INVESTIGATION OF ADMITTANCE FOR CdHgTe-BASED MIS-STRUCTURES WITH SINGLE QUANTUM WELLS UNDER THE WIDE TEMPERATURE RANGE (8—200) K

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Abstract — Paper presents research results of metal-insulator-semiconductor (MIS) structures admittance based on $Hg_{1-x}Cd_xTe$ grown by molecular-beam epitaxy (MBE) method including single HgCdTe/HgTe/HgCdTe quantum wells (QW) in the surface layer of the semiconductor structure. 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. Measurements were conducted in the range of temperatures from 8 to 200 K. It is shown that for structure with quantum well based on HgTe capacitance and conductance oscillations in the strong inversion are observed. These oscillations are related with the recharging of quantum levels in HgTe.

ИССЛЕДОВАНИЕ АДМИТТАНСА МДП-СТРУКТУР НА ОСНОВЕ CdHgTe, ВКЛЮЧАЮЩИХ ОДИНОЧНЫЕ КВАНТОВЫЕ ЯМЫ, В ДИАПАЗОНЕ ТЕМПЕРАТУР 8—200 К

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Аннотация — В работе представлены результаты исследований структур металл-диэлектрик-полупроводник (МДП) на основе материала $Hg_{1-x}Cd_xTe$ (КРТ), выращенных методом молекулярно-лучевой эпитаксии, включающих одиночные квантовые ямы (КЯ) типа HgCdTe/HgTe/HgCdTe в поверхностном слое полупроводниковой структуры. Толщина квантовой ямы в исследуемых структурах составляла величину 5,6 нм, а состав барьерных слоев с толщиной 35 нм был около 0,65 мол. дол. Измерения проводились в диапазоне температур от 8 до 200 К. Показано, что для структуры с КЯ на основе HgTe в режиме сильной инверсии наблюдаются осцилляции вольт-фарадной характеристики (ВФХ), которые, вероятно, связаны с перезарядкой уровней размерного квантования в квантовой яме HgTe.

I. Introduction

HgCdTe MBE method provides new opportunities to optimize the characteristics of highly sensitive infrared detectors by growing heteroepitaxial structures based on HgCdTe with a pre-defined distribution of stochiometric composition in epitaxial films. Today the most common is creation of varyband layers with increased stochiometric composition of CdTe near the borders of the epitaxial layer. It allows reducing the influence of surface recombination on the charge carrier lifetime in the bulk of the epitaxial film, as well as to reduce the series resistance and improve the threshold characteristics of photodiodes based on p-n-junctions. Investigations of characteristics of MIS structures based on HgCdTe with inhomogeneous distribution of stochiometric composition are actual because of the need in passivation of infrared optoelectronic devices based on HgCdTe (laser diodes based on heterostructures or surface-emitting lasers [1], far-infrared range photodetectors [2]).

The aim of this scientific work is the investigation of electrophysical characteristics of MIS structures based on heteroepitaxial HgCdTe with a single HgCdTe/HgTe/HgCdTe quantum well by admittance methods in wide frequency (1 kHz till 2 MHz) and temperature (8 K to 300 K) ranges.

II. Main Part

Investigated MIS structures were fabricated by molecular-beam epitaxy method on the basis of mercury cadmium telluride on the substrates of GaAs (013) in Institute of Semiconductor physics of Siberian branch of Russian Academy of Sciences (Novosibirsk, Russia). Some of the investigated structures did not include a quantum well in the surface region. A structure with a single quantum well had a CdTe composition in the $Hg_{1-x}Cd_xTe$ 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_4As dielectric applied over the CdTe 40 nm layer was used as the dielectric coating.

Measurements were carried out with the use of an automated admittance spectroscopy installation based on non-optical Janis cryostat and Agilent E4980A immittance meter.

Figure 1 shows capacitance-voltage characteristics (CVC) of MIS structures based on varyband *p*-HgCdTe (x = 0.22) without quantum wells measured at 20 K and different frequencies of test signal. Electrophysical measurements at lower temperatures for *p*-HgCdTe (x = 0.22-0.36) with conversion of conductivity type after annealing are less accurate because of the sharp increase in epitaxial film's bulk resistance during cooling from 20 K to 8 K. For comparison, figure 8 shows capacitance-voltage characteristics of MIS structure based on HgCdTe with a single quantum well, measured at 30 K and various frequencies of test signal. It is seen from figures 1 and 2 that for MIS structures based on HgCdTe without quantum wells there are no non-monotonic changes of capacity in strong inversion.

III. Discussion

We will briefly describe the most likely mechanism for the CVC maxima appearance in the strong inversion for the MIS structure comprising a single quantum well.

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Surface potential (as well as the potential in the field of quantum well) for p-HgCdTe depends on the bias voltage in the strong inversion because of the effects of degeneracy and conduction band nonparabolicity. When the Fermi level in the field of quantum well approaches to the level of quantization, quantization level recharges following a change of the AC test bias voltage. Capacity of dimensional quantization level in the quantum well contributes to the full capacity of the structure and appears at intermediate frequencies in the strong inversion.

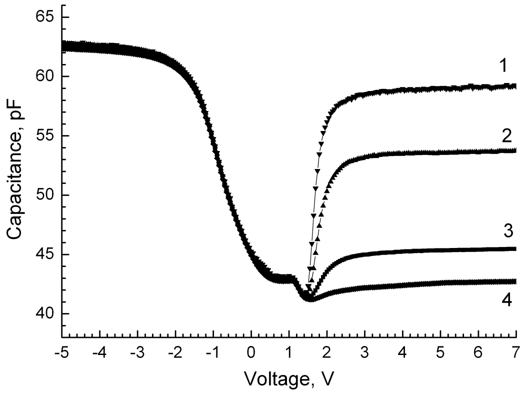

Fig. 1. CVC of MIS structure based on varyband HgCdTe without QW measured at 20 K at different frequencies: 1 – 10 Hz, 2 – 20 kHz, 3 – 50 kHz, 4 – 100 kHz.

Рис. 1. ВФХ МДП-структуры на основе варизонного HgCdTe без КЯ при температуре 20 К при различных частотах смещающего напряжения: 1 – 10 Гц, 2 – 20 кГц, 3 – 50 кГц, 4 – 100 кГц

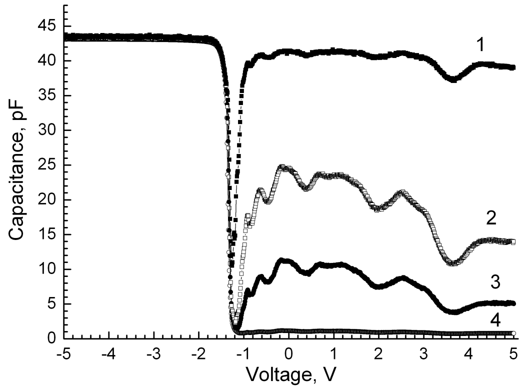

Fig. 2. CVC of MIS structure based on HgCdTe containing QW measured at 30 K at different frequencies: 1 – 1 kHz, 2 – 5 kHz, 3 – 10 kHz, 4 – 50 kHz.

Рис. 2. ВФХ МДП-структуры на основе HgCdTe с КЯ при температуре 30 К при различных частотах смещающего напряжения: 1 – 1 кГц, 2 – 5 кГц, 3 – 10 кГц, 4 – 50 кГц

Energies of dimensional quantization levels in a quantum well can be approximately defined by analogy with [3]. To do this it is necessary to define the flat-band voltage in MIS structure comprising QW in terms of flat-band capacitance value and to obtain surface potentials corresponding to maxima of capacity in the strong inversion. Then it is necessary to build the potential spatial distribution in the HgCdTe surface layer and to find the potential under the given bias voltage in the quantum well. Knowing the position of the Fermi level in the flat-band mode, position of dimensional quantization levels can be find relative to the allowed energy bands in HgCdTe barriers.

The flat-band capacitance value is 33.56 pF in our case. Hence the flat-band voltage is -1.36 V. E_g of barrier layer is 0.838 eV. Fermi level location is (E_v + 0.010 eV) or (E_c – 0.828 eV). Then two first maxima of capacitance for quantum well MIS structure under the direct sweep bias voltage correspond to energies (E_c – 0.520 eV) and (E_c – 0.210 eV). Here E_c is the energy of conduction band edge of the barrier layer near the border.

Another way for estimation of dimensional quantization energies levels is the using of theoretical model described by us earlier in [4]. This model based on self-consistent solution of Poisson and Shrödinger equations for heterostructure comprising QW with taking into account real parameters of MBE-grown CdHgTe solid solution such as electron affinity and concentrations of ionized acceptors and donors. Calculation of dimensional quantization levels for structure under consideration at 7.7 K gives values (E_c – 0.597 eV) for first level of electrons E_{c1}, (E_c – 0.347 eV) for second level of electrons E_{c2}, (E_c – 0.486 eV) for first level of heavy holes E_{h1}, (E_c – 0.517 eV) for second level of heavy holes E_{h2}. Then two first maxima of capacitance observed on the CVC in the experiment may be associated with the presence of dimensional quantization levels. It was confirmed by estimation. But the accuracy of used calculation methods does not allow give more precise results and does not allow interpret each observed peak

IV. Conclusion

Thus the admittance of MIS structures based on MBE HgCdTe with a single 5.6 nm quantum well located in the surface layer of semiconductor was experimentally investigated. It is shown that the presence of a single quantum well thickness of 5.6 nm can lead to the appearance of capacitance-voltage and conductance-voltage characteristics peaks in the strong-inversion mode. Capacitance maxima in the strong inversion mode are observed in an intermediate case between the low frequency and high frequency capacitance-voltage characteristics (5-50 kHz for a sample with a single quantum well). 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. Maxima in capacitance in strong inversion mode are not observed for samples without quantum wells.

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V. References

[1] Pautrat J.L., Hadji E., Bleuse J., Magnea N. Resonant-cavity infrared optoelectronic devices. *Journal of Electronics Materials*, 1997,Vol. 26, issue 6, pp. 667-672.

[2] Grein C.H., Jung H., Singh R., Flatte M.E. Comparison of normal and inverted band structure HgTe/CdTe superlattices for very long wavelength infrared detectors. *Journal of Electronics Materials*, 2005, Vol. 34, issue 6, pp. 905-908.

[3] Voitsekhovskii A.V., Davydov V.N. *Photoelectric MIS Structures Based on Narrow-Band Semiconductors*, Tomsk, Radio I Svyaz', 1990, 327 p.

[4] A.V. Voitsekhovskii, D.I. Gorn, I.I. Izhnin, A.I. Izhnin, V.D. Goldin, N.N. Mikhailov, S.A. Dvoretskii, Yu.G. Sidorov, M.V. Yakushev, V.S. Varavin. Analysis of the photoluminescence spectra of $Cd_xHg_{1-x}Te$ heteroepitaxial structures with potential and quantum wells grown by molecularbeam epitaxy. *Russian Physics Journal*, 2013,Vol. 55, issue 8, pp. 910-916.