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Composite Polymer Materials for Image Reproduction Systems on the Basis of Thermo-induced Phase Transitions

Here we present the research results of quality of light scattering by composite polymeric materials. It is shown that the polymeric films based on formation of interpolymer complexes between polyacrylamide networks and non ionic thermo responsive polymers (Polyvinylcaprolactam PVCL, Polyethylene glycol methacrylate PEGMA, Isopropylmethacrylamide IPMAA) can be used as working substance in information reproduction systems of new type. The main advantages of such information reproduction systems are full transparency in switched off state, relatively low weight and small thickness per square meter of screen. These advantages make attractive the usage of screen built with composite materials as working substance in façade desing for office and non-residental buildings for display advertising information.

Key words: Thermally responsive polymers, image reproduction, phase transition, composite polymers**.**

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Жылу индукцияланған фазалық өткел негізінде бейнелердің жаңғырту жүйесіне арналған композиттік полимерлік материалдар

Жұмыста композициялық полимерлі материалдардың жарықтың шашырау сапасын зерттеуінің қорытындылары көрсетілген. Полиакрилдік желі мен иондық емес жылусезгіш полимерлер арасында интерполимерлік комплекстердің пайда болуында негізделген композиттік полимерлік материалдар жаңа түрлі бейнелердің жаңғыртуына арналған келешектік материал болып табылатыны көрсетілген. Осындай ақпаратты бейнелеу жүйелердің артықшылығы өшірілшген қалыптағы экранның мөлдірлігі болып табылады. Бұл артықшылық әртүрлі ғимарат қасбетінде ірі габаритті экрандардың «Терезе/Экран» режимің асыруға мүмкіндік береді.

Түйін сөздер: жылусезгіш полимерлер, бейнелердің жаңғыртуы, фазалық өткел, композиттік полимерлер

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Композитные полимерные материалы для систем воспроизведения изображений на основе термоиндуцированного фазового перехода

В работе представлены результаты исследования качества рассеяния света композиционными полимерными материалами. Показано, что полимерные пленки, основанные на образовании интерполимерных комплексов между полиакриловыми сетками и неионными термочувствительными полимерами (Поливинилкапролактам ПВКЛ, полиэтеленгликольметакрилат ПЭГМА, изопромилметакриламид ИПМАА), могут быть использованы в качестве рабочего вещества для систем воспроизведения информации нового типа. Основными преимуществами таких систем отображения информации является то, что в выключенном состоянии экран является прозрачным, обладает сравнительной небольшой массой и толщиной на единицу площади экрана. Данные преимущества позволяют использовать экран, разработанный с использованием в качестве рабочего вещества композиционные материалы, в оформлении фасадов офисных и нежилых зданий для отображения рекламной информации.

Ключевые слова: термочувствительные полимеры, воспроизведение изображений, фазовый переход, композитные полимеры

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COMPOSITE POLYMER MATERIALS FOR IMAGE REPRODUCTION SYSTEMS ON THE BASIS OF THERMO-INDUCED PHASE TRANSITIONS

Introduction

Nowadays large-size systems of information display are even more often used as means of outdoor advertising, and as an element of architectural design of cities. The operation principle of vast majority of screens, that are used now, is based on use of light-emitting diodes (LED technologies, [1]), or gas-discharge equipment (plasma, [2]). The main disadvantage of such screens is the considerable weight and considerable thickness so that light-emitting diode and plasma screens have to be placed on blank walls of buildings, or on individual special designs.

In [3,4] the new type of the screen based on use of phase transitions in solutions of thermally responsive polymers, allowing to overcome this disadvantage was offered. The screen offered in the quoted works represents the thin layer of solution of thermally responsive polymer placed between two transparent glasses. The plane of the screen is divided into separate areas, each of them is supplied with a separate heating element (resistor). Advantage of this type of screen in comparison with known analogs [1,2] is a complete transparency in the initial (switched-off) state. This, in particular, allows to replace windows located, for example, on a facade of office building, with system of information display of the offered type. In the daytime, the system performs the usual functions of a window, and at night turns into a screen. Provided that rooms aren't operated at night (office) it doesn't cause any inconveniences.

Offered in [3,4] screen operates as follows. When heated to the critical temperature in the given pixels (screen area) phase transition occurs, as a result the medium that fills the screen gains ability to scatter light. When illuminated by an external source of light pixels, in which phase transition occurred, are visually perceived as lit and in which transition didn't happen – as darkened, this gives the chance to form the image.

The main disadvantage of the operating principle of the screen [3,4] are the high requirements to the speed of the phase transition, defined by the physiological characteristics of sight (24 frames per second). Realization of such high speeds of phase transition is complicated, in particular it is necessary to use the solutions containing nanoparticles [5, 6]. Stability of such systems isn't sufficient for ensuring long-term operation of screens yet. Furthermore, the need to use liquid-phase media creates additional difficulties, especially in the manufacture of considerable dimensioned screens.

At the same time, there are thermally responsive polymeric materials, from the technological point of view much more convenient for drawing on flat surfaces of the big area. They are composite materials obtained by the interpolymer reaction between the crosslinked interpolymer mesh and nonionic solutions of thermally responsive polymers [7,8]. (As it is noted in the quoted works, the corresponding complexes are stabilized by hydrogen communications). However, such materials possess rather low speed of phase transition (about several seconds). Nevertheless, they can also be used for realization of screens on the basis of phase transitions in thermally responsive polymers if the scheme will be modified a little.

The purpose of this work is development of the composite materials providing functioning of the considered above scheme of the screen on the basis of phase transitions in thermally responsive polymers, and also development of screen scheme modification for which the speed of phase transition isn't critical parameter.

The modified system scheme of image reproduction on the basis of thermally responsive polymers

To implement the switching mode «Window / Screen» it is enough to provide phase transition at once in all pixels provided that the establishment of the luminance distribution (reproduced image) will be carried out in any other way, in particular, discussed below.

To preserve the main advantage of the developed screen (partial or full transparency in an initial state) in this case it is expedient to use light-guide properties of flat glasses. Namely, provided that the index of refraction of glass is higher, than the index of refraction of environment, any flat glass represents the flat light guide thanks to effect of full internal reflection. If glass contacts to the disseminating film, the part of the light extending on the light guide will experience dispersion. The corresponding scheme is submitted in Fig. 1.

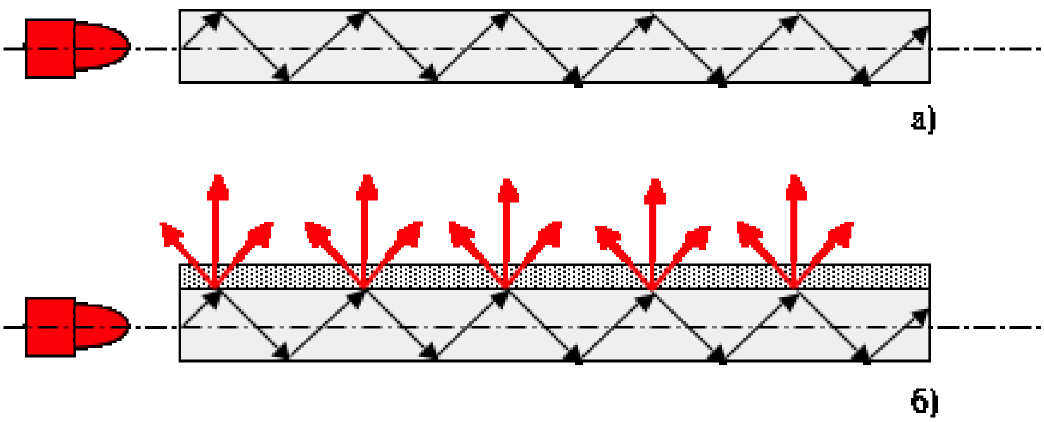

Figure 1 – An illustration to the operation principle of the screen using light-guide properties of flat glasses and light-scattering materials; a) – the path of rays in the flat light guide, b) – the appearance of light in the application of the additional light-scattering covering.

Fig. 2 shows photographs of the demonstration image, which clearly illustrates the effect of the light-scattering covering (film) imposed on Plexiglas, to which light sources are connected according to the scheme in fig. 1. The turbidity of the used film is characterized by an indicator 0,82 (coefficient of amplitude weakening of the light, extending in the direction, perpendicular to the covering planes). It is evident that with such indicator of connected side sources of light and in the absence of external light sources (night time) the surface of a sample is visually perceived as luminous. On the contrary, at the disconnected side sources of light and at rather bright external lighting the sample is perceived as partially transparent, and degree of transparency is regulated due to selection of the polymer experiencing phase transition.

It is expedient to use the considered properties of flat light guides with the imposed light-scattering covering for production of large screens. Indeed, the existing television standard of high resolution assumes that along a line about one thousand pixels are settles down (more precisely, 1920). Replacement of a window facade of modern office building with the screen assumes that width of the screen has to coincide with facade width, i.e. it must be about 20 - 30 m and more. Therefore, is admissible to consider that the purpose of the screen answers the sizes of separate pixel in 2-3 cm and more.

Such indicator allows to use the following scheme of reproduction of the image (fig. 3a).

The screen is divided into N1 vertical strips (1). Each bar represents a three-layer composition, the external layers of which are performed, for example, from Plexiglas. Between them the thermally responsive film, and also the heating elements which are carried out, for example, from a thin nichrome thread are settled.

Width of each strip corresponds to the doubled width of luminescence area of one light-emitting diode. Control of illumination of each pixel is exercised independently by use of LED tapes on the basis of a WS2812 chip providing individual management of a signal of each light-emitting diode line. (In particular, in the market the WS2812B LED tapes which are controlled by the standard microcontroller on the SPI bus are presented).

The controlling light-emitting diodes (2) are located on each of two sides of a strip, i.e. on each of strips 2N2 pixels are located.

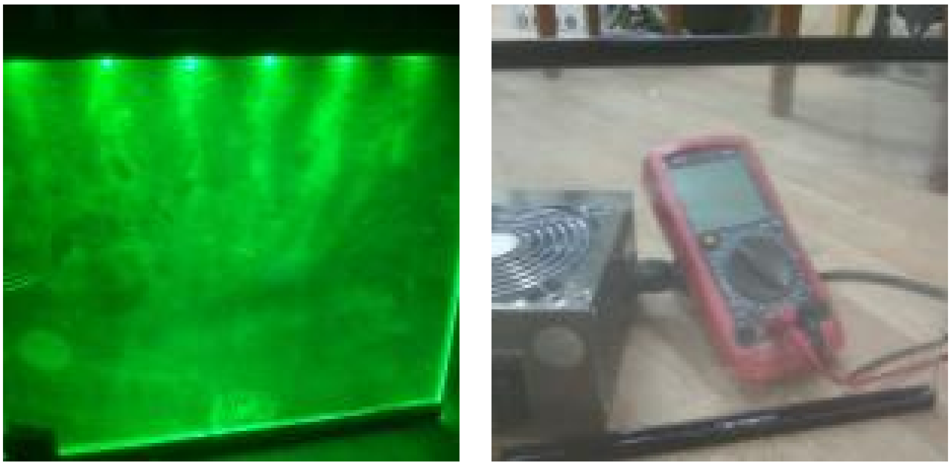

Figure 2 – Photos of light guide, a light-scattering system on the basis of Plexiglas and a light-scattering film at the switched on and off light sources.

Splitting a strip into pixels is carried out due to selection of light distribution at the plane of the light guide, light-scattering element. Namely, the scattering coefficient of the material used at temperatures above the phase transition temperature should provide a significant drop in intensity at distances about the size of pixel. In this case, the light patterns created by separate light-emitting diodes won't be blocked (fig. 3). Let's emphasize that the size of a pattern is regulated through coefficient of dispersion (turbidity) of a film that allows to coordinate it with the geometrical size of pixel.

Thus, if to use the LED lines providing possibility of independent management of each of LED (in industrially made LED tapes the RGB light-emitting diodes allowing to realize polychrome image are used), it is possible to realize the screen using thermally responsive polymeric materials with a low speed of phase transition. Really, in this case switching of the Window/screen mode is carried out, on average, about two times per day, i.e. the speed of phase transition can be increased to about one minute.

Therefore, the list of polymeric compositions that can be used for functioning of image reproduction systems offered in this work significantly extends. Ensuring the acceptable mechanical strength of a film and simplicity of its technological application on glass becomes the main requirement.

We also emphasize that the bandwidth, providing light scattering by 60 mm, thickness of the LED tape located on the end face of glass makes about 2 mm, ie its presence is easily masked by elements of window frame décor, which allows to operate the proposed system of image reproduction with switching of the Window/Screen mode.

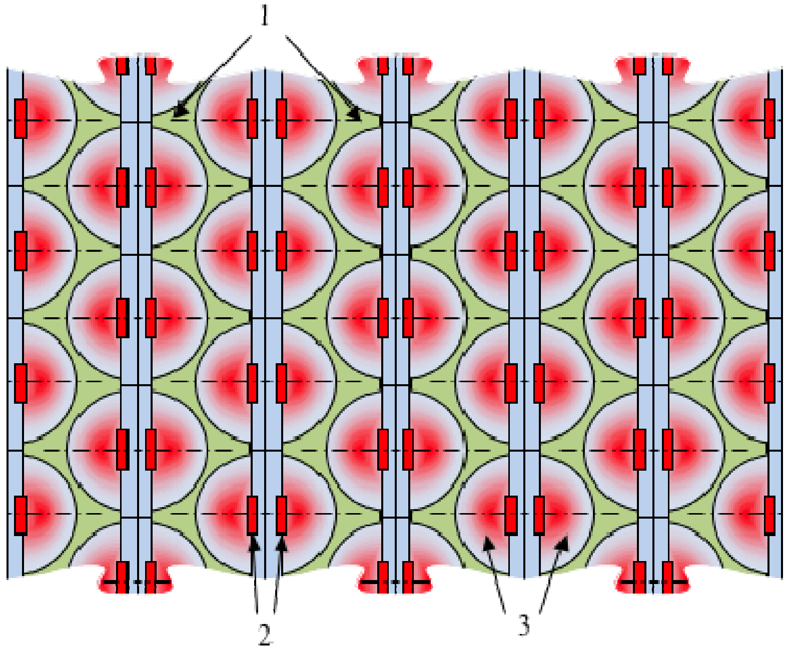

Figure 3 – The arrangement scheme of light-emitting diodes in the screen on the basis of light-guide properties

Experimental

One of the simplest methods for obtaining thermally responsive films is to use crosslinked interpolymer reactions between grids based on polycarboxylic acids and nonionic thermally responsive polymers. The formed complexes are stabilized by hydrogen bonds.

The main advantage of such approach is the possibility to control the transparency of films (at temperatures higher than temperature of phase transition) due to the inhomogeneous distribution of the nonionic polymer concentration by volume (surface) of the synthesized composite material. It seems essential, since a nonuniform distribution of the light scattering coefficient is capable to compensate the effects connected with falling of light intensity with increase in distance to a source.

Besides, there are fulfilled techniques allowing to provide adherence of gels on the basis of polyacrylic acid to hydrophobic polymers, in particular, ones that can be used and as material of the flat light guide, and as an external covering of the screen.

In this work as the matrix that enter into interpolymer reaction with the nonionic polymer the film on the basis of polyacrylic acid (PAK) sewed under the influence of ultra-violet light was used. The concentrated aqueous solution (15-25 wt. %) was applied with thin layer (0.5 mm) on a transparent flexible film of polyethylene terephthalate (PET).

Then, the solution and the PET film were subjected of UV irradiation (the standard quartz lamp was used).

It should be emphasized that the UV radiation not only led to the linking PAC to the grid (gel), but also provides the mesh grafting to the substrate material from PET.

Experimentally it has been shown that with increasing time of UV radiation crosslinking degree of PAA gel grafted to the surface of the PET is increased and the equilibrium degree of swelling it in water is reduced from 150 to 8 g of water per 1 g of dry polymer.

The received two-layer composition was further used as a matrix for implementation various kinds of not ionic thermally responsive polymers in it.

Results and discussion

Fig. 4 shows photographs of films produced in the implementation of a two-layer composite matrix of copolymer molecules of hydroxyethylacrylate with hydroxyethyl methacrylate at different temperatures.

The similar pictures taken for a case when PNIPAM molecules implemented into a polymeric matrix are submitted in fig. 5.

Figures 4 and 5 show that the formed complex really reacts to changes of temperature. Moreover, it shows that the complex can be created locally. As it was noted above, it is significant in terms of creating an inhomogeneous distribution of turbidity for correcting non-uniform distribution of illumination on a surface of a light-scattering film.

Similar results are received also at saturation of a composite (or a pure film on the basis of PAA) by the polyvinylcaprolactam.

Thus, the offered technique of composite materials synthesis satisfies the criteria formulated above, i.e. they can be used to implement systems of image reproduction on the basis of phase transitions.

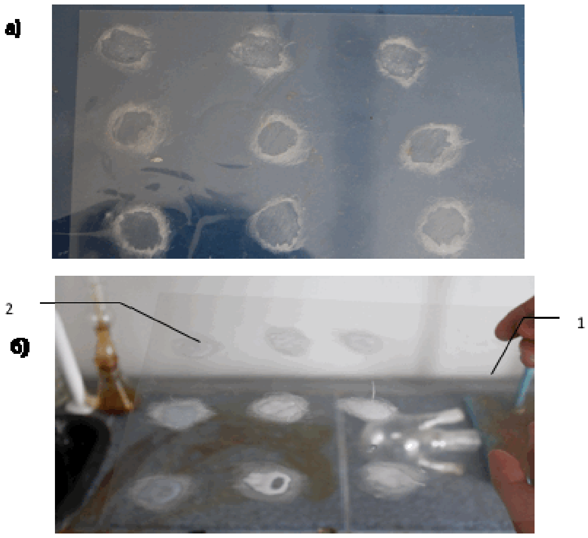

Figure 4 – Photo of the cross-linked film PAA grafted onto PET areas comprising the applied solution of hydroxyethylacrylate copolymer with hydroxyethyl methacrylate at different temperatures; 1 – film – matrix 2 – area with applied thermally responsive polymer; a) – 250C; b) – 35^{0}C

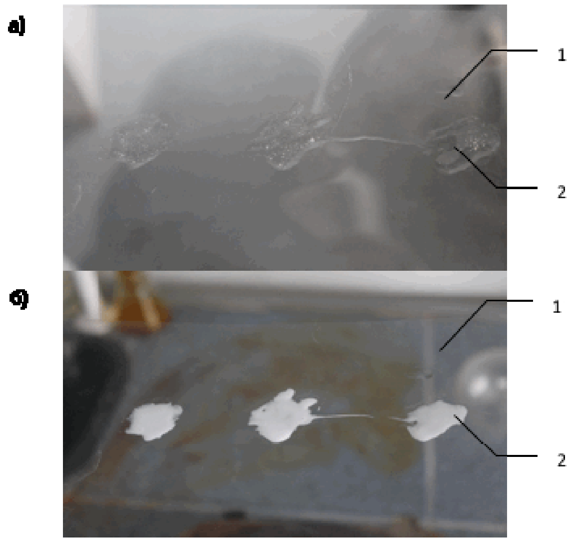

Figure 5 – Photo of the cross-linked film PAA grafted onto PET areas containing the applied PNIPAAM solution at various temperatures, the same designations, as in fig. 4; a) – 250C; b) – 350C; c) 450C

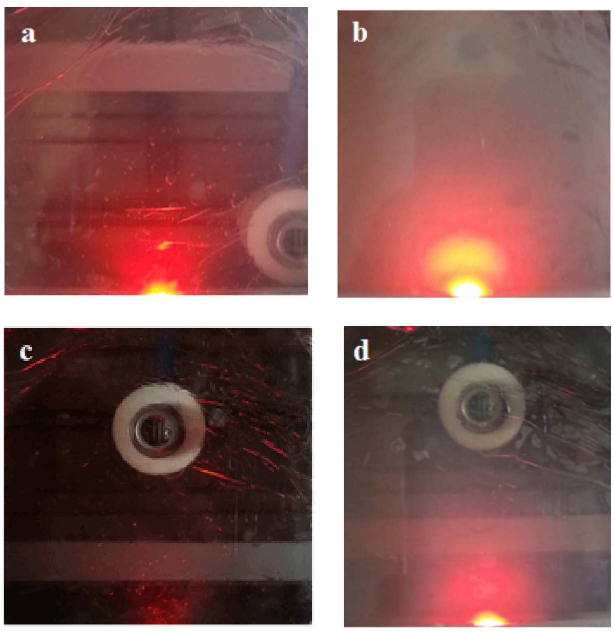

Figure 6 – Photos of one pixel area at various temperatures and PVCL concentration

Photos of the separate pixels showing operability of the received complexes are shown in fig. 6, a) – T=260C, b) – T = 320C, when the mass fraction of PVCL makes 5% of weight of the grid; c) – T=260C, d) T= 450C, PVCL proportion is 1%.

It is visible that the offered technique of making films really ensures functioning of big sized screens based on light-guide properties of glasses.

Conclusion

Thus, the offered technique of receiving thermally responsive coverings (films) provides implementation of following requirements arising from a screen design based on the light-guide properties of flat glasses.

1. The films received on the basis of complexes between the sewed grids and thermally responsive polymers get the necessary degree of turbidity at temperature increase from 25 to 35 0C. This range gives opportunity to use the screen, provided that it settles down indoors.

2. The resulting complex is formed locally, there is also a possibility to block the diffusion of thermally responsive polymer due to grid material perforation imparted to the substrate.

3. It is possible to produce thermally responsive films with a given distribution of light scattering coefficient on the area. It provides illumination uniformity of pixel due to uneven distribution of light-scattering components on the area.

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