Low-dimensional heterostructures obtaining from an intelligent material and carbon material on a silicon

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Abstract. The results of the study of the technological regimes of the formation of a microcantilever beam of layered heterostructures based on the integration of smart material and silicon carbide are presented. Layers of silicon dioxide (SiO₂), silicon nitride, silicon carbide, and platinum (lower electrode) are successfully formed on a silicon substrate. The results of an experimental study of the Pt / PZT / Pt / SiC heterostructures parameters confirmed the technological compatibility of the layers and the promise of using these structures in sensors of dynamic deformation when creating new generation sensors, including those operating in heavy rocket conditions of space technology.

1. Introduction
The new generation MEMS allow miniaturizing sensor equipment, but due to physical limitations, increased reliability requirements, the problem of finding materials and synthesizing new structures with improved physical and mechanical parameters that can react to changes in external or internal conditions by changing dynamic behavior is relevant [1, 2].

This article proposes the use of intelligent materials as an element of transformation, which can significantly reduce the threshold sensitivity of dynamic deformation sensors based on piezoelectric films; increase the sensitivity of sensors based on MEMS technologies by two orders while maintaining long-term stability [3]

2. Technological conditions for the formation of a microcantilever beam of layered heterostructures based on the integration of smart material and silicon carbide
The film obtained by the CVD method is characterized by a coarse-grained polycrystalline structure, which, in turn, is the cause of the high surface roughness. Figure 1 shows the surface of a diamond film obtained by a Hirox 7700 optical microscope with a magnification of 1,400 times.

Silicon-carbide-PTS thin-film heterostructures are formed on a silicon substrate by the method of high-frequency magnetron sputtering of a PbZr₁₋ₓTiₓO₃ ceramic target in an oxygen atmosphere and a silicon carbide target in an argon atmosphere. This composition corresponds to a rhombohedral solid solution adjacent to the morphotropic phase boundary. In this case, the piezoelectric properties reach optimal values, which was confirmed in [4].
Figure 1. The surface of the diamond film at a magnification of 1400 ×, obtained by an optical microscope Hirox 7700.

On a silicon substrate films of silicon dioxide (SiO2), silicon nitride, silicon carbide, and platinum (lower electrode) are formed sequentially. A layer of silicon dioxide with a thickness from 0.2 to 0.5 μm is obtained by thermal oxidation. Silicon nitride was obtained by CVD method by deposition from the gas phase in the plasma of the ratio of the gases of ammonia, monosilane and argon. A layer of silicon carbide with a thickness of 1 μm was obtained by high-frequency magnetron sputtering with sequential ionic support to obtain the required surface roughness, with the result that the interface with the PZT film became monophasic. The lower platinum electrode with a thickness of 0.8 μm is applied by resistive evaporation. The thickness of the PZT ferroelectric film at a deposition temperature of 450 °C was 0.3 μm. Before use, the platinum surface was treated with an ion source. Then the process of deposition of the ferroelectric film alternates with the treatment of the deposited surface with an ion source. This made it possible to increase the film continuity. The top electrode with a thickness of 0.8 μm was formed by resistive evaporation.

3. Method for detecting defects in silicon structure

The well-known optical, electronic, X-ray versions of microscopy, topography and tomography, spectroscopic methods for identifying defects in silicon structures are widely applicable. The low density of structural defects in silicon indicates the feasibility of using the etching method to reliably identify individual defects. This method is based on a visual and microscopic analysis of the surface relief of a defective plate after it has been treated with etchant solutions (etchant Sirtle-Adler, Dash, Secco), specially designed to detect dislocations. After a similar surface treatment, a relief is formed on it, representing traces of micro-defects in the form of hills and craters. The method has a limitation due to a not high enough resolution for studying the crystal structure, as well as the difficulty of identifying the detailed structure of the defect and the impurities present. At the same time, the alternation of plate etching and microscopic studies makes it possible to obtain information on the distribution of defects over the sample depth [5]. The method of identification of swirl defects is based on the difference in etching rates of perfect crystallographic regions of the plate and its areas with micro-defects. The etching rate varies in areas with micro-defects, which leads to the formation of a flat-bottomed pit, its geometry is due to the type of micro-defects and the orientation of the plane under study [6].

The image of a plate with swirl defects is shown in Figure 2 (a), Figure 4 (b) shows etching pits inherent in micro-defects forming a swirl pattern (magnification 800 times).
To identify swirl defects, a HF solution was used: an aqueous solution of CrO$_3$ (1200 g / l) = 1: 4. The duration of etching was 25 minutes.

4. Results of experimental studies of Pt / PZT / Pt / SiC heterostructure

A number of studies have been devoted to the study of the electro-physical properties of the heterostructures [7, 8]. In [9, 10], the results of the study of the electro-physical parameters of thin PZT films with the help of the software and hardware measuring complex proposed by the authors are presented. As a result of the analysis of experimental data on the choice of the optimal technological regimes of hot polarization of a piezoelectric film integrated in a heterostructure with a carbon material, it was found that the use of such a polarization method is quite stable from the point of view of practical use of film samples as converters. The temperature dependence of the residual piezomodule $d_{33}$ was obtained (fig. 3), from which it follows that when heated to 250 °C $d_{33}$ decreases by no more than 10% and, most importantly, the sample is not depolarized, which is consistent with [11]. Note that as a general principle, for large tables font sizes can be reduced to make the table fit on a page or fit to the width of the text.
Figure 4. PEM image of the cross section of the Pt / PZT / Pt / SiC heterostructure.

The effect of increasing the residual piezomodule immediately after the creation of a stable polarized state in films due to the ongoing processes of its polarization in the charge region trapped in traps in the bulk of the film in accordance with [3] is established.

The study of the interface of the obtained heterostructure was carried out on a scanning electron microscope (Fig. 4). Analysis of this image confirms the absence of mutual diffusion between the integrated thin heterostructure layers.

The work uses the technology of manufacturing sensitive elements of the beam type, which is implemented through the selection of the optimal technological modes of applying thin layers with a thorough inter-operative control. There is a technological compatibility of hetero-structures made on the basis of high-strength carbon-containing materials and smart materials in combination with conductive layers of metals. MEMS, manufactured using the considered technology of creating micro-cantilever beams based on smart materials, can serve as a starting platform for highly intelligent sensors for detecting new-generation aerospace structures designed for operation in harsh environments. Tables should be centred unless they occupy the full width of the text.

5. Conclusion

Heterostructures made on the basis of high-strength carbon-containing materials and smart materials in combination with conductive layers of metals are technologically compatible. MEMS, made with the use of the considered technology based on smart materials, can serve as a launching platform for highly intelligent detection sensors of a new generation, working in hard operating conditions of rocket and space technology.

References

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