THERMAL TRANSPORT V NANOCOMPOSITES ZnO/PMMA

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Abstract. *The thermal conductivity of zinc oxide-polymethyl methacrylate (PMMA) composites was measured . Using theoretical models, the thermal resistance values of ZnO-NW/PMMA interfaces (NW—nanowire) were estimated. And critical radius particles, higher whom Maybe promotion thermal conductivity composite. On basis these measurements determined addiction thermal conductivity nanowires zinc oxide from them diameter.*

Keywords: *thermal conductivity of zinc oxide-polymethyl methacrylate (PMMA) composites, thermal resistance of ZnO-NW/PMMA interfaces (NW - nanowire), critical radius of particles, dependence of the thermal conductivity of zinc oxide nanowires on their diameter*

Introduction

Semiconductor Zinc Oxide Nanowires (ZnO-NW), are promising for new nano-sized electronic and optoelectronic devices, hybrid solar elements [1,2]. Problems thermal management in these structures requires determining the thermal conductivity (λ*)* of nanowires, which is associated with great technical and technological difficulties [3,4]. IN works [5.6] was shown fundamental opportunity definitions thermal conductivity these systems based on measuring the thermal conductivity of nanocomposites polymer - semiconductor, it would be of interest to apply this method to a wider range of problems. At the same time, the creation of new polymer structures stimulated the development of conductive polymer composite materials containing filler nanoparticles, For example, шп as [5], fullerenes, CdS [7,8].

Behind check less size and more uniform distribution particles filler, it is necessary to introduce a smaller amount of filler (only $0.1-5$ wt.%), which allows maintaining the remaining physical properties of the polymer. Attractiveness and prospects of using composite materials based on zinc oxide as a nano-sized filler connected with those what he, so same how and other nanomaterials, makes it possible to obtain the required characteristics of the material with a small load, but has two orders of magnitude lower cost.

This work presents the results of studies of the effect of zinc oxide nanowires ZnO-NW of various geometries and orientations on thermal conductivity composite ZnO-NW/polymethyl methacrylate (ZnO-NW/PMMA).

Samples and methodology measurements

At the first stage, the synthesis of single-crystal nanowires oxide zinc on silicon substrate was carried out using the gas transport method at temperatures of $800-1000\ ^{\circ}$C without use catalyst. High-clean zinc and oxygen (99.995%) were used V quality reagents; purity nitrogen, applied as a gas carrier, was 99.999%. ZnO-NW samples of different diameters, lengths, and nanowire densities were obtained by changing growth conditions. Using X-ray spectral microanalysis, only signals of zinc and oxygen were detected in a ratio corresponding to stoichiometry, as a result of measurements low temperature (T = 10 K) photoluminescence confirmed that ZnO-NWs have a crystalline structure. Further samples ZnO-NW were removed from the silicon substrate and mixed with PMMA. The ZnO-NW/PMMA composite was obtained using a technology similar to described V [9]. For comparisons a ZnO/PMMA composite was also prepared, where commercial ZnO crystals with a particle diameter of ~ 1 μ m. The characteristics of the studied composites are given in the table. Finally, on the surface of the nanocomposite by thermal evaporation a thin film of bismuth with a thickness of about 100 nm. This ensured a high degree of surface blackness, which guarantees efficient and uniform absorption of the incident laser beam.

The thermal conductivity of the composites was measured using a modulated laser beam (Angstrom method). The measurements were carried out in a vacuum cryostat (Janis Research VPF-475) *at* fixed temperatures (± 0.05 K) in stationary conditions in the absence of any dynamic problems according to the method [10].

For promotion sensitivity and accuracy measurements thermal diffusivity us was the system has been improved registration ac signal thermocouples. Using digital complex amplifier - analyzer SR830 (DSP Lock-In Amplifier) allowing define "thermal diffusivity by formula

Options composites ZnO/PMMA

Number curve in Fig. 1	Components composites	*dZnO* , _ nm	*LZnO* , _ μ m	*f*	Size sample, mm
1 *2*	PMMA ZnO/PMMA	~ 1000		0.234	2 . 5 × 10 × 0 . 07 5.0 × 10 × 0.07
3	ZnO-NW/PMMA	~ 40	~ 35	0.119	5.0 × 10 × 0.07
4	ZnO-NW/PMMA	~ 480	~ 40	0.034	5.0 × 10 × 0.07

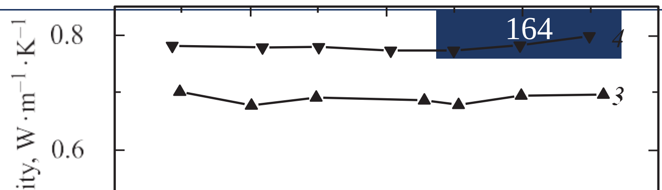
Note : *dZnO* , _ *LZnO* , _ *f* — diameter, length And volumetric share ZnO respectively, ZnO/PMMA — composite With micron particles ZnO.

$$D_{\varepsilon} = \sqrt{D_A D_{ph}}, \qquad (1)$$

where D_A and D_{ph} are the thermal diffusivity values determined amplitude and phase measured signals accordingly. Based on experimentally obtained data on D_{ε} using the formulas given in [10], the thermal conductivity λ *is calculated.* The relative error in thermal conductivity measurements can be estimated as being on the order of 5–7 %.

Results and discussion

On pic. 1 presented results research temperature dependencies thermal conductivity (λC _ ~ T^n) of ZnO-NW/PMMA composites and data for comparison for ZnO/PMMA. As can be seen from Fig. 1, the thermal conductivity of these composites ~ 1 . 5 − 3 . 5 times (T = 300 K) greater than for films PMMA, however much less by comparison with thermal conductivity composite with vertically oriented ZnO-NW [6] . Because the composite consists of close-packed ZnO-NWs in PMMA and PMMA It has much more low great thermal conductivity (λ O) , value λ C determined by the thermal conductivity of ZnO-NW (λ P) . Nevertheless, heat transfer in such composites occurs through two channels with various thermal conductivity, at this heat exchange between them is determined by thermal conductivity (Geff) _ borders section Wednesday and critical radius $r_0 = \lambda_O / G_{eff}$, which determines the increase in λ C (r > r 0) or her decrease (r < r 0) .



240 260 280 300 320

Pic. 1. Temperature dependence of thermal conductivity fine (~ 70 μ m) PMMA film (1) , ZnO/PMMA composite with unoriented ZnO microparticles (2) , ZnO-NW/PMMA composite with unoriented ZnO nanowires of diameter 40 (3) and 480 nm (4)

We ignore thermal resistance interface Bi/composite because of his Very small quantities By comparison With thermal resistance of the composite itself. It is known [11] that the smallest possible value for this interface at room temperature G ~ 8 · 10 6 W · m − 2 · K , while G 0 for ZnO-NW/PMMA with a thickness of ~ 70 μ m is equal to ~ 1 . 8 10 4 W m − 2 _ _ · K − 1 . IN works [12,13] proposed methods calculation pa-dimensions, defining heat transfer V composites various structures. For preliminary estimates of these parameters let's take advantage expressions For ZnO/PMMA nanoparticles [12] :

$$\lambda_C = \lambda O \quad 1 + 3f \, \frac{l_P \quad (c-1) - \textit{2л}_O}{\lambda P_{\_} \;\; \gamma(\gamma+2) + 2\gamma\lambda_O}, \qquad (2)$$

$$\gamma = rG_{\mathrm{eff}}/\lambda_O . \qquad (3)$$

Hence, V compliance With According to the results of work [12], changes in thermal conductivity depend relatively weakly on $r\,G_{\mathrm{eff}}$, but the value λ_C sensitive To $Geff_{\_}$ V range sizes particles

$$0.3 < r/r_0 < 0.8.$$

Using appropriate analysis of experimental data on the thermal conductivity of ZnO-NW/PMMA also established what $Geff_{\_} \approx 8 \cdot 10^5 - 3 \cdot 10^6$ W · m $^{-2}$ · K $^{-1}$ and thermal conductivity com-positive. IN this case determined V greater degreesratio $\lambda P_{\_}/_{\lambda O}$, how size $Geff$ .One of the results of this work is the experimentally observed increase in the thermal conductivity of the composite by ~ 1 . 5 − 3 . 5 times (T = 300 K) upon injection ZnO V PMMA.

Promotion thermal conductivity V ~ 2 . 6 times observed Also V qualitatively similar to the InAs/PMMA composite [5] . In [12] , an increase in thermal conductivity V composite Al_2O_3/PMMA slightly(3 − 5%) . In [15] , a significant decrease was experimentally shown (at T = 300 K) thermal conductivity of the C60 /PMMA composite with increasing C60 concentration . Concentration addiction thermal conductivity is- of the following samples shows that already at 1 wt.% of fullerene, the thermal conductivity decreases by 20%. How noted higher, more likely Total, This due to thermal conductivity Geff _ borders section Wednesday and critical radius r 0 = λO / Geff , _ _ which determines the increase λ C (r > r 0) or her decrease (r < r 0) . WITH another sides, at calculations Geff _ and analysis exp-experimental results for λ C it is believed that the thermophysical properties of the matrix boundary layer remain unchanged, however, in a number of works, for example [16,17] , it is shown that that at low concentrations (f < 1) near the filler maybe education border layers matrices with distinctive physical parameters leading to a significant increase in thermal conductivity. Thus, in [8] it was shown that the increase in physical parameters, for example, thermal stability, is due precisely to the presence of ZnO nanocrystals in the initial monomer, their influence on the polymerization of PMMA and, ultimately, on the structure of the composite. As noted above, the main goal of this work is to obtain new experimental data on thermal conductivity λ P ZnO-NW, therefore first queue necessary highlight from λ C size λ P . To do this, we used the results of [13] .

Conclusion. Based on measurements of the thermal conductivity of the composite products ZnO-NW/PMMA, it was established that heat conduction. The strength of ZnO-NW decreases significantly with decreasing diameter. It is shown that this is due to the increased role of phonon-boundary scattering processes. The experimental results can be useful in the development of new composite materials based on zinc oxide and PMMA, as well as a method for determining the thermal conductivity of nanowires.

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