Description (profile) of a scientific research project (SRP) for postdoc track participants in the "Open Doors: Russian Scholarship Project"

UNIVERSITY	**MOSCOW POLYTECHNIC UNIVERSITY (Moscow Polytech)**
Scientific Research Project	Modeling of thermal and deformation processes of silicon membranes in micro bolometric devices
Department	Scientific and Technical Center "Optoelectronics" at Moscow Polytech
Department Head	Vladimir K. Nikolayev, Candidate of Economic Sciences, Senior Researcher
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Language	English, Russian

Goals and Objectives

The project is aimed at solution of a fundamental scientific problem, connected with research and development of efficient Photovoltaic semiconductor materials and structures based on them, as well as investigation of the features of the mechanics of deformation and destruction of multilayer thin-film materials based on semiconductors under conditions of non-stationary heating.

The research is aimed at:

- Determination of the dependencies of thermal resistance between the sensing elements and the substrate for different geometries and sizes of membranes;
- Determination of "critical" values of the magnitude of mechanical stresses, leading to deformation of supporting consoles and to the appearance of direct contact between the sensor element and the substrate (conditions of contact heat exchange);
- Creation of a hardware and software complex, manufacturing of the test structures based on multilayer thin-film structures, the development of a technique for temperature dependences of thermal conductivity of thin films SiO_2, Si_3N_4 and amorphous Si (having the thickness not more than 150 nm) and experimental determination of the value of thermal conductivity coefficients for films of different thicknesses.
- Conducting numerical simulations and experiments on studying of transient processes in such structures during thermal cycling and increased thermal loads.

Scientific approaches and methods

- **The methods of formation of multilayer thin-film structures on silicon.** When forming model structures of metal-semiconductor and metal-dielectric-semiconductor, as substrates will be used phosphorus-doped silicon monocrystalline plates, having with a resistivity in the range of 1.01 ohms.300-350 microns thick. On the part of the plates, there will be grown thin films of silicon oxide (SiO_2), silicon nitride (Si_3N_4). Aluminum and copper films will be used as a conductive metal film. The deposition of silicon nitride films will be realized by pyrolytic deposition of dichlorosilane with ammonia on silicon plates at a reduced (~50 Pa) pressure in the temperature range 700-900 0C. The thermal oxide will be grown in diffusion furnaces using standard technology in the temperature range 1150-1250 0C in dry oxygen. The formation of the test structure will be performed by optical photolithography.
- **The method of studying of thin films thermal properties.** Investigation of test structures will be implemented by means of the method of using the voltmeter-ammeter method based on the electrical response taken from its various sections during the passage of single current pulses of various shapes. The temperature changes of the structures under consideration were judged by the inclusion oscillograms. The presence of dielectric sublayers with different values of the thermal conductivity coefficient is clearly reflected in the oscillograms during the passage of current pulses. he temperature dependences of the values of the thermal conductivity coefficient of the SiO_2 and Si_3N_4 films under study will be calculated using experimental inclusion oscillograms and data on the thickness of dielectric films.

- **The method of studying the destruction of multilayer thin-film structures.** An experimental setup consisting of a source of rectangular current pulses with an amplitude of up to 60 A and a duration of up to 1 ms, a digital storage oscilloscope and a digital optical microscope for recording the processes of "thermal" destruction of multilayer thin-film structures was used for research. The processes of cracking will be recorded by metallographic studies, optical and electron microscopy. During the implementation of the processes of melting–crystallization of aluminum on the surface of dielectric films, the formation of cracks is assumed at the interfacial boundaries. In addition, the processes of peeling films from substrates are possible.
- **Calculation of stress-strain state by the finite element method.** Calculation of stress-strain state of a structure will be implemented at the ANSYS software package. For numerical modeling of the structure, there will be use such elements as Plane 183 and Solid 185, use of other elements is not excluded. The plane 183 element is a two-dimensional element of the second order with eight nodes having two degrees of freedom at each node: movements in the direction of the X and Y-axes of the nodal coordinate system. The element may be used for modeling flat stressed, flat deformed states. Element Solid 185 will be used for 3-dimensional modeling of semiconductor microstructure. The given element consists of 8 nodes having three degrees of freedom in each node. Initially, the solution is supposed to be carried out in a geometrically linear formulation.

Equipment and methods

For solution of issues in the project the following equipment and methods will be used:

- The installation of oscillography analysis, which, in combination with the original text structures and the developed methodology, will allow in situ monitoring of the state of multilayer thin-film systems on silicon (by temperature dynamics) during the passage of current pulses. At this stage, the pulse generator will be improved in terms of increasing the power of the current pulse (the duration of current pulses has been increased from 600 μs to 5 ms), which will allow to record the degradation of structures in conditions of heat stroke. This method is well developed and allows for the diagnosis of critical operating modes of the studied structures (of various geometries and topologies) depending on changes in the amplitude-time parameters of current pulses;
- Metallography methods for analyzing the degradation processes of multilayer thin-film structures on semiconductor substrates (selective etching method; electron microscopy, a method developed by the authors of the project for diagnosing the nature of the dislocation structure by changing nonlinear elastic modulus during static deformation of samples;
- Modeling of thermal fields, as well as thermoelastic stresses (using the ANSYS 14.0 CAE system) arising in metallization systems and semiconductor substrates. The use of this software will make it possible to simulate the "critical" operating modes of multilayer thin-film systems of complex geometry,
- electron microscopy (JEOL scanning microscope) for the analysis of thin-film systems before and after heat stroke.

Planned use of experimental equipment:

- An installation for electro-chemical etching of semiconductors;
- An installation for ultrasound welding of contacts (wire diameter 30-80 microns);
- A set of optical microscopes INFRAM-I, MII-4, METAM-1, allowing to provide the required magnification;
- JEOL scanning electron microscope;
- Atomic force microscope FSM Nanoview 1000 with anti-vibration platform TMC TableTop CSP, a set of monocrystalline plates of silicon, gallium arsenide and sapphire for the formation of test structures;
- microhardness meters;
- Equipment to study the stress-strain state of both individual pixels (with a sensitive element) and the matrix as a whole, an Amorphous silicon microbolometer UL will be purchased 04 27 2 - 032 (Ulis, France) or its full equivalent. In addition, microbolometers will be offered by university industrial partners.

Technological equipment of the Center for Collective Use of Moscow Polytechnic University and Skoltech will also be used in the work.