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Design of Nanostructured Luminofor Coating for a Multi-Junction Solar Cell

Design of the highly efficient solar cells is a hot area of semiconductor physics and material science. One of the major concerns is a substantial shift between the solar radiation spectra and optical absorption spectra of a photoelectric transducer. A new method based on synthesis of luminophor layer functioning as a radiation converter was proposed. It's shown that nanostructured pyrazoline coatings could convert the incoming solar radiation into the secondary optical radiation for optimal matching with the active spectral range of the solar cell. Results of the experimental investigation revealed high potential capabilities for optical properties engineering of the luminophor through laser annealing. It was found that produced samples of nanostructured organic composites are characterized by sufficiently enough spectral shift (200–400 nm) that can be varied by doping during synthesis, high quantum yield (near 80 %), and are enough stable under circumstances of intensive long term radiation.

Key words: *luminophor coating, quantum yield, white zeolite, pyrazoline dye, nanostructured materials, solar cell.*

Introduction

Demand for solar cells has been growing [1, 2] approximately by an average of 30 % annually in past a few decades. It's driven by the following.

1. Strong support of both, government and customers for green energy.
2. High electricity rates encourage development of alternative sources of energy.
3. Providing international agendas for reducing carbon footprint [3].

One of the prominent problems in this area consists in a narrow absorption band of solar cell elements which implies great losses of solar power on heating of photoelectric transducer. Existing shift between the solar radiation spectra and optical absorption spectra of the photoelectric transducer leads to the significant decreasing of solar cell efficiency and lifetime. The only approach in this area was the synthesis of the corresponding structures photoelectric transducer with wide absorption band, which was realized on multi-junction solar cell [4, 5]. Such a kind of photovoltaic element does achieve high efficiency by combining several p-n junctions. In this case each subcell in the structure, is composed of particular semiconductor material, each with a different energy bandgap. This causes phenomena of light absorption in a different portion of the solar spectrum. But it must be noted, the obtained multi-junction photoelectric transducers are characterized by extremely high price [6].

Theory

Our concept is based on coating of conventional and cheap photoelectric transducer with luminophor that transmits longer wavelengths of the sunlight and absorb shorter wavelengths. Photoluminescence (PL) phenomena are characterized by Stocks shift and converts wide solar spectrum to the absorption spectrum of the solar cell and thus may drastically increase quantum efficiency of solar cell (Fig. 1). It must be noted that photoluminescent light is not collimated and thus losses may reach up to 50 % of converted light. However microrelief formation leads to increasing of effectiveness of a solar cell surface.

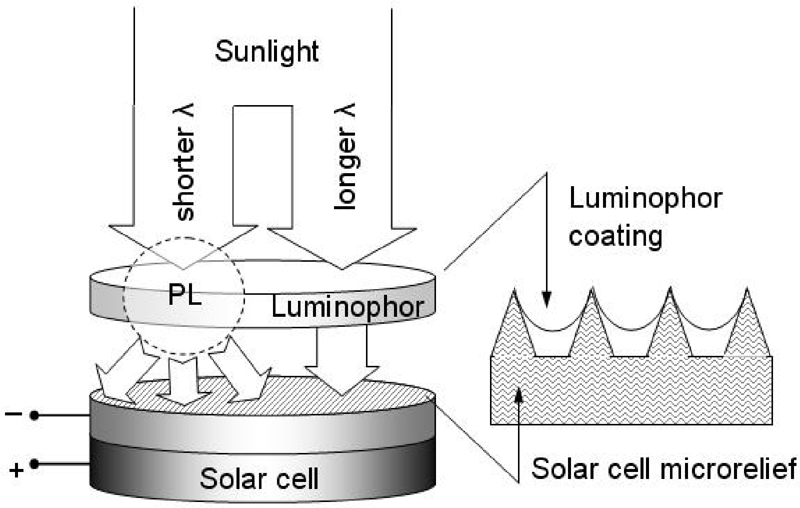

Fig. 1. Conversion of sunlight spectrum to the absorption spectrum of a photoelectric transducer

In order to fulfill abovementioned, one of the tasks is to synthesize cheap PL materials with following parameters:

1) high quantum yield (more than 50 %);

2) sufficiently big spectral shift (0,3–0,6 μm) that can be varied during ongoing synthesis;

3) the possibility of an absorption band variation of the material;

4) the stability of optical properties of the materials under circumstances of being radiated by solar power for long term.

Experimental

Analysis of previous achievements in the field indicates that industrial production of luminophors [7–11] does not satisfy the most of the abovementioned requirements. We proposed synthesizing specific nanostructured materials based on organic dyes. In order to achieve mentioned goal following composite organic pyrazoline dyes: 53SM (base pyrazoline UV dye with 5 % addition of polymethylmethacrylate); 59HM (pyrazoline «orange-red» dye with 5 % addition of polymethylmethacrylate); 53SC (pyrazoline UV dye with 5 % addition of polystyrene); 59HC (pyrazoline «orange-red» dye with 5 % addition of polystyrene) as shown at table.

Synthesis of pyrazoline dyes set

Doping / pyrazoline dye	Base pyrazoline UV dye	Pyrazoline «orange-red» dye
No doping	53M	59M
Polymethylmethacrylate	53SM	59HM
Polystyrene	53SC	59HC

All of them are extremely effective luminophors with a quantum yield of PL up to 70 %, relaxation time less than 100 ns, wide spectrum of the PL and possibility of two-photon absorption phenomena. Nevertheless, further research demonstrated potential of the significant characteristic's improvement [12, 13]. The method is based on the introducing of organic dye molecules in the white zeolite matrix. The series of experiments confirmed theoretical consideration that zeolite submicron- and subnanopores bulk of the dye to nanoparticles and subnanoparticles with improved optical properties [12, 13]. One of them is PL quantum yield gain and can be characterized by following relation [12]:

$$\eta \sim 1/(1+\beta D^2),$$

where η is quantum yield; β is a constant and D is diameter of a nanoparticle.

The growing of the main PL intensity peak for pyrazoline dyes is up to 20–30 %. Complementary laser annealing made this parameter increased at least in two times causing complete pores fill with the dye. The growth of PL quantum yield is caused by the quantum size effects which change molecular energy structure of the dye and thus some forbidden transitions are turning to partially allowed ones. An organic dye absorption growth in this case is also concerned with an appearance of the new allowed transitions. In zeolite submicron porous structure exited molecules relax to the lower levels and thus absorb larger quantities of the incident light [12].

Such effects theoretically may also cause the rising of additional PL peaks, which was demonstrated by means of by spectrophotometer for all types of the pyrazoline dyes (Fig. 2).

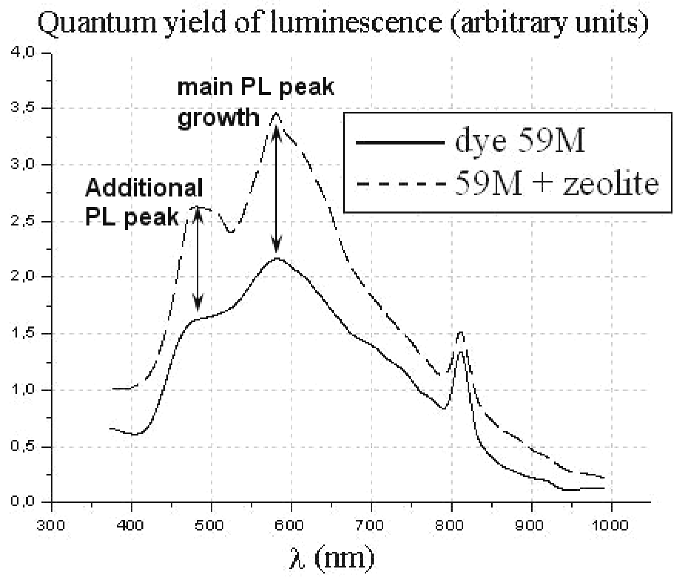

Fig. 2. Growth of PL main peak and changing of PL spectrum for nanostructured dyes of pyrazoline 59M

It was investigated that for complex synthesized pyrazoline dyes are crucial $\pi\pi^*$ cross-linking with an active energy hydrogen bond with a typical effect of transmission spectrum infrared shift which was also confirmed by experiment (Fig. 3).

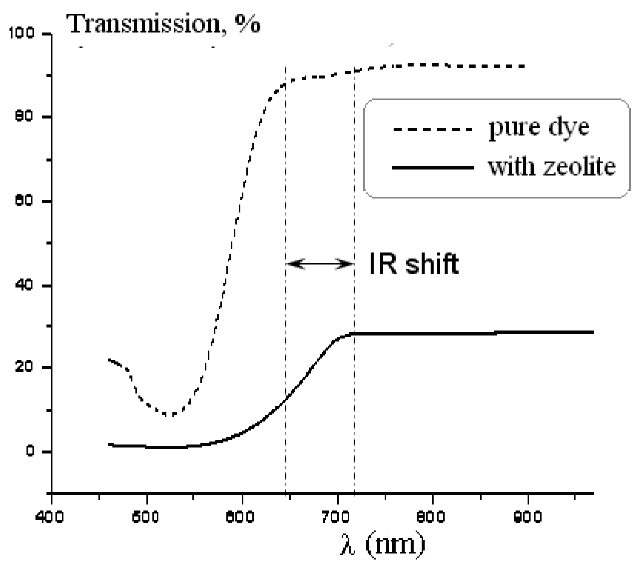

Fig. 3. Infrared shift of nanostructured pyrazoline dye transmission spectrum

It was shown that addition of the zeolite also decreased PL relaxation time twofold. Moreover, complex structure of the PL kinetics graph (Fig. 4) showes that a composite pyrazoline dye does not fave completely filled white zeolite porous. Further laser annealing allows solving this problem and further optimizing parameters of the synthesized layer.

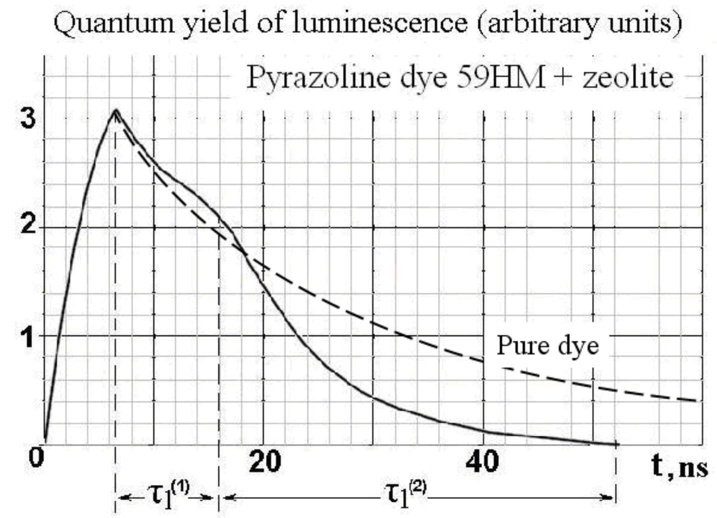

Fig. 4. Reducing of PL relaxation time for nanostructured pyrazoline dye 59HM

For an industrial usage it is necessary to check optical properties stability under circumstances of being radiated by solar power for a long term. It is especially important for nanostructured medium because nanoparticles tend to migrate which leads to heterogeneity of the material. Experimental results have shown that PL spectrum of pyrazoline (with accuracy of ±0,2 a.u.) dye didn't change shape, bandwidth and amplitude for last 10 years (Fig. 5). It was decided that obtained stability is being caused by porous matrix of white zeolite.

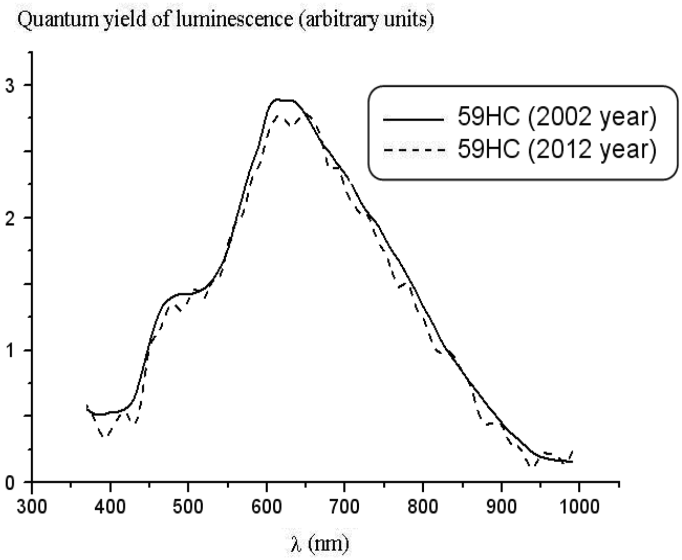

Fig. 5. Change of PL spectrum of nanostructured pyrazoline dye 59HC with bypassed time (10 years)

Conclusions

Luminofor coatings which convert incoming solar radiation into the secondary optical radiation for optimal matching with the active spectral range of the solar cell allow developing a new kind of multi-junction solar cell. These cells are characterized by high optical efficiency. In order to improve its characteristics we synthesized and studied a new class of nanostructured PL materials with high quantum yield, possibility of PL and absorption spectrum variation. The stability of optical properties of the materials under circumstances of being radiated by solar power for long term is proved. We recognize that we need to discuss about size- and structure-dependent materials and devices properties but not only about the structure-properties relationship.

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