PROCEEDINGS OF THE INTERNATIONAL CONFERENCE NANOMATERIALS: APPLICATIONS AND PROPERTIES
Vol. 1 No 3, 03PCSI14(3pp) (2012)

Examination of Thermally Induced Deformations of Composite System "Porous Silicon – Liquid"

A.G. Kuzmich*, D.A. Andrusenko, P.A. Tesel'ko, M.V. Isaiev, and R.M. Burbelo

Faculty of Physics, Taras Shevchenko National University of Kyiv, 64, Volodymyrs'ka St., 01601 Kyiv, Ukraine

(Received 23 June 2012; published online 24 August 2012)

In the paper results of analyze of the pressures that appeared in composite system "porous silicon – liquid" under its heating is presented. The value of thermally induced pressures of liquid in the pores from photoacoustic measurement was estimate. The temperature dependence of pressures that occurred by interaction forces between solid matrixes and liquids was experimentally measurement. The values of these two pressures where compared.

Keywords: Porous Silicon, Composite System, Thermally Induced Deformations, Photoacoustic.

PACS numbers: 65.40.De, 62.25.De

1. INTRODUCTION

The main interest for modern material research is provided by multicomponent advanced materials such as composite structures of different nature. Among such system should be marked out the complex composite materials the separated components of which have very different properties. Especially its deals with materials which structure have been designed in vitro from the smallest scale up. This system can behave like any materials that can be found in nature [1].

For this kind of materials nano-composite structures "porous solid matrix – liquid" may be included. From applied point of view investigations of composite system "porous silicon – liquid" properties are very important because such structures appear in different fields of science and technology (e. g. medicine, chemistry industry, optoelectronics [2], alternative energy craft [3] etc.). Under practical implementations this structures subjected to thermal loads that why investigation of elastic deformations and pressures that occur in such materials is necessary.

The thermal physical properties of such inhomogeneous structures are often investigating by photoacoustic techniques because these methods are noncontact and nondestructive. Such methods give the possibility to exanimate the thermoelastic deformations of porous matrix, thermal induced pressures of liquid in the pore and even taking in consideration liquid' moving in porous media. Let notice that the value of thermally induced pressures that appeared in composite systems "porous matrix – liquid" as result of its thermal loads (stationary or non-stationary heating) because of complex nature of its component is ambiguous.

In the paper we investigate thermally induced deformations that appear in composite system "porous silicon – liquid".

2. THERMALLY INDUCED DEFORMATIONS

2.1 Thermoelasticity stresses of solid state

In the sample occur elasticity strain under it heating from the temperature T_0 to T, the value of this strain is

$$\varepsilon_{ij} = \alpha_T (T - T_0)\delta_{ij} ,$$

here α_T – coefficient of thermal expansions, δ_{ij} - Kronecker delta.

So, in the sample occurs thermoelastic source of forces, which can be numerically estimate by the elastic stresses that it caused

$$\Delta\sigma = K\varepsilon = -K\alpha_T \Delta T , \qquad (1)$$

here K - elastic modulus, $\Delta T = T - T_0$.

In the paper [4] the formations of photoacoustic response (piezoelectric type formations) in porous silicon on substrate was experimentally measurement. It was shown that expressions (1) described thermoelasticity stresses in porous media but the elasticity modulus and thermal expansions coefficient must be taken effective.

2.2 Thermally induced pressures of "porous matrix - liquid" composite system

Under heating composite system "porous matrix – liquid" to thermoelastic source of forces (1) the term that include liquid expansions must be added

$$\Delta\sigma = -(K\alpha_T + \xi\beta_T / \beta)\Delta T , \qquad (2)$$

here ξ - porosity of porous matrix, β_T - liquid thermal expansions coefficient, β - liquid compressibility.

The expression (2) describes the source of thermal induced pressures (TIP) that appeared in the composite structure under it heating in the case of viscount liquid.

In the [5] was shown that liquid' moving in the pore can influence significantly on TIP distribution in the structures. In the more general case the liquids moving should be taking in considerations. So in general case

$$\Delta\sigma = -K\alpha_T \Delta T - \xi p , \qquad (3)$$

here p - pressures of liquid in the pores, that included thermal expansions and relaxations (that depend on

* kuzmich@univ.kiev.ua

liquid moving) components.

The expressions (3) do not depend on interactions between the solids matrix and liquids filler. This interaction forces can influence on general structures deformations and will analyzed more details in the next sections.

3. INTERECTIONS BETWEEM SOLID MATRIX AND LIQUIDS

It is known [6] that general deformations of structure "Porous matrix – liquid" depend on interactions forces of different nature (such as surface tension and disjoining pressure) between solid matrix and liquid. The pressures that caused by these forces from grand potential (Ω) adjusted

$$p_s = \left(\frac{\partial \Omega}{\partial V}\right)_{\mu,T},$$

μ – chemical potential.

In this sections we will experimentally estimate the value of these forces and will analyzed its dependence on temperature.

3.1 Experiment and results

As sample the plate (50×5×0.53 mm) which consist layer of porous silicon (thickness 0.24 mm, porosity 60%) and monocrystalline Si (thickness 0.29 mm) wafer was chosen. Sample was immersed in a cell with an ethanol under temperature 293 K. As a result of alcohol absorption in the pore the sample was bended. The value of bending (see Fig. 1 a) become $\delta = 375$ µm. The sample bending in this case is provided by pressures that appeared at development interphase boundary of porous silicon specific surface area of which in 10^3-10^4 more than the area of monocrystalline Si [7].

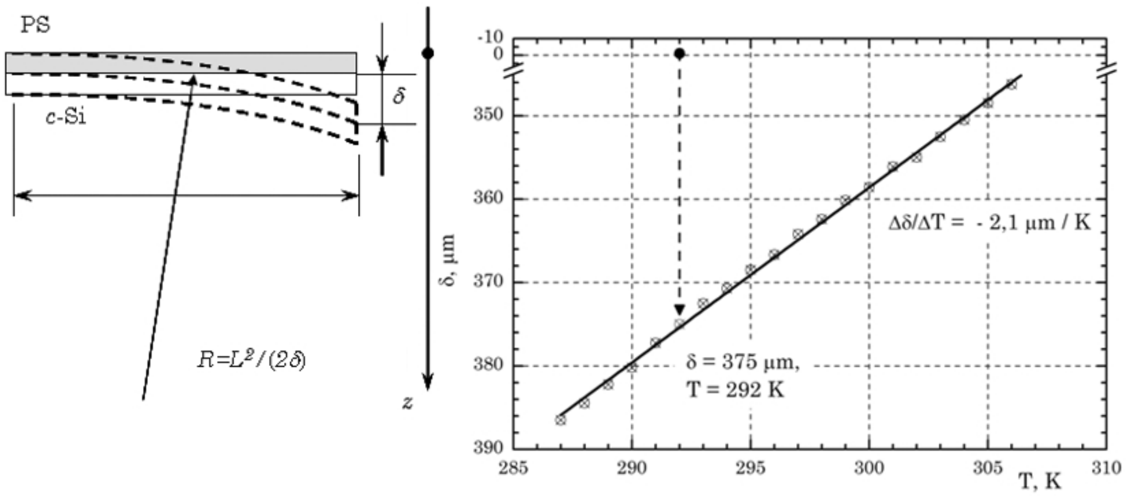

Fig. 1 – a) geometry of the experiment b) dependence of the bending on temperature

In the cell with the sample the temperature was changed slowly in diapason 285-310 K and sample' bending was measurement. The dependence δ on temperature is presented at the fig. 1 b.

Let us estimate the value of pressures that provide the experimentally observed initially bending of the sample on the basis of balance forces and moment forces:

$$\begin{aligned} &\int_0^{h_{\rm PS}} \left(\sigma_{\rm PS} - p_s\right) dz + \int_{h_{\rm PS}}^{h_{\rm PS}+h_{\rm c\text{-}Si}} \left(\sigma_{\rm c\text{-}Si} - p_s\right) dz = 0 \\ &\int_0^{h_{\rm PS}} \left(\sigma_{\rm PS} - p_s\right) z dz + \int_{h_{\rm PS}}^{h_{\rm PS}+h_{\rm c\text{-}Si}} \left(\sigma_{\rm c\text{-}Si} - p_s\right) z dz = 0 \end{aligned},$$

here $\sigma_{\rm PS} = E_{\rm PS}/(1-\nu_{\rm PS}) \times \varepsilon_{\rm PS} = \tilde{E}_{\rm PS} \times \varepsilon_{\rm PS}$, $\sigma_{\rm c\text{-}Si} = E_{\rm c\text{-}Si}/(1-\nu_{\rm c\text{-}Si}) \times \varepsilon_{\rm c\text{-}Si} = \tilde{E}_{\rm c\text{-}Si} \times \varepsilon_{\rm c\text{-}Si}$ – the thermoelasticity stresses; $E_{\rm PS}$, $E_{\rm c\text{-}Si}$ - Young's modulus; $\nu_{\rm PS}$, $\nu_{\rm c\text{-}Si}$ - Poisson's ratio; $h_{\rm PS}$, $h_{c-{\rm Si}}$ - the thickness of porous monocrystalline layer respectively; p_s - interphase pressures.

According that the sample' strain is linear [8]

$$\varepsilon = (a - bz),$$

the thermoelasticity stresses of porous silicon and c-Si described by expression (1) and that $b = 1/R = 2\delta/L^2$ (R – bending radius and L - the sample length) we can obtained

$$\delta = \left[p_s + \tilde{E}_{\rm PS}\left(\alpha_{T\rm PS} - \alpha_{T\, c\text{-}{\rm Si}}\right)\Delta T\right] \times \times \frac{3L^2}{h_{c-{\rm Si}}\tilde{E}_{c-{\rm Si}}} \times \frac{m(m+1)}{m^4 n^2 + n\left(4m^3 + 6m^2 + 4m\right) + 1}, \quad (4)$$

here $n = \tilde{E}_{\rm PS}/\tilde{E}_{c-{\rm Si}}$, $m = h_{\rm PS}/h_{c-{\rm Si}}$.

Using value of Younge' modulus of porous silicon and c-Si and its Poisson' ratio [9] the value of the interface pressures calculated by (4) is $p_s \approx (3,9 \div 4,6) \times 10^6\,{\rm Pa}$.

Experimentally observed changing δ on temperature ($d\delta/dT$) is negative, so the sample extension under heating. The change of pressures value that caused decreasing bending ($\Delta\delta$) can be estimated as

$$\left[p_s + \tilde{E}_{\rm PS}\left(\alpha_{T\rm PS} - \alpha_{Tc\text{-Si}}\right)\right]\Big/\Delta T \approx -\mathbf{0.024}\times\mathbf{10^6}\ \mathrm{Pa/K}\ .$$

Using the value of thermal expansions coefficient for porous silicon and c-Si [10] changing of interphases pressures on temperature can be estimated as

$$d\,p_s/dT \approx -\mathbf{6}\times\mathbf{10^4}\ \mathrm{Pa/K}\ .$$

4. CONCLUSIONS

In the paper the value of pressures that appeared at interphase surface "porous matrix – liquid" was estimate. The dependence of these pressures on temperature was presented. The results of experimental measurement were analyzed in such cases:

- The porous matrix was filled by liquid;
- The "porous silicon – liquid" was subjected by heating;

The results obtained where compared with results of thermally induced pressures measurement obtained by photoacoustic methods. It was established that the value of thermally induced pressures that appeared in structure under it heating much more than the value of temperature changing pressures of interaction between solid matrix and liquid.

AKNOWLEDGEMENTS

Authors are grateful to the Dr. V. Lysenko from INSA Lion (France) for porous silicon samples providing and for valuable discussions

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