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Investigation of Heat Transfer in Nanocomposite Structures "PS-liquid" Using Photoacoustic Method

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The thermal properties of porous silicon and composite «PS-liquid» system have been investigated in this paper. Using the photoacoustic method the values of thermal conductivity of porous silicon and composite systems with liquid have been obtained. It is shown that the value of thermal conductivity «PS-liquid» substantially exceeds the value determined by the model of «parallel structures». The increase of thermal conductivity is due to the improvement of thermal contacts among the crystallites when introducing liquid into the pores.

Keywords: Photoacoastic Method, Porous Silicon, Composite System, Thermal Conductivity.

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1. INTRODUCTION

The study of nanostructured materials, such as porous semiconductors is an important modern materials researches [1].Among the porous semiconductors porous silicon (PS) is studied most intensively [2]. PS is used more often in the form of composite systems with different type of fillers in application development. Composite systems: «PS-liquid» more widely used. They are perspective for using them, for example, in alternative energy (fuel cells), medicine, in the chemical industry (catalysts). It should be mentioned that the composites of this type appeared in process of PS fabrication [3] and in a some methods for investigation of their morphological characteristics. The information of thermal parameters of such composite systems is important to provide devices reliability which based on them. Processes of heat transfer in such composite systems practically weren't studied.

The theoretical modeling of thermophysical parameters of the composite systems which based on PS is problematic because of their specific morphology, that brings forward experimental methods for their determination. Photoacoustic (PA) methods are perspective for the study of porous semiconductors layers [4, 5] particularly gas-microphone configuration [6]. In this paper a microphone detection version for the open photoacoustic (OPC) technique [7] is proposed for experimental research of heat transfer in composite «PS-liquid».

2. EXPERIMENT

PS samples were investigated in the kind of the porous layer with thickness of 240 mkm on mono-crystalline silicon substrate with thickness of 290 mkm. Porous layer were obtained by localized electrochemical dissolution of mono-crystalline silicon substrates in electrolyte solutions composed of a mixture of 50 % HF acid and absolute ethanol in a ratio of 1 : 1 [8]. For fabrication of the samples, (1 0 0)-oriented p+-type (boron doped) Si wafers (10^{-2} Ωcm) were used. PS porosity was about 60 %. Composite system «PS-liquid» was prepared through immersion of the sample in liquid after preliminary air evacuation. Oil as a filler was chosen because it properly wets PS, has a relatively low viscosity and is stable under normal conditions.

PA method in geometry of the transmission detection configuration [**Ошибка! Закладка не определена.**, 9] was used to investigate this samples, to simplify analysis of the experiment results thermoelastic mechanism of formation of PA signal was excluded through damping of sample. For this purpose, monocrystalline surface of the sample was rigidly connected with a quartz window (Fig. 1) using a transparent glue. The porous layer surface bordered with an internal volume of PA cell.

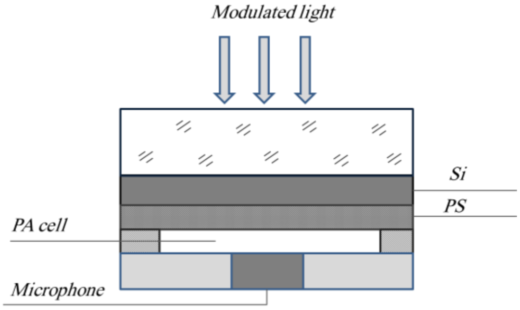

Fig. 1 – Configuration of experiment

Fig. 2 shows the phase-frequency dependence of the PA signal for PS and composite «PS-liquid». Phase shift, from heat wave passing through a monocrystalline substrate was taken into account.

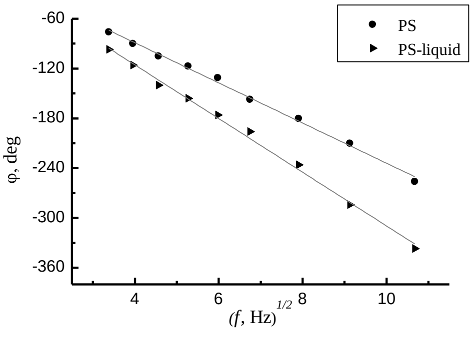

Fig. 2 – Phase-frequency dependence of the PA signal for PS

and composite «PS-liquid»

To determine the thermal conductivity of samples was used expression for the phase-frequency dependence of PA signal in the method of passing a heat wave through the sample [10]:

$$\varphi = h\omega^{1/2}/D_T^{1/2},$$

where h - thickness of the porous layer, ω - modulation frequency, D_T – thermal diffusivity.

From the experimental results values of thermal conductivity of porous silicon $\chi_{PS} = 0.23$ *W/(m·K)* and composite system «PS-liquid»– $\chi_C^{exp} = 0.48$ *W/(m·K).* were obtained

3. RESULT AND DISCUSSION

There is a number of models to describe the thermal conductivity of composite systems [11], but among them there are no models that describe the thermal conductivity of composite systems with a morphology similar to porous silicon. The most suitable is the model of composite material where the heat is distributed along the axis of symmetry of the structural elements (wires) of the filler [12]. In this case, heat transfer is made by components of composite systems independently of each other, and thermal conductivity of the composite system χ_C^{th} is defined as:

$$\chi_C^{th} = \chi_{PS} + \varepsilon \cdot \chi_{Oil}$$

where, χ_{PS} - χ_{Oil} thermal conductivity of porous silicon and of oil respectively

According to this expression, values of thermal conductivity of composite system were calculated and they turned out to be significantly less than values obtained from the experiment ($\chi_C^{exp} = 1,7\chi_C^{th}$).

Increase of the value of thermal conductivity can be explained by improvement of thermal contact among the crystallites. If pores considered as an area of the gap between the crystallites in this case, when the direction of gradient does not match with the orientation of the plane gap, the redistribution of heat flow happens, that increases the overall thermal conductivity of the composite. Conversely, when the plane of the gap is parallel to the direction of local gradient temperature field, then filling the pore with liquid does not change the heat flow.

Fig. 3a shows columnar morphology of porous silicon, which investigated, where phonon heat conduction occurs along an axis of the crystallites [13]. Distribution of heat in side branches of quasi-fractal structure is difficult, because they are separated by pore spaces. Areas where the improvement of the thermal contact between the crystallites with the introduction of fluid into the pores is possible are marked with rings.

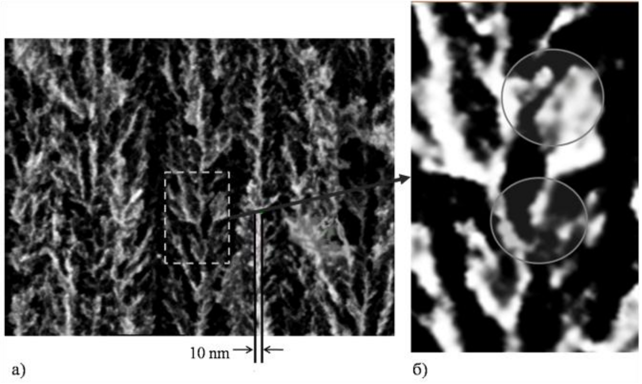

Fig. 3 – Columnar structure of porous silicon, crystallites light areas, seasons – dark

On the other hand, the increase of thermal conductivity may be due to changes of thermophysical properties of liquid in the pores compared to its free state. The increase of thermal conductivity of nanostructure liquid is described in [13].

From our point of view both process make contribution to the increase of thermal conductivity, but a significant difference between χ_C^{exp} and χ_C^{th} indicates the first mechanism, because change in times thermal conductivity of nanostructured liquid is doubtful [14].

4. CONCLUSIONS

In this paper porous silicon and composite systems: «PS-liquid» has been investigated using photoacoustic method in geometry of the transmission detection configuration. From the experimentally phase-frequency dependencies of PA signal the values of thermal conductivity for the investigated materials were obtained. It is shown that the thermal conductivity of composite systems «PS-liquid» is more than the value that can be obtained based on the model of «parallel structures». The increase of conductivity can be explained by the improvement of thermal contacts among the crystallites by introducing liquid into the pores and the possible increase of the value of thermal conductivity of the liquid due to the limited improvement in the structure of porous material.

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REFERENCES

1. H. Foll, J. Carstensen, and S. Frey, *Journal of Nanomaterials.* **2006**, 1 (2006).
2. H. Foll, M. Christophersen, J. Carstensen, G. Hasse, *Mater. Sci. Eng.* **R 280**, 1 (2002).
3. S. Gom`es, L. David, V. Lysenko, A. Descamps, T. Nychyporuk, and M. Raynaud, *J. Phys. D: Appl. Phys.* **40**, 6677 (2007).
4. D. Andrusenko, R. Burbelo, A. Kuzmich, *Tech. Phys. Lett.* **36** No12, 1121 (2010).
5. Q. Shen, and T. Toyoda. *J. Thermal Analysis and Calometry* **69**, 1067 (2002).
6. P. Charpentier, F. Lepoutre, L. Bertrand, *J. Appl. Phys.* **53**(1), 608 (1982).
7. W. Mahmood Mat Yunus, C.Y.J. Fanny, I.V. Grozescu, S.A. Halim and M.M. Moksin, *J. on Science and Technology for Development* **18** No1, 55 (2001).
8. S. Gomes, L. David, V. Lysenko, A. Descamps, T. Nychyporuk, and M. Raynaud, *J. Phys. D: Appl. Phys.*

40, 6677 (2007).

9. D. Luković, P.M. Nikolić, S. Vujatović, S. Savić, D. Urošević, *Science of Sintering* **39**, 161 (2007).
10. S.A. Vinokurov, *J. of Engineering Physics* **44**, № 1. 60 – 66 (1983).
11. P. Keblinski, S.R. Phillpot, S.U.S. Choi, J.A. Eastman, *Int. J. of Heatand Mass Transfer* **45** No4, 855 (2002).
12. K. S. Reddy, and P. Karthikeyan, *Hindawi Publishing Corporation Advances in Mechanical Engineering* **2010**, 14 (2010).
13. P. Chantrenne, and V. Lysenko, *Phys. Rev. B* **72**, 035318 (2005).
14. P. Keblinski, S.R. Phillpot, S.U.S. Choi, J.A. Eastma, *Int. J. of Heat and Mass Transfer* **45**, 855 (2002).