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Electrical characterizations of MIS structures based on variable-gap *n*(*p*)-HgCdTe grown by MBE on Si(0 1 3) substrates

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HIGHLIGHTS

- The In-Al_2O_3-HgCdTe/Si(0 1 3) metal–insulator-semiconductor structures were studied.
- Variable-gap *n*(*p*)-HgCdTe grown by molecular beam epitaxy on Si (0 1 3) substrates.
- Using the «narrow swing» method, the spectra of fast surface states are studied.
- Impact of substrate type on differential resistance of structures was studied.
- Dark current in HgCdTe/Si structure is limited by Shockley-Read generation at 77 K.

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ABSTRACT

Metal–insulator–semiconductor (MIS) structures based on *n*(*p*)-$Hg_{1-x}Cd_xTe$ ($x = 0.22–0.40$) with near-surface variable-gap layers were grown by the molecular-beam epitaxy (MBE) technique on the Si (0 1 3) substrates. Electrical properties of MIS structures were investigated experimentally at various temperatures (9–77 K) and directions of voltage sweep. The "narrow swing" technique was used to determine the spectra of fast surface states with the exception of hysteresis effects. It is established that the density of fast surface states at the MCT/Al_2O_3 interface at a minimum does not exceed 3×10^{10} $eV^{-1} \times cm^{-2}$. For MIS structures based on *n*-MCT/Si(0 1 3), the differential resistance of the space-charge region in strong inversion mode in the temperature range 50–90 K is limited by the Shockley-Read-Hall generation in the space-charge region.

1. Introduction

The fundamental properties of the narrow-band solid solution of mercury cadmium telluride ($Hg_{1-x}Cd_xTe$, MCT) make it the main semiconductor material for the development of highly sensitive infrared focal plane arrays for the LWIR spectral range (8–14 μm) [1,2]. Heteroepitaxial structures with the controlled distribution of composition *x* and impurity concentration along the film thickness can be created using molecular beam epitaxy (MBE) method. Growing of surface variable-gap layer (VGL) with a wide band gap allows one to improve the performance of infrared detectors by eliminating the effect of the surface recombination on the charge carrier lifetime in the working layer [3].

The cost of the MBE MCT material is significantly reduced by using alternative substrates based on silicon or gallium arsenide [3] instead of CdZnTe substrates [1,4] that are matched by the lattice constant with epitaxial films. The disadvantage of CdZnTe substrates is the difference in the thermal expansion coefficients with silicon, which is used to create a readout integrated circuit in hybrid matrix detectors [5,6]. The use of Si substrates is very promising because of the possibility of reducing the cost of the epitaxial material and the lack of problems connected with the thermal expansion. It should be noted that the difference in types and parameters of crystal lattices between silicon substrate and MCT film leads to a high concentration of defects of various types and makes it difficult to grow a material suitable for the development of high performance devices [5,6]. Defect formation during

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the MBE growth of MCT films on Si (0 1 3) substrates is actively investigated [7,8].

MIS structures are often used to study the properties of the insulator (dielectric) -semiconductor interface and the near-surface semiconductor region [9]. Cadmium telluride is traditionally used for the surface passivation of planar detectors based on MCT [1,10]. Plasma enhanced atomic layer deposition (PE ALD) of Al_2O_3 is a new bidding technique for the passivation of MCT mesa devices with a high aspect ratio [11,12]. The investigation of the admittance of MCT MIS structures is a widespread and informative method [13–15]. But there are still not enough experimental research of the properties of MCT/Si MIS structures.

The aim of this work is investigation of the features of the admittance of MIS structures based on PE ALD Al_2O_3/$n(p)$-MCT/Si (0 1 3) with VGLs and determination of the main electrical parameters of such structures.

2. Materials and methods

Investigated metal-insulator-semiconductor samples were created on the basis of $n(p)$-$Hg_{1-x}Cd_xTe$ (x = 0.22–0.40) grown by the MBE technique on Si (0 1 3) substrates in Rzhanov ISP SB RAS. During heterostructures growth VGLs with a high composition x were created on the both sides of the working layer. To approximate the dependence of the composition on the coordinate z in the MCT film, the following formula was used [16]:

$$x(z) = x_0 + A_1 \cdot Exp\left(-\frac{z}{B_1}\right),$$

where x_0 is the composition x in the MCT bulk, A_1 and B_1 are the factors that determine the composition distribution in the VGL.

Table 1 shows some technological and electrical parameters of the explored hetero-epitaxial films. Majority carrier concentrations and mobilities, as well as conductivities (σ) were determined by the Hall method (the Van der Pau configuration) at 78 K.

As-grown samples Nos. 1–3, 7–10 had an electronic type of conductivity due to intrinsic defects of the donor type, and films Nos. 4–6 had a hole type of conductivity after low-temperature annealing (vacancy-doped p-MCT). Samples Nos. 9 and 10 were grown by the MBE on GaAs (0 1 3) substrate to investigate the impact of the substrate type on the electrical properties of MIS structures. For the structures Nos. 8 and 10 the VGLs were removed by etching in Br_2-HBr solution and then Al_2O_3 dielectric was deposited. For the samples Nos. 1–7 and 9, the PE ALD Al_2O_3 dielectric was formed over the upper VGL. The thickness of the Al_2O_3 dielectric was about (65–75) nm. For all the MIS structures the indium electrode areas were determined. The distribution of CdTe content over the film thickness for the sample No. 1 is schematically shown in Fig. 1. Fig. 1 also shows design of the MIS structure.

The experimental setup and measurement techniques are presented in the works [15–17]. The bias voltage change from negative values to positive ones was taken as the forward voltage sweep, and the change in bias voltage in the opposite direction was taken as the reverse voltage sweep.

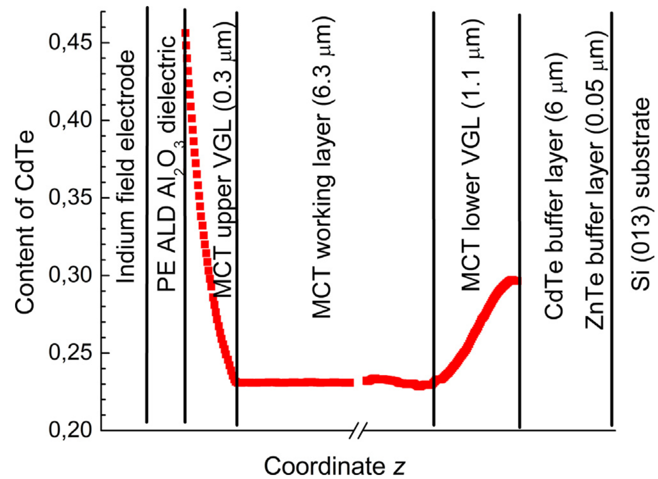

Fig. 1. Composition distribution over the thickness of MCT film No. 1 and design of this sample.

3. Results and discussion

3.1. Capacitive properties

Figs. 2 and 3 demonstrate the capacitance–voltage (C-V) curves for the MIS structures based on n-$Hg_{0.78}Cd_{0.22}Te$ with VGL (No. 7) and without VGL (No. 8), respectively, measured at 500 kHz at 9 K and 77 K for various directions of voltage sweeps. The hysteresis of capacitive characteristics is clearly noticeable for the structure with VGL (Fig. 2), which is associated with charge exchange of slow surface states.

The main features of hysteresis phenomena in MCT MIS structures with the PE ALD Al_2O_3 and SiO_2/Si_3N_4 dielectrics are similar [18]. For the sample No.7, decrease in the temperature leads to a high-frequency (HF) shape of the capacitive dependences.

It is seen from Fig. 3 that for the structure without VGL, a small hysteresis and a low-frequency (LF) shape of the C-V curves at the frequency of 500 kHz are typical in the temperature range 9–77 K. At the temperature of 9 K, the value of the capacitance in the minimum of the LF C-V curve decreases significantly. It is associated with an increase in the charge exchange time of fast surface states at low temperature.

For MIS structures based on MCT with variable-gap layer at the frequency of 500 kHz at the temperature of 77 K, an intermediate shape of the C-V curves is observed, and at the temperature of 9 K a practically HF shape of the capacitive dependence is observed.

Table 1
Technological and electrical parameters of MCT films.

Sample No.	Substrate type, conductivity type	A_1	x_0	B_1, μm	Majority carrier concentration, cm^{-3}	Majority carrier mobility, $cm^2/(V \times s)$	σ, $Ohm^{-1}cm^{-1}$
1	Si, n	0.238	0.229	0.114	4.5×10^{14}	31000	2.21
2	Si, n	0.180	0.294	0.176	2.3×10^{14}	12000	0.38
3	Si, n	0.107	0.398	0.077	8.2×10^{14}	7000	0.79
4	Si, p	0.248	0.221	0.132	9.9×10^{15}	384	0.62
5	Si, p	0.167	0.298	0.125	8.2×10^{15}	397	0.50
6	Si, p	0.194	0.394	0.085	5.1×10^{15}	225	0.19
7	Si, n	0.257	0.221	0.154	5.3×10^{14}	35000	3.11
8	Si, n	–	0.221	–	5.3×10^{14}	35000	3.11
9	GaAs, n	0.214	0.226	0.160	3.5×10^{14}	68000	3.92
10	GaAs, n	–	0.226	–	3.5×10^{14}	68000	3.92