Computer processing of the output optical image of a focal plane array of uncooled bimaterial IR-detectors by method of feature-oriented scanning

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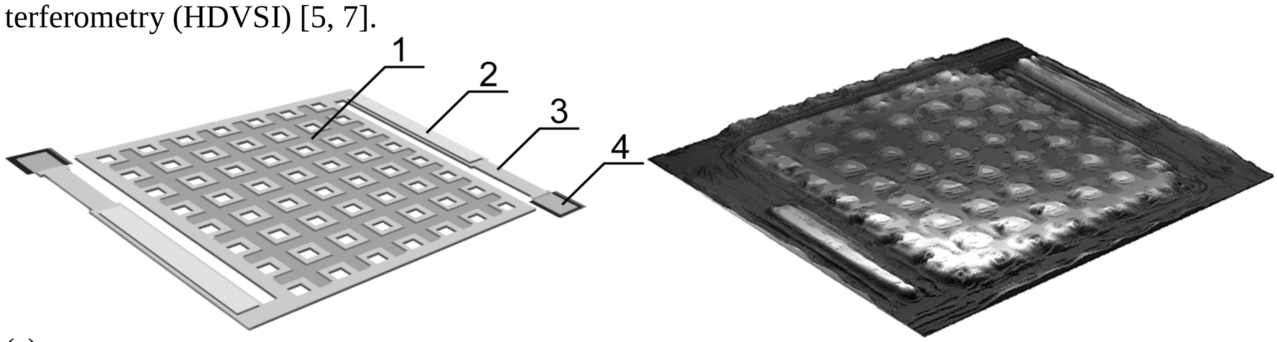
Today, uncooled micromechanical bimaterial IR-detectors are a rapidly developing approach [1, 2]. The focal plane array (FPA) M3-50 consisting of 32×32 uncooled micromechanical bimaterial IR-detectors was designed and fabricated at the Moscow Institute of Electronic Technology [3]. The FPA is a microoptomechanical system (MOMS), where reading out of an IR-image is carried out with an optical method. The FPA is intended for acquiring thermal images in 8-14 μm range.

Operation principle of the FPA sensing element (see Fig. 1(a)) is based on the thermomechanical effect. According to this effect, a bending of a bimaterial microcantilever takes place when temperature of an absorbing plate is changed. The bending occurs due to a difference between the coefficients of thermal expansion of a pair of materials (silicon nitride and aluminium) from which the bimaterial microcantilever is fabricated. Submicron thickness microminiature membrane of silicon nitride covered with a thin nichrome film is used as the absorbing plate. The same plate is used as a mirror while reading out the FPA in visible spectrum. Temperature change of a source of IR-radiation by 1 K causes membrane deflection by several hundreds of nanometers in similar IR-detectors [1-4] that can be quite reliably registered by modern instruments.

The image of a single bimaterial sensing element of the infrared FPA at high magnification (see Fig. 1(b)) is obtained with the optical profiler (interference microscope) Wyko NT9300 (Bruker, Germany) [5, 6]. The membrane of increased rigidity is well seen in the figure. The membrane is suspended over a substrate on the microcantilevers. The distance between the membrane and the substrate makes approximately 0.5 μm. The through holes in the membrane improve access of etchant to the sacrificial layer of SiO_2 at fabrication. The highly reflective aluminium bimaterial regions are clearly seen on the microcantilevers.

The output optical image formed by the FPA is shown in Fig. 2. The image was registered (read out) with the optical profiler. The measurements were conducted in vacuum 10^{-3} Torr at blackbody temperature 50°C. The used profiler carries out noncontact measurement of a surface topography with height differences up to 10 mm. The utmost vertical resolution of the profiler makes 0.1 nm, the lateral resolution – 0.6 μm. The measurements of optical response from the bimaterial MOMS IR-detector were carried out in the mode of high definition vertical scanning interferometry (HDVSI) [5, 7].



(a) (b)

Fig. 1. Uncooled bimaterial sensing element of the infrared FPA M3-50. The element has sizes 50×50 μm^2. (a) Design of the sensing element: 1 is an absorbing membrane-reflector, 2 is a bimaterial microcantilever, 3 is a thermoinsulation region of the microcantilever, 4 is an attachment point of the microcantilever to a substrate (anchor). (b) Image of the sensing element obtained with the optical profiler Wyko NT9300. Magnification ×101, HDVSI mode, stitching.

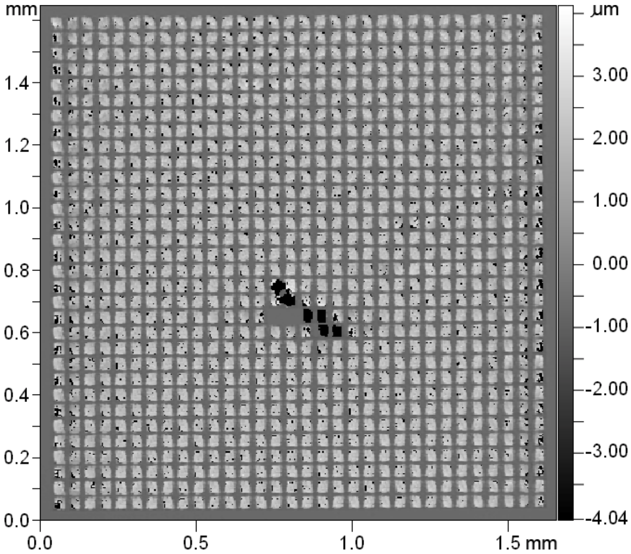


Fig. 2. Optical image 555×555 points of FPA M3-50 consisting of 32×32 uncooled bimaterial IR-detectors. The image is obtained with the optical profiler. Magnification ×10.2, HDVSI mode. The locations, where the profiler was unable to execute reading because of a large slope of membrane edges, are conditionally shown in black color. A manufacturing fault is well seen approximately in the center of the FPA. The measurements were conducted in vacuum 10^{-3} Torr at blackbody temperature 50°C.

Since the area occupied by the sensing elements directly forming the image makes approximately 70% of whole FPA area, the obtained optical image would include a large number of points which do not carry any useful information about the imaged IR-object (see Fig. 1, Fig. 2). Spaces between the IR-detectors and the regions occupied by the elements of the membrane suspension (sections of thermal isolation of the microcantilevers, attachment points of the microcantilevers to the substrate) are such points. Thus, before an operator would receive a final picture, the digitized optical image of the FPA should be subjected to a mathematical treatment during which all the information not related to the observed IR-scene should be eliminated from the image.

Since the surface image of each membrane consists of many points (from hundreds to several thousands) even at a low lateral magnification of the profiler, this set of points should be presented on the output image by a single point. Thus, the image having dimensionality of the original FPA, i. e., 32×32 points should be obtained at the output of the program of mathematical treatment, where brightness of each point on such image is a mean value of brightnesses of the points belonging to the corresponding membrane.

Analysis of the above formulated task peculiarities shows that methods of recognition should be used for effective computer processing of the obtained image. To build an appropriate recognition algorithm, it was decided first to conduct mathematical treatment of the image by means of an already existing recognition program and then, based on the got experience, to formulate requirements to the algorithm and write own recognition program which later could be built into a commercial device.

The program of feature-oriented scanning (FOS) [8] developed at the Institute of Physical Problems named after F. V. Lukin was used as the recognition program. The main purpose of the FOS program is control of a scanning probe microscope (SPM) and conduction of ultra-precise measurements of topography and surface properties at the nanoscale. At present, the OOC program is used at the Solid Nanotechnology Laboratory of the above mentioned institute and controls the commercial instrument Solver™ P4 (NT-MDT, Russia).

Besides real scanning mode, the FOS program has a mode of virtual scanning. In this mode, an image (real or synthesized) of a surface topography is fed into the program input, after that the image is “scanned” and recognized by the program which models operation of a probe microscope. In our case, the optical image obtained on the profiler and presented in Fig. 2 was fed at the input of the FOS program. The separate IR-detectors (membranes-reflectors) of the FPA under recognition are considered as surface features on such image. The surface features are used by the FOS program as reference points.

The result of the FOS program operation (see Fig. 3) is an FPA image assembled of separate fragments (segments). In order to avoid appearance of complex feature contours and shifts of feature coordinates during recognition, the black points were temporally replaced for the white ones. Since the fragments are partially overlapped and the relative coordinates between them are precisely determined by the FOS program, the reconstructed image has no distinctions from the original one.

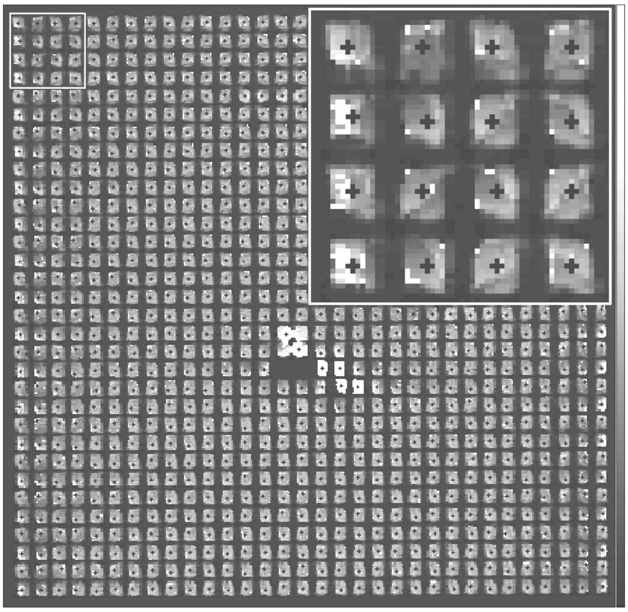


Fig. 3. Result of recognition of the infrared FPA by the FOS program. The surface image is assembled of separate fragments (segments). The recognized elements of the FPA (membranes) are marked with "+" sign.

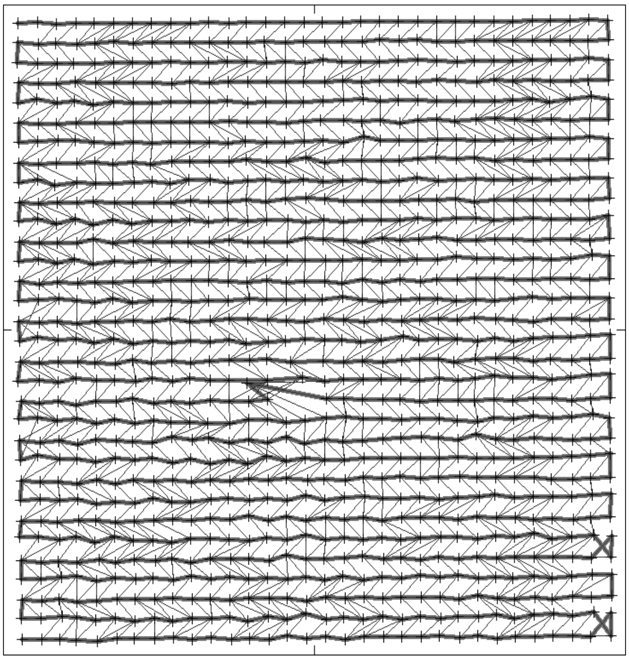


Fig. 4. Raster-like trajectory of connection of the features in a chain. The trajectory is created during the virtual FOS. The positions of the detected features (FPA membranes) are marked with "+" sign. The "movements of the SPM-probe" are shown by thin lines.

The trajectory of connection of the features in a chain shown in Fig. 4 is automatically built during the FOS process. Usually, the formed connection trajectory visually looks like a raster. When some membranes are absent at their predefined positions, for example, as in the case of imperfect infrared FPAs, the regular path of the connection trajectory will be disturbed. The "movements of the SPM-probe" from one feature to another are shown by thin lines. It does not matter for the FOS method, how the topography elements under recognition are arranged. Thus, an order violation in arrangement of the sensing elements in the imperfect FPA would not effect on the final result of the computer processing. This means that any *a priori* information about mutual arrangement of the sensing elements of the analyzed FPA is not required.

The sought for optical image of 32×32 points formed by the FPA is shown in Fig. 5. Each image point (points have a square shape) represents a response of the corresponding bimaterial IR-detector shown in Fig. 2. The dark points represent detectors with heavily deformed membranes, the black points – with completely absent membranes.

Usually, the membrane deformation relates to a curving of the membrane edges as a consequence of hogging. Hogging is caused by uncompensated mechanical stresses appeared in the membrane during device fabrication. The sought for image is built by a surface assembler adapted to the task under consideration. The surface assembler is a special program being part of the FOS software package, which builds a reconstructed surface image of segments.

With a uniform illumination of the FPA by IR-radiation, for example, from a lengthy radiating plate of a blackbody simulator, the obtained array of signals of the output image can be used for correction of unequal thermomechanical sensitivity of the FPA detectors. The information on sensitivity of each detector can be stored in an IR-camera memory and then it can be taken into account for each frame processing. The response inequality among the bimaterial IR-detectors is caused by the always taking place technological variation of sizes, differences in composition and structure of the used materials, inhomogeneity of the treatment methods across wafer surface, etc.

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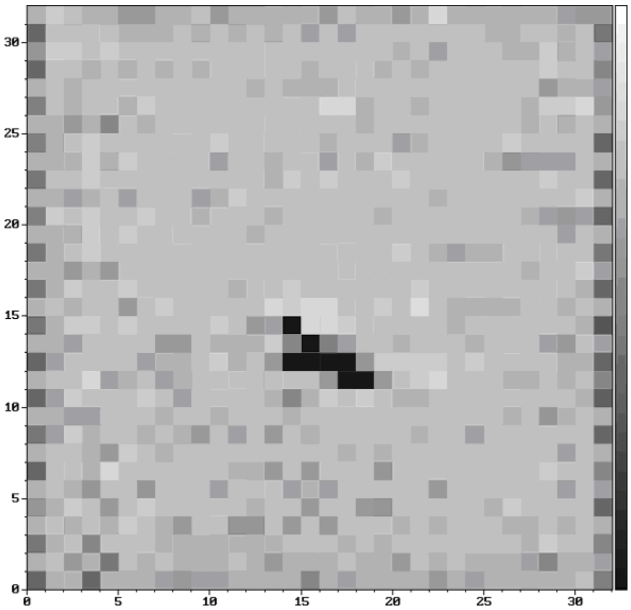

Fig. 5. The required image 32×32 points formed by the FPA M3-50 uniformly illuminated from an IR-source (blackbody simulator) with temperature 50°C. Each point (depicted as a square) represents a response from the corresponding bimaterial IR-detector. The image was obtained during computer processing according to the FOS method. The dark points correspond to strongly deformed membranes and the black points – to completely absent ones.

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