construction with respect to heat dissipation in real conditions.

ACKNOWLEDGMENTS

This work was supported by project KAN401770651 from The Academy of Sciences of the Czech Republic and by grant FT-TA3/048 from the Ministry of Industry and Trade of the Czech Republic.

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