ISSN 1063-7397, Russian Microelectronics, 2014, Vol. 43, No. 7, pp. 516–518. © Pleiades Publishing, Ltd., 2014.
Original Russian Text © D.B. Rygalin, E.A. Fetisov, R.Z. Khafizov, V.I. Zolotarev, I.A. Reshetnikov, G.A. Rudakov, R.V. Lapshin, E.P. Kirilenko, 2013, published in Izvestiya Vysshikh Uchebnykh Zavedenii. Elektronika, 2013, No. 3(101), pp. 60–63.

Promising Integral Matrix Detectors of Thermal Radiation with Optical Reading

D. B. Rygalin[a, b], E. A. Fetisov[a], R. Z. Khafizov[b], V. I. Zolotarev[a], I. A. Reshetnikov[a], G. A. Rudakov[c], R. V. Lapshin[d], and E. P. Kirilenko[a]

[a]*National Research University of Electronic Technology, proezd 4806, 5, Zelenograd, Moscow, 124498 Russia*
[b]*OAO Zelenograd Innovation Center of Technology, proezd 4806, 5, str. 20, Zelenograd, Moscow, 124496 Russia*
[c]*Research and Production Complex "Center of Technology," proezd 4806, 5, Zelenograd, Moscow, 124498 Russia*
[d]*Research Institute of Physical Problems, 4806 proezd 4806, 6, Moscow, 124460 Russia*
e-mail: reshetnikov@zitc.ru

Received November 11, 2012

Abstract—IR detectors of a new type, which use a bimaterial effect to transform IR radiation into optical response, are considered. Several constructions of bimaterial IR detectors, which served as a basis for several matrices of various dimensionalities, are proposed. Operation simulation of bimaterial IR detectors is performed in the ANSYS system. The thermomechanical sensitivity of detectors, which constituted about 100 nm/K, is determined in the course of measurements.

DOI: 10.1134/S1063739714070142

Integral bimaterial matrix detectors of thermal radiation, which were fabricated by the technology of microoptomechanical systems (MOMS), belong to promising IR-range radiation detectors [1, 2]. The functioning of this type of devices is based on the thermomechanical effect, according to which, the bimaterial microconsole bends upon varying the temperature of the receiving part (membrane). The bend appears because of the difference of thermal expansion coefficients (TEC) of the used pair of materials. The pair is formed from the material with a small TEC (for example, silicon nitride) and from the material with a large TEC (for example, aluminum). The magnitude of deviation of a microconsole upon varying the temperature of the observed IR object by 1 K constitutes from several units to several hundreds of nanometers. The substantiation of the solution based on the construction of the developed MOMS detectors was verified by measuring their thermomechanical sensitivity.

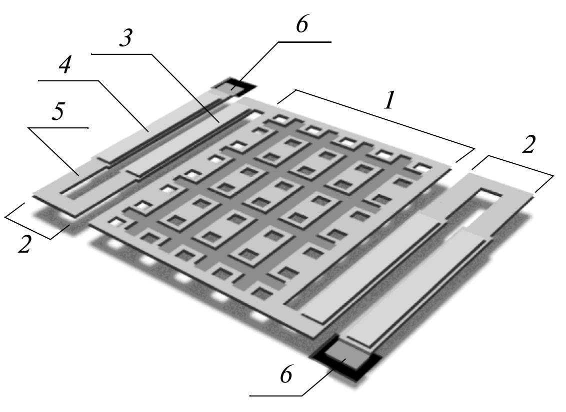

Fig. 1. Design of the sensitive element of the uncooled MOMS IR matrix: (*1*) receiving membrane; (*2*) microconsoles; (*3, 4*) main and compensating bimaterial segments of the microconsole, respectively; (*5*) thermal insulation segment; and (*6*) places of microconsole fastening to the substrate (anchor). Sizes of the sensitive element are 50×50 μm.

Receiving membrane 1 of the bimaterial IR detector (Fig. 1) is fabricated from Si_3N_4 of about 400 nm thick and coated with a thin NiCr layer [3]. The membrane is suspended over the substrate surface at a distance of approximately 500 nm with the help of microconsoles *2*, which are also fabricated from Si_3N_4. Microconsoles have bimaterial segments formed with an aluminum layer about 500 nm thick. To reduce the deformations which appear during the fabrication of IR detectors the membrane contains a reinforcing network (ribbings). Microconsoles of bimaterial detectors have two segments (arms) consisting of Si_3N_4 and Al, notably, the main segment *3*, which responds to the variation of the temperature of the IR object, and compensating segment *4*, which is intended to eliminate the heating of sensitive device elements from the substrate during the detector operation. In addition, the compensating arm serves to counteract the thermal deformations which appear in the course of the fulfillment of high-temperature production operations when fabricating the MOMS. The microconsole has a segment of thermal insulation *5* in order to reduce the heat exchange between the sensitive element and the substrate. The bimaterial IR detector is fastened to the substrate in two places *6*. In order to

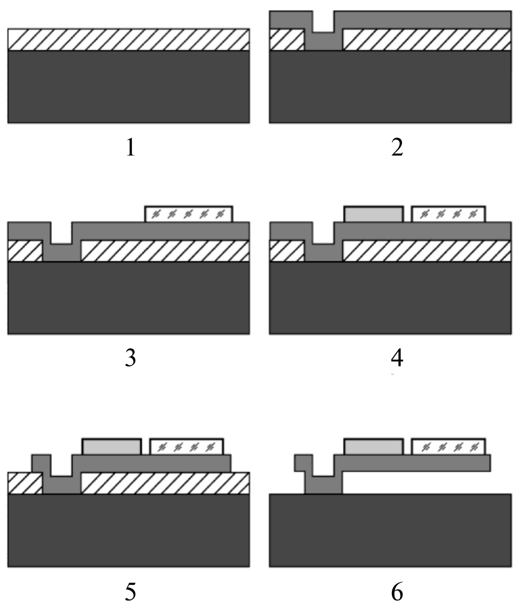

Fig. 2. Main fabrication operations in production of bimaterial uncooled MOMS IR detectors: (1) deposition of the sacrificial SiO_2 layer, (2) etching of windows in the sacrificial layer for the formation of anchors and deposition of the Si_3N_4 layer, (3) deposition of the NiCr layer and its etching (formation of the reflecting mirror), (4) deposition of the Al layer and its etching (formation of the bimaterial console part), (5) etching of the Si_3N_4 layer (formation of the membrane geometry), and (6) removal of the sacrificial SiO_2 layer.

substantially decrease the heat exchange between the sensitive element and the substrate, the device is arranged in an evacuated case.

Figure 2 shows the sequence of main production operations of fabricating bimaterial MOMS IR detectors.

To measure the thermomechanical deformations of IR detectors, we used a JSM-6490LV scanning electron microscope (SEM) (Jeol, Japan) and a Wyko NT9300 optical profilometer (interferometric microscope) (Bruker, Germany) [4]. The substrate temperature of the MOMS matrix was specified using an MK3 vacuum-compatible table (Deben, Great Britain), which enables setting, holding, and measuring the sample temperature from −30 to +160°C. The feature of the used methods of investigation is the possibility of visual observation of functioning of the MOMS bimaterial.

Figure 3 shows microphotographs of the MOMS detector with elongated consoles, which make it possible to increase the mechanical displacement of the membrane. Microphotographs are recorded at temperatures of −24 and +150°C. Being cooled, microconsoles bend in the direction from the substrate, and being heated they bend in the direction to the substrate, since the aluminum layer, which forms the bimaterial segment, is arranged above.

The positions of ends of microconsoles $z_1 = 39.4$ μm and $z_2 = 22.4$ μm at temperatures $T_1 = -24$°C and $T_2 = +150$°C, respectively, were determined from SEM images in Fig. 3, allowing for the slope angle of the sample of 60°. The thermomechanical sensitivity $K = (z_1 - z_2)/(T_2 - T_1)$ was about 98 nm/K.

The design of the detector presented in Fig. 4 implies compensation of the initial bending of the microconsoles. The invariable position of mirror membranes over the entire range of specified temperatures confirms the efficiency of a the thermocompensating mechanism laid in the design of this detector.

Comparative measurements of various variants of bimaterial MOMS detectors allow us to determine the best constructive solutions for uncooled matrix IR detectors with an optical reading.

The developed MOMS IR matrices have the following advantages: the lower cost production compared to production of IR detectors based on microelectromechanical systems (MEMS) with an electrical reading; there is no need for the detector cooling to low temperatures.

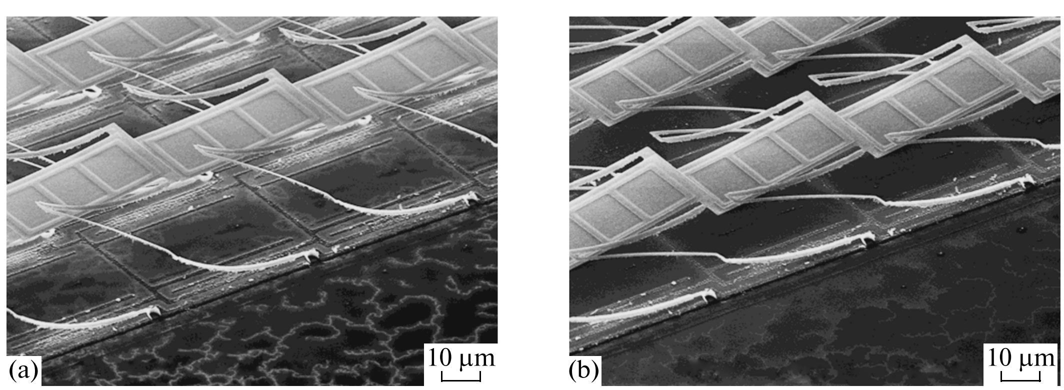

Fig. 3. SEM image of the bimaterial MOMS IR detector with elongated microconsoles at the substrate temperature of (a) −24°C and (b) +150°C.

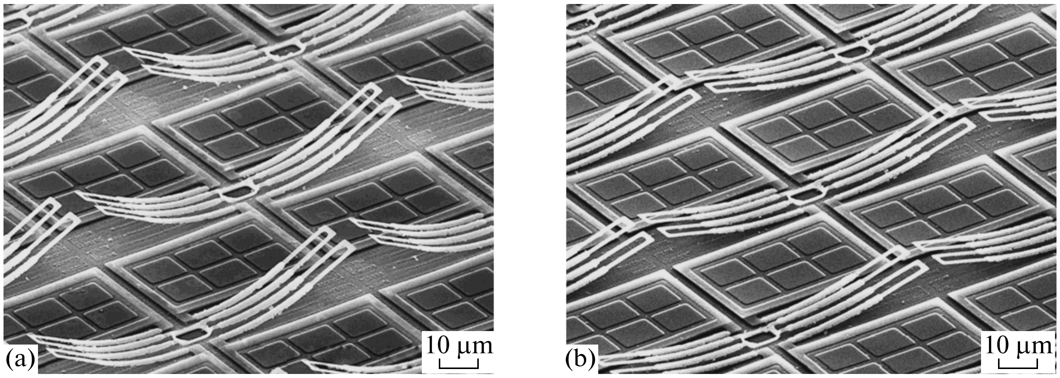

Fig. 4. SEM image of the bimaterial MOMS IR detector with the thermal compensation at the substrate temperature of (a) −24°C and (b) +150°C.

The proposed IR matrices can find broad application both in military and in civilian spheres. As the civilian application, we should note such fields as building, industry, power engineering, and the housing-and-municipal sector, where it is required to reveal and liquidate heat losses; and motor transport, where the safety of motion on roads in the twilight, in the fog, and at night can be considerably increased by means of equipping them with relatively low-cost night-viewing systems. The IR viewing systems based on the proposed IR detectors can also be used by emergency services when searching for people, by firefighters for better orientation in conditions of strong smoke formation, and in medicine when inspecting organs and localizing the places of their inflammation.

ACKNOWLEDGMENTS

This study was supported by the Ministry of Education and Science of the Russian Federation, state contract no. 14.514.11.4074 using the equipment of the Collective Use Center "Microsystem Equipment and Electron Component Base of the National Research University MIET," state contract no. 16.552.11.7061.

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Translated by N. Korovin