CAPACITANCE-VOLTAGE CHARACTERISTICS OF CdHgTe MIS STRUCTURES WITH SINGLE QUANTUM WELLS BASED ON HgTe

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Abstract — The paper presents research results of the admittance of metal-insulator-semiconductor (MIS) structures based on $Cd_xHg_{1-x}Te$ grown by molecular-beam epitaxy (MBE) method including single CdHgTe/HgTe/ CdHgTe quantum wells in the near-surface layer of the semiconductor. The thickness of a quantum well was 5.6 nm, and the composition of barrier layers with the thickness of 35 nm was close to 0.65. It is shown that, for structures with quantum well based on HgTe capacitance oscillations in the strong inversion are observed. These oscillations are related to the recharging of quantum levels in HgTe.

ВОЛЬТ-ФАРАДНЫЕ ХАРАКТЕРИСТИКИ CdHgTe МДП-СТРУКТУР С ОДИНОЧНЫМИ КВАНТОВЫМИ ЯМАМИ НА ОСНОВЕ HgTe

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Аннотация — В работе представлены результаты исследований адмиттанса МДП-структур на основе МЛЭ $Cd_xHg_{1-x}Te$ с одиночной квантовой ямой CdHgTe/HgTe/CdHgTe в приповерхностном слое полупроводника. Толщина квантовой ямы составляла 5.6 нм, а состав в барьерных слоях толщиной 35 нм близок к 0.65. Показано, что для структуры с квантовой ямой на основе HgTe наблюдаются осцилляции емкости в области сильной инверсии, связанные с перезарядкой квантованных уровней в HgTe.

I. Introduction

Investigations of characteristics of MIS structures based on CdHgTe with inhomogeneous distribution of stochiometric composition are actual because of the need in passivation of infrared optoelectronic devices based on CdHgTe (laser diodes based on heterostructures or surface-emitting lasers [1] and far-infrared range photodetectors [2]). It should be noted that studies of the characteristics of MIS structures based on CdHgTe with inhomogeneous composition distribution are still extremely rare. The influence of surface graded-gap layers on the electrical characteristics of MIS structures based on MBE CdHgTe heteroepitaxial structures is studied [3]. The properties of a MIS structure based on MBE *n*-$Cd_{0.25}Hg_{0.75}Te$ comprising CdTe/HgTe superlattice in the surface region of the semiconductor were experimentally investigated [4]. It is shown that at high hole concentration ($p > 10^{17}$ cm^{-3}) quantisation of density of states in the inversion layer of p-CdHgTe is possible, which leads to quantum oscillations in the strong inversion of photoelectromotive force, capacitance and conductance. There are scientific works devoted to the research of quantum-size structures by electrophysical methods using surface-barrier structures, e.g., Schottky barriers with InGaAs/GaAs quantum wells [5] or Schottky barriers with GeSi/Si quantum dots [6].

The aim of this scientific work is the investigation of electrophysical characteristics of MIS structures based on heteroepitaxial CdHgTe with a single CdHgTe/HgTe/CdHgTe quantum well by admittance methods in wide frequency (1 kHz–2 MHz) and temperature (8–200 K) ranges.

II. Main Part

Investigated MIS structures were fabricated by MBE on the basis of CdHgTe on the substrates of GaAs (013) in the ISP SB RAS, Novosibirsk, Russia. A structure with a single quantum well had a CdTe composition in the $Cd_xHg_{1-x}Te$ barrier layer of x = 0.65, and the quantum well thickness was 5.6 nm. Barrier layers had a thickness of 35 nm. A low-temperature double-layer SiO_2/Si_3N_4 insulator was used as the passivation coating. Fig. 1 shows the basic layout of the layers in the structure of the quantum well. Measurements were carried out with the use of an automated admittance spectroscopy installation based on non-optical Janis cryostat and Agilent E4980A immittance meter.

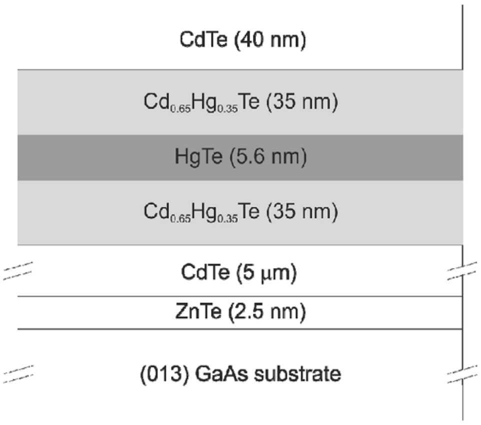

Fig. 1. Scheme of the layers position in structure with single quantum well with the thickness of 5.6 nm.

Рис. 1. Схематическое изображение расположения слоев в структуре с одиночной квантовой ямой толщиной 5.6 нм

Fig. 2 show dependencies of capacitance on bias voltage for MIS structure with 5.6 nm single quantum well measured at a temperature of 7.7 K for various frequencies of alternating test signal. From Fig. 2, it may be seen that CdHgTe has a *p*-type conductivity, and in the area of strong inversion at the range of frequencies from 500 Hz to 100 kHz non-monotonic change in capacitance is observed.

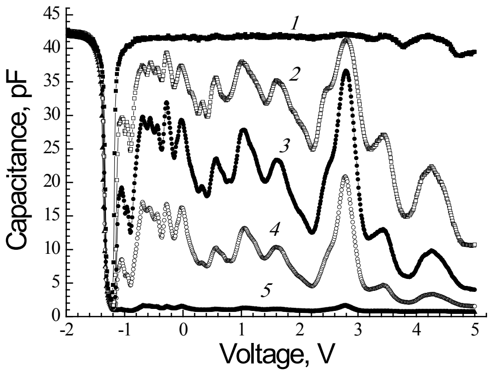

Fig. 2. Capacitance-voltage characteristics of MIS structures based on CdHgTe with quantum well measured at 7.7 K at different frequencies: 1–500 Hz, 2–5 kHz, 3–10 kHz, 4–20 kHz, 5–100 kHz.

Рис. 2. Вольт-фарадные характеристики МДП-структур на основе CdHgTe, содержащего квантовую яму, измеренные при температуре 7.7 К и частотах: 1 – 500 Гц, 2 – 5 кГц, 3- 10 кГц, 4 – 20 кГц, 5 – 100 кГц

Fig. 3 shows capacitance-voltage characteristic for a MIS structure with a quantum well measured at 10 kHz at different temperatures in the range of temperatures from 7.8 K to 77 K. It is seen that capacitance maxima in strong inversion are pronounced at low temperatures, and in the range from 30 K to 77 K, maxima are pronounced weakly.

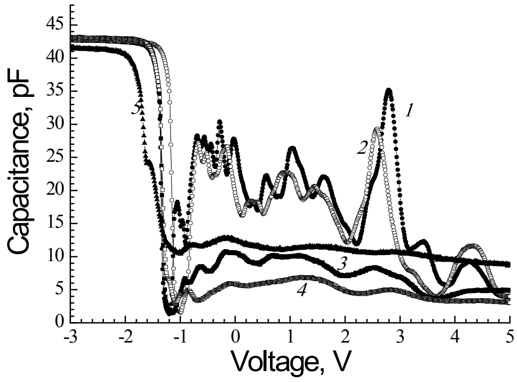

Fig. 3. Capacitance-voltage characteristics of MIS structures based on CdHgTe with quantum well measured at 10 kHz at different temperatures: 1–7.8 K, 2–10 K, 3–30 K, 4–50 K, 5–77 K.

Рис. 3. Вольт-фарадные характеристики МДП-структур на основе CdHgTe, содержащего квантовую яму, измеренные при 10 кГц и температурах: 1 – 7.8 К, 2 – 10 К, 3 – 30 К, 4 – 50 К, 5 – 77 К

III. Discussion

We will briefly describe the most likely mechanism for the capacitance maxima appearance in the strong inversion for the MIS structure comprising a single quantum well. Surface potential (as well as the potential in the field of quantum well) for *p*-CdHgTe depends on the bias voltage in the strong inversion because of the effects of degeneracy and conduction band non-parabolicity. When the Fermi level in the region of quantum well approaches to the level of quantisation, quantisation level recharges following a change of the alternating test bias voltage. Capacitance of dimensional quantisation level in the quantum well contributes to the full capacity of the structure and appears at intermediate frequencies in the strong inversion. When a capacitance-voltage characteristic has a low-frequency view, capacitance of the MIS structure in the strong inversion tends to the insulator capacitance and maxima associated with dimensional quantisation levels do not appear. When a capacitance-voltage characteristic has a high-frequency view, the carrier concentration in the inversion layer does not have enough time to follow the test signal and contribution of the quantisation levels capacitance at overall capacitance decreases because the quantum well is located at a distance of 35 nm from the interface. Since the charge carriers thermal energy increases with the increase in temperature, dimensional quantisation effects are mild.

IV. Conclusion

Thus, the admittance of MIS structures based on MBE CdHgTe with a single 5.6 nm quantum well was experimentally investigated. It is shown that the presence of a single quantum well can lead to the appearance of capacitance-voltage characteristics peaks in the strong-inversion. The capacitance maxima in strong inversion mode are particularly pronounced at low temperatures (8–10 K), although they are weakly apparent up to 77 K. It is assumed that the dimensional quantisation levels recharge capacitance in the quantum well contributes to the overall capacitance of the structure and appears in the capacitance-voltage characteristics in the strong inversion.

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V. References

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