Admittance of barrier nanostructures based on MBE HgCdTe

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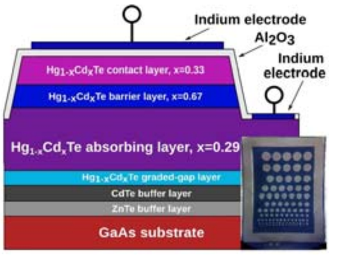
EXPERIMENTAL: SAMPLES AND TECHNIQUE

- $Hg_{1-x}Cd_xTe$ barrier structures were grown at Rzhanov Institute of Semiconductor Physics with molecular-beam epitaxy (MBE) on GaAs (013) substrates with CdTe/ZnTe buffer layers.
- The working region of the nBn structure consisted of an absorbing layer, a barrier layer, and a contact layer. For samples A and B, the composition in the barrier layers was 0.67 and 0.84, and the thicknesses of these layers were 120 and 210 nm, respectively. A superlattice of 18 periods $Hg_{0.2}Cd_{0.8}Te$ (9 nm) – CdTe (2 nm) was used as a barrier layer for sample C.
- In the fabrication of device nBn structures, the HgCdTe film was etched to form a mesa configuration. After that, about 90 nm thick PE ALD Al_2O_3 dielectric film was deposited. Device structures of two types were created: nBn structures and MIS devices based on nBn structures.
- Measurements were carried out with the use of an automated admittance spectroscopy setup based on Janis cryostat and Agilent E4980A admittance meter in temperature range of 8–300 K and frequency of 10–2000 kHz.



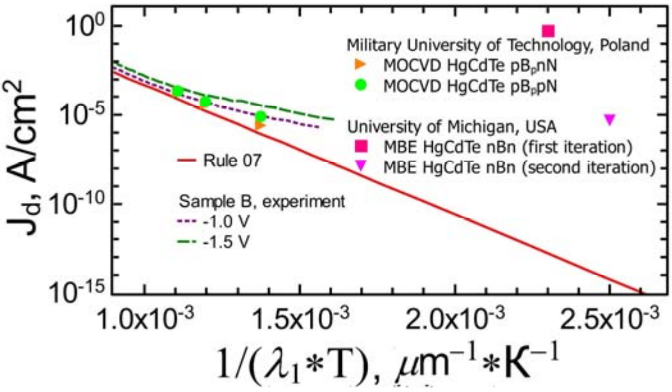
Schematic view of test MIS device based on nBn structure (No. A). The inset shows a photograph of the manufactured sample.

RESULTS

DARK CURRENT STUDY

Surface (J_S) and bulk (J_B) components of the dark current density.

Sample	Diameter range, μm	J_B, A/cm^2	J_S, A/cm
A	200–500	--	8.48×10^{-3}
	20–150	1.56	6.69×10^{-4}
B	50–300	1.10×10^{-2}	2.69×10^{-5}
C	20–150	0.139	3.99×10^{-4}
	200–500	0.280	--



Comparison of dark current values for different barrier structures based on HgCdTe with the empirical model Rule 07.

Sample A. The current-voltage characteristics are almost symmetrical at forward and reverse biases. The dark current density weakly depends on temperature; upon cooling from 300 to 10 K, the current density decreases by about 10 times.

Sample B. Current density values for sample B are noticeably lower than for sample A. For sample B, current density values at reverse voltage biases are lower than values at forward (positive) voltages. When the structure is cooled from 300 to 180 K, the current density at reverse voltages decreases by more than 100 times.

Sample C. The current density values for sample C at the same voltages (for example, at the voltage of -0.4 V) are lower than for sample A, but higher than for sample B. When cooled from 300 to 90 K, the current density for sample C decreases more than 10 times.

Dark current limitation. For sample A, a surface-limited dark current is realized, and for samples B and C, a bulk-limited dark current is realized. The bulk current density for superlattice samples C is more than 10 times higher than the current density for sample B, which may be associated with a decrease in the potential barrier for holes.

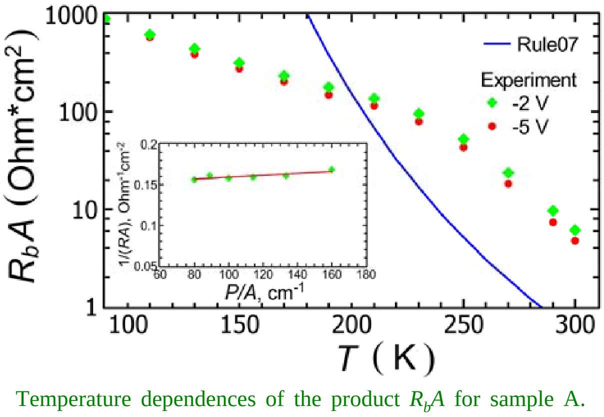
Dark current comparison for sample B. In the temperature range of 180–300 K, the dark current values correspond well to the empirical model of Rule 07. These values are comparable with the dark current values for modern mid-infrared barrier detectors based on MOCVD HgCdTe and III–V materials. The studied nBn structures have lower dark currents than the previously described analogues based on MBE HgCdTe, which may be associated with high-quality passivation of the side walls of the mesa structure.

ADMITTANCE STUDY

The admittance dependences of barrier structures (nBn and MIS devices) were investigated in a wide range of frequencies and temperatures.

nBn structures. It is shown that measurements of the C–V characteristics of nBn structures based on MBE HgCdTe can be used to determine the dopant concentration in the absorbing layer in a wide range of frequencies and temperatures. At temperatures close to room temperature, an adequate description requires a more complex equivalent circuit due to the effect of defect level recharge at the heterointerface and large current values at forward voltage bias. The activation energy of surface states at the boundary between the barrier and absorbing layers was determined, which turned out to be equal to about 359 meV.

MIS devices based on nBn structures. The frequency dependences of the capacitance and conductance of the MIS device can be explained using the equivalent circuit, in which the elements R_b and C_b characterize the barrier layer, and R_{bulk} – the resistance of the absorbing layer bulk. All elements of an equivalent circuit are easily found from admittance measurements. An interesting feature of the admittance measurements is the ability to determine the dynamic resistance of the barrier layer. In this case, information on the bulk component of the current can be obtained, even if the dark current is limited by surface leakage. A. It can be seen that with the exception of surface leakage for this sample with a composition close to the optimal in the barrier layer (x = 0.67), diffusion-limited characteristics can be obtained.



Temperature dependences of the product R_bA for sample A. The inset shows the dependence of $1/(R_bA)$ value on the P/A ratio at the voltage of 2 V and the temperature of 300 K.

CONCLUSIONS

The dark current and admittance of MWIR nBn structures based on MBE HgCdTe with various parameters of the barrier layers (wide-gap material, superlattice) were studied in a wide range of conditions. Admittance measurements of barrier structures (nBn structures and MIS devices) make it possible to determine the main parameters of the absorbing, barrier, and contact layers. Equivalent circuits of barrier structures are proposed, which can be used to describe the experimental dependences of admittance. It has been established that measurements of the admittance of test MIS devices from nBn structures based on MBE HgCdTe make it possible to determine the dynamic resistance of the barrier layer with the exclusion of surface leakage current.