PACS nambers:65.40.De, 62.25.De
UDC 53.096; 53.092; 539.89

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THERMOLELASTIC STRESSES STUDY IN NANOCOMPOSITE SYSTEM "POROUS SILICON – LIQUID"

In the paper the results of thermoelastic properties of nanocomposite system "porous silicon – liquid" study is presenting. Contribution of different mechanisms that lead to such system deformation under its heating was evaluated. Different sources of such deformation – as dynamical, related with thermal induced pressures of liquids in the pores, as stationary, related with forces of different nature that occur at the interface "porous matrix – liquid" – were compared.

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 nanocomposite structures "porous solid matrix – liquid" may be included. From applied point of view investigations of composite system "porous silicon – liquid" properties [2, 3] are very important because such structures appear in different fields of science and technology (e. g. medicine, chemistry industry, optoelectronics [4], alternative energy craft [5] 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 [6] 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 thermalelasticity properties of complex composite systems "porous matrix – liquid" are ambiguous.

In the paper the results of thermaelasticity stresses investigations in nanocomposite systems "porous silicon –liquid" are presenting.

2. THERMALLY INDUCED DEFORMATIONS

2.1 Thermoelasticity stresses of solid state

Value of elasticity strain that occur in unbounded sample under it heating from the temperature T_0 to T is

$$\varepsilon_{ij} = \alpha_T \left(T - T_0\right)\delta_j$$

here a_T – coefficient of thermal expansions, d_{ij} - Kronecker delta.
These strain occur as results of thermoelastic source action, which can be estimate as

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

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

In the paper [7] the formations of photoacoustic response (piezoelectric type formations) in porous silicon on substrate was experimentally measurement. It was shown that expressions described thermoelasticity stresses in porous media but the elasticity modulus and thermal expansions coefficient must be taken in effective media approximation.

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

Under nanocomposite system "porous matrix – liquid" heating beside thermoelastic source the liquid expansions influence on overall sample stresses have been also considered

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

here x - porosity of porous matrix, β_T - liquid thermal expansions coefficient, β - liquid compressibility. For ethanol the value $\beta_T = 108\times10^{-5}\,\mathrm{K}^{-1}$, $1/\beta = 1275\times10^{6}$ Pa and $\beta_T/\beta = 1{,}3\times10^{6}$ Pa/K respectively.

The expression 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 [2] was shown that liquid' moving in the pore can influence significantly on TIP distribution in the structures. 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 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 between solid matrix and liquids

It is known [8] 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 $p_s = \left(\partial\Omega/\partial V\right)_{\mu,T}$, μ – chemical potential.

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

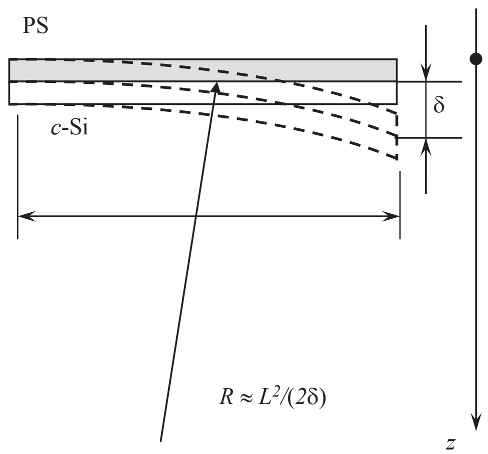

Fig. 1 – **Geometry of the experiment**

3.1 Experiment and results

As sample the plate (50x5x0.53 mm) which consist layer of porous silicon (thickness 0.24 mm, porosity 60%) on monocrystalline Si (thickness 0.29 mm) wafer was chosen. Sample was immersed in a cell with an ethanol under temperature 293 K. Under alcohol in the pores absorption the sample was bended as results of pressures that appeared at development interphase boundary of porous silicon specific surface action [9]. The initial value of this bending (see fig. 1) was δ = 375 μm.

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.2.

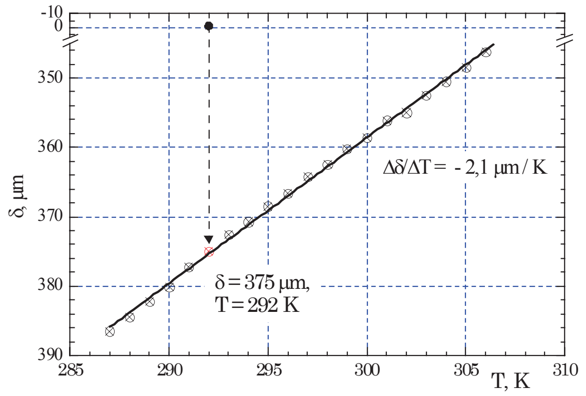

Fig. 2 – **Dependence of the bending composite system "porous silicon – liquid" on temperature. Let us estimate the value of pressures that provide the experimentally observed initially bending of the sample on the basis of balance forces and moment forces:**

$$\int_0^{h_{PS}} (\sigma_{PS} - p_s)dz + \int_{h_{PS}}^{h_{PS}+h_{c-Si}} (\sigma_{c-Si})dz = 0$$

$$\int_0^{h_{PS}} (\sigma_{PS} - p_s)zdz + \int_{h_{PS}}^{h_{PS}+h_{c-Si}} (\sigma_{c-Si})zdz = 0$$

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

According to the linear law of spatial sample strain distribution [10] $\varepsilon = (a - bz)$ and taking in account that $b = 1/R = 2\delta/L^2$ (R – bending radius and L - the sample length) we can obtained

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

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

Using value of Younge' modulus of porous silicon and c-Si and its Poisson' ratio [11] the value of the interface pressures calculated by is

$$p_s = (3.9 \div 4.6) \times 10^6 \text{ Pa}.$$

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

$$\left[p_s + \hat{E}_{PS}(\alpha_{T\,PS} - \alpha_{T\,c\text{-}Si})\Delta T\right]/\Delta T \approx -6 \times 10^4 \text{ Pa/K} \textbf{ Pa /K.}$$

Using the value of thermal expansions coefficient for porous silicon and c-Si [12] changing of interfaces pressures on temperature can be estimated as

$$dp_s/dT \approx -6 \times 10^4 \text{ Pa/K} \textbf{ Pa /K}$$

4. Conclusions

In the paper the value of pressures that appeared at interface 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 value of the pressures where compared with value of thermally induced pressures 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.

The results of this paper at the 2nd International Conference "Nanomaterial: Applications and Properties" was presented.

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The article is received in editorial 21.05.2013

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

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ТЕМОУПРУГИЕ НАПРЯЖЕНИЯ В НАНОКОМПОЗИТНОЙ СИСТЕМЕ «ПОРИСТЫЙ КРЕМНИЙ – ЖИДКОСТЬ»

Резюме

В роботе представлены результаты исследования термоупругих напряжений, которые возникают в нанокомпозитной системе «пористый кремний – жидкость». Оценен вклад различных механизмов, приводящих к деформациям указанных систем под воздействием теплового возмущения. Проведен сравнительный анализ различных источников таких деформаций: динамических, связанных с термоиндуцированным давлением жидкости в порах, и стационарных, связанных с силами взаимодействия различной природы, которые возникают на интерфейсе «пористая матрица – жидкость».
Ключевые слова: пористый кремний, композит, термоиндуцированные деформации, термоиндуцированное давление.

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Резюме

В роботі приведено результати дослідження термопружних напружень, що виникають у нанокомпозитній системі «поруватий кремній – рідина». Оцінено внесок різних механізмів, що призводять до деформацій вказаних систем при термічному збудженні. Проведено порівняльний аналіз різних джерел таких деформацій: динамічних, зумовлених термоіндукованим тиском рідини в порах, та стаціонарних, пов’язаних із силами взаємодії різної природи на інтерфейсі «порувата матриця –рідина».
Ключові слова: поруватий кремній, композит, термоіндуковані деформації, термоіндукований тиск.