MATERIALS FOR PRODUCING THERMAL IMAGE IR SENSORS AND NONVOLATILE MEMORY AND TECHNOLOGIES OF ITS PRODUCING

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Analysis of tendencies of development of domestic and foreign IR-sensors witnesses to promising trends in developing of quantum wells infrared photodetectors – QWIP-arrays (based on semi-conducting superlattices A_3B_5) and uncooled resistive microbolometer arrays (URMA). Every of these two devices has its own, inherent sphere of applications. At present arrays on quantum wells make serious competition to photodetectors, produced on the basis of the cadmium-mercury-tellurium(CMT) materials. They are compatible with silicon structures, that makes us able to integrate detecting chip into reading electronics. It provides us with the possibility of creating intellectual devices, that can process information directly in chips. Since spectral range of the QWIP-arrays is defined by its structural parameters and by structure of initial material, it becomes able to create detectors with a given wavelength. Moreover, two-colored or three-colored devices can be created with any combination of working areas of spectrum (close, average and far IR-range). The deciding advantage of the arrays based on quantum wells, compared with photodetectors based on CMT, is essentially lower cost of the initial material and lesser spending on its producing.

The second direction is creation of uncooled microbolometer arrays. Lead zirconates-titanates $Pb(Zr_{1-x}Ti_x)O_3$ (PZT), barium-strontium niobates $Ba_{1-x}Sr_xNbO_3$ and titanates $Ba_{1-x}Sr_xTiO_3$, vinylenefluoride copolymers are used as materials for pyroelectric detectors. Modifications of vanadium oxides V_xO_y, polycrystalline and amorphous silicon are used as materials for microbolometers. Technology of producing of micobolometer arrays is also based on conventional technological processes of producing of silicic integrated circuits, what serves as a powerful stimulus of its development. Since scanning devices and cryogennic cooling systems are not needed when building thermal imaging systems on the basis of microbolometers, its cost, weight and size are essentially lower comparing with similar parameters of conventional devices. At the same time reliability and working life of TID are increased, and also its servicing and maintenance are simplified. If fast optics is used temperature sensibility of micobolometer array is less than 0,1 K. Achievements of the leading foreign countries in equipping of armed forces with devices for target reconnaissance and weapon pointing are extensively caused by opportune developing and realization of national programs of unification of thermal direction-finding, thermal imaging, low-level television systems and its main components – IR-photoreceiving devices (PRD), CCD-arrays and specialized integrated circuits of information processing. Implementation of these programs resulted in rapid limitation of the nomenclature of components, being included into channels of technical vision, what made us available to develop progressive technologies of its repetition work, depreciation and introduction of the systems of uniform modules (UM) into the forces. This approach allowed to provide optimal ratio between performance characteristics and cost parameters of UM, effective service during operation and possibility of improvement of system performances at the expense of improvement of module's parameters as production technology is developed. [1-3]

Main parameters of the typical samples of commercially producible arrays for IR-sensors are tabulated in Table 1.

Table 1. Typical parameters of commercially producible arrays for IR-sensors.

Country, Producer	Array type	Sensitivity area, µm	Resolution (number of pixels)	Pixel size, µm	Working temperature, K	Temperature sensitivity (NETD), mK
Germany, AEG Infrared-Module GmbH	QWIP	8□10	640x512	24x24	70	25
France, LIR	CMT	3□5	640x480	23x23	77	14
Germany, AEG Infrared Module GmbH	CMT	8□10	256x256	40x40	77	20
Russia, "SIA "Orion"	CMT	8□10,5	384x288	35x35	80	
Russia, Corp. "Array technologies"	PtSi	3□5	256x256	25x25	80	30
USA, Cincinnati Electronics Corp.	InSb	3□5	256x256	30x30	77	40
Russia, CSRI "Electron"	PbS	1,5□4	128x128	60x60	80	20
Russia, CSRI "Electron"	PbSnTe	6□14	256x256	60x60	25	5
USA, Lockheed Techsystems	MB	8□14	320x240	48x48	300	50
USA, Raytheon	MB	8□14	320x240	50x50	300	20

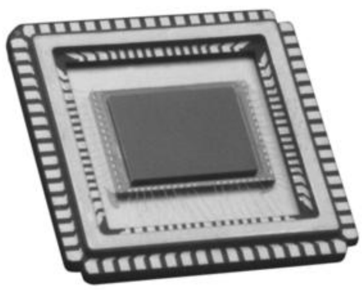

Fig. 1. Outward appearance of IR-array

Fig. 2. Night binoculars based on uncooled IR-array

A lot of materials listed above are perspective for producing of nonvolatile Ferroelectric Random Access Memory (FRAM). Basis of FRAM is a thin film of one of the ferroelectric materials with good repolarization properties: $Pb(Zr_{1-x}Ti_x)O_3$ (PZT), membranous bismuth containing ferroelectrics $SrBi_2Ta_2O_9$ (SBT), $Bi_4Ti_3O_{12}$ (BIT) and doped with niobium $Bi_{4-x/3}Ti_{3-x}Nb_xO_{12}$ (BITN), lanthanum La and zirconium Zr; $Ba_{1-x}Sr_xTiO_3$, $Pb(Sc_{1-x}Ta_x)O_3$ and $Ba_{1-x}Sr_xNbO_3$, which are characterized as materials with high record rate and almost unlimited number of switching cycles, low repolarization voltage and minimal leakage currents. Electrical polarization of one element of material is used for holding 1 bit of information. Access time in FRAM devices is 70 nanoseconds while consumption is 1 mA in standby mode and less than 100 mA in operating mode [4-8].

For the first time in the laboratory of semiconductors in ISSPS NASB thin films of $Ba_{1-x}Sr_xTiO_3$ compound were obtained with pulsed laser deposition technique (PLD). The PLD system consists of an infrared pulsed Nd: YAG laser at 1064 nm with a repetition rate of $3{\cdot}10^{-2}$ Hz and a pulse width of 1.1 μs. The laser energy reaching the target was varied from 160 to 190 J per pulse. All depositions were performed at substrate temperatures 450 - 550 ^{0}C in a vacuum chamber with a base pressure of 20 Pa. The film thickness was between 300 and 400 nm and the deposition rate was 5-7 nm/pulse. After deposition, the substrate temperature was lowered to room temperature and oxygen pressure was increased gradually to normal pressure during 2 hours.

The bulk composition and surface morphology of the targets and films were investigated by energy-dispersive X-ray (EDX) analysis using a JEOL 6400 SEM apparatus. The depth profiling was done by Auger electron spectroscopy (AES) using a Perkin Elmer Physical Electronics model 590. An Ar ion beam was used for sputter etching. Morphological studies of the films surface have been performed by utilizing scanning electron microscope (SEM). The crystal structure of the materials was studied by X-ray diffraction (XRD) using a Siemens D-5000 diffractometer with CuK_α (λ = 1.5418 Å) radiation. The observed phases were determined by comparing the *d*- spacing with the Joint Committee on Powder Diffraction Standard (JCPDS) data files.

Fig. 3 given below demonstrates two-dimensional image of BST film. The SEM images show smooth areas with nanocrystalline structure but droplets and rings of different sizes can also be found (Fig. 4). The droplets and rings do not significantly differ in chemical composition compared with the target according to microprobe analysis. Bulk composition analysis is demonstrated in Table 2

Table 2. Bulk composition analysis of BST target and thin film.

Composition elements	Target		Smooth area		Droplet	
	Weight %	Atomic %	Weight %	Atomic %	Weight %	Atomic %
Ba	44.3	14.5	37.8	7.5	42.3	13.5
Ti	21.5	20.2	12.3	6.9	22.3	20.3
Sr	10.2	5.2	6.1	2.1	11.7	5.9
Si	0	0	20.7	19.9	0.1	0.1
O	21.4	60.1	37.5	63.5	22.0	60.2

As can be seen variations in atomic concentrations are caused by different reasons. Large amount of silicon and oxygen in smooth area compared with target is explained by penetration of silicon from the substrate and oxygen from atmosphere during deposition. Other deviations are caused by inherent physical properties of each of the components. “Spitting” from the target material, that is one of the major problems of the PLD process, results in these defects. Particles “ejected” from the target material can be entrapped inside the layer during the deposition and lead to inhomogeneous film growth. In our experiments this effect has been reduced by lowering laser power, defocusing of laser beam and using targets with good microstructure.

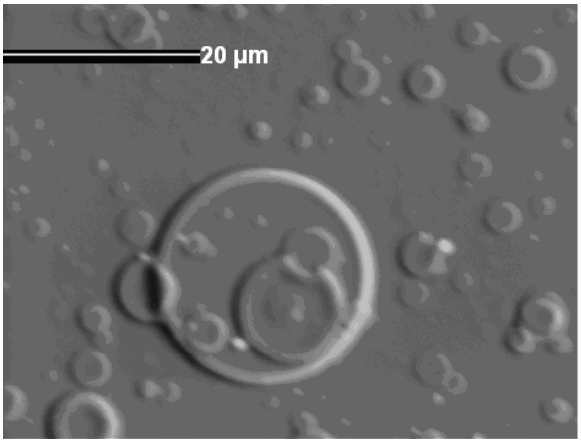

Fig.3. Surface image from SEM

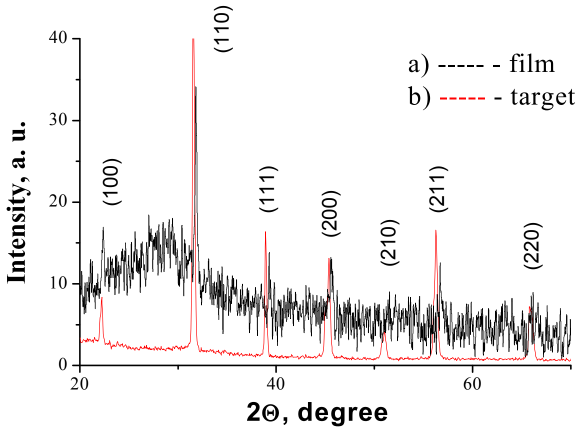

Fig.4. XRD patterns of BST: a) target; b) film

X-ray diffraction pattern of as-grown BST thin film and target is shown in Fig.4. Cubic perovskite structure of polycrystalline BST films was typically obtained under conditions described above. It was established that the crystal orientation and crystallinity of the films are strongly dependent on the substrate temperature.

Preliminary investigations of physical properties showed, that obtained layers can be used as a material for producing IR-arrays and FRAM memory.

[1] Pevtsov E., Chernokozhin V. Electron components **1**, 32 (2001).
[2] Pevtsov E., Chernokozhin V. Electron components **2**, 30 (2001).
[3] Pevtsov E., Chernokozhin V. Electron components **3**, 12 (2001).
[4]. Scott J.F. Ferroelectrics Rev. **1**, 1 (1998)
[5]. Scott J.F., Paz de Araujo C.A. Science, V. **246**, 1400 (1989)
[6]. Jpn. J. Appl. Phys. **42**, 6486 (2003)
[7]. Jpn. J. Appl. Phys. **42**, 6226 (2003)
[8]. Fujitsu Semiconductors Data Sheet (2004)