Summary

The title of the dissertation: Defects levels study in HgCdTe heterostructure photodiodes used for infrared radiation detection.

Mercury cadmium telluride (HgCdTe) is still the dominant material for designing of high-temperature infrared detectors. In order for HgCdTe photodiodes to comply with "Law 19", the material must have good structural quality and low defect concentration. Therefore, it is necessary to know and control defect states in semiconductor materials to improve the quality of the optoelectronic devices. Non-equilibrium HgCdTe heterostructure photodiodes with several junctions are fabricated in the WAT–VIGO laboratory. However, the presence of several junctions makes the analysis of defects significantly more difficult. To enable the analysis of defects in the produced heterostructures without the need to grow single layers, this work proposes a method of dividing a multijunction photodiode into single p-n junctions. This method made it possible to characterize the defects and assign them to individual layers of the heterostructure.

HgCdTe photodiodes optimized for the short- (SWIR), mid- (MWIR) and long-wave infrared (LWIR) ranges were used for the research. In order to prove the validity of the method, theoretical analyzes were first carried out to determine the location of the highest electric field in the heterostructure. Then, experimental studies were carried out, which enabled the identification and assignment of trap levels to a specific layer in the photodiode. Two independent measurement methods were used in the study: deep level transient spectroscopy (electrical method) and photoluminescence measurement (optical method).

The obtained results are consistent with the literature data and confirm the occurrence of several defects levels in $Hg_{1-x}Cd_xTe$. In the dissertation, their ionization energies were determined for the Cd molar composition from $x = 0.17$ to $x = 0.6$. The first defect level is a shallow acceptor formed by neural mercury vacancies. Another deep defect level can be formed by singly charged Hg vacancies – the neutral mercury vacancy has six electrons from its Te neighbors, so it tends to accept one or two more electrons, producing the singly or doubly negatively charged vacancy levels with higher energy than for the neutral state. Depending on the band gap, this level can be treated as a deep acceptor (for $x > 0.35$) or a donor level (for $x < 0.25$), and for HgCdTe with a low Cd composition it can be located in the conduction band, creating a resonant state. For $x \sim 0.3$, it can be treated as a deep defect level located in the mid of the energy gap.

Above the main defect level, two additional trap states can be found, most likely formed by oxygen atoms substituted for mercury. The neutral oxygen has two extra electrons in comparison with the cation it replaces, and creates a trap level with an energy of ~100 meV above the main level. By donating one electron it become singly positively charged and creates a trap level with an energy of ~40 meV above the main level.

Oxygen atoms can take the place of cations if the HgCdTe sample is exposed to air after annealing, etching or anodic oxidation process. For example, in the standard process of chemical etching with bromine-methanol, the damage to the surface is usually deep, even up to tens of nanometers, and an activated Te-rich layer at the surface is easily oxidized. Then oxygen atoms easily diffuse into the bulk via a Hg vacancy assisted mechanism. If trap levels in HgCdTe originates from oxygen atoms replacing Hg vacancies, important at a certain technological stage is not only the annealing of the sample, but also effective passivation of the sample surface against the effects of atmospheric factors. This shows that the research carried out is not only scientifically significant, but also can contribute to improve the technology of detectors manufactured in VIGO Photonics.

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