IR diode structures based on II-Type InAs/GaSb superlattices grown by MOCVD

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Abstract. This work demonstrates the possibility of growing Type-II InAs/GaSb superlattices by MOCVD. The Type-II InAs/GaSb superlattices consisting of 20 pairs of alternating InAs and GaSb layers of equal thickness (1 nm / 2 nm) were grown at a temperature of 500°C. The obtained structures were studied by transmission electron microscopy and electroluminescence. The electroluminescence spectra demonstrated a maximum at about 0.25 eV.

1. Introduction
Infrared radiation has a quite extensive spectrum, from 0.8 to several hundred micrometers. Currently, infrared (IR) devices are widely used to solve problems in agriculture, medicine, astronomy, military application, and other areas. Therefore, there is a need for discovering new IR semiconductor materials. The main problem of such material systems is Auger-recombination, which reduces the quantum efficiency of devices based on these materials at high temperatures. The material system of strained Type-II InAs/GaSb superlattices makes it possible to lower Auger recombination and raise the operating temperature of the device \cite{1-2}. The main method for growing Type-II InAs/GaSb superlattices is molecular beam epitaxy (MBE) \cite{3}. The aim of this work was to study the possibility of growing a Type-II InAs/GaSb superlattice by the alternative metalorganic chemical vapor deposition method (MOCVD).

2. Experiment
All the structures were grown with an AIX-200 reactor (AIXTRON, Germany) on n-GaSb substrates (001). The pressure in the reactor was 76 Torr. The carrier gas was purified H\textsubscript{2} with a dew point not worse than −100°C and a total flow through the reactor of 5.5 lpm. The sources of growth elements were trimethylindium (TMIn), triethylgallium (TEGa), trimethylstibane (TMSb) and arsine (AsH\textsubscript{3}). The sources of alloying impurities were diethyltellurium (DETe) as a donor and silane (SiH\textsubscript{4}) as an acceptor, and the active area was not doped. For the GaSb buffer and covering layers, the growth temperature was $T = \text{600°C}$, TMSb/TEGa = 2, and the growth rate was about 23 nm/min. For the active area (superlattice), the growth temperature was $T = \text{500°C}$, AsH\textsubscript{3}/TMIn = 124, TMSb/TEGa = 22.5, and the growth rate was about 1 nm/min.

The grown structures consisted of an n-GaSb substrate ($n = (5-7)\times10^{17}\text{cm}^{-3}$), an n-GaSb:Te buffer layer ($d = 0.5 \mu\text{m}$, $n = 1\times10^{18}\text{cm}^{-3}$), an undoped Type-II InAs/GaSb superlattice composed of 20 periods (with similar thicknesses of an InAs quantum well and a GaSb barrier with $d = 1 \text{nm}$ and 2
nm), and a covering $p$-GaSb:Si layer ($d = 1 \, \mu m$, $p = 1 \cdot 10^{18} \, cm^{-3}$). Figure 1 shows a diagram of the studied structures. In such a structure a minizone is formed for both electrons and holes due to the transparency of potential barriers. The effective bandgap of this superlattice is the distance between minizones of electrons and holes. This bandgap is smaller than the bandgaps of InAs and GaSb in the superlattice. Optical transitions between minizones of electrons and holes are direct.

![Figure 1. Schematic representation of the investigated heterostructures with Type-II InAs/GaSb superlattices composed of 20 periods.](image)

To prevent the growth of variable composition material at the boundaries of the layers, the superlattice was grown with interruption for purging the reactor with pure hydrogen for a complete change of the gas atmosphere between the growth of different layers. For all the layers, the time of interruption was 10 seconds, which is more than the time calculated for the given geometry of the reactor. However, as will be seen later, these conditions were not enough to prevent the appearance of transition layers.

The study of the sample microstructures was performed by transmission electron microscopy with a JEM2100F microscope at a 200 kV accelerating voltage. The samples were also studied by electroluminescence.

3. Experimental Results

It was found that the superlattice with 1 nm layers has a high density ($(1-2) \cdot 10^{10} \, cm^{-2}$) of defects (figure 2 (a)). The superlattice with 2 nm layers has very few defects (less than $4 \cdot 10^{9} \, cm^{-2}$) (figure 2(b)). The thickness of the layers is non-uniform in both lateral and "layer by layer" directions. The darker border contrast, as compared to GaSb and InAs layers, indicates the formation of thin transition layers of InGaAsSb and/or GaAsSb at the boundaries.

![Figure 2. TEM image of a Type-II InAs/GaSb superlattice with a layer thickness: (a) $d = 1$ nm; (b) $d = 2$ nm.](image)
The diodes with a diameter of ~700 µm were produced on the basis of the superlattice structure with a layer thickness $d = 2$ nm. The electroluminescence (EL) spectra of diodes were studied at a temperature 77 K under excitation by 1 µs current pulses with a frequency of 1 kHz.

The EL spectra at $T = 77$ K are shown in figure 3. The excitation current pulse was in the 2 – 8 A range. The apparent maximum was observed at about 0.25 eV. The maximum of the emission spectra differs from the energy of the band gap of InAs, GaSb, and, possibly, a Ga$_{0.5}$In$_{0.5}$As$_{0.4}$Sb$_{0.6}$ solid solution. This follows from the equality of the growth rates and the growth times of the layers. The lower content of As in relation to Sb is determined by the desorption due to a higher vapor pressure of arsenic at the growth temperature. The dependence of the electroluminescence intensity on the supplied current (inset of figure 3) demonstrates a fivefold luminescence increase when the current is doubled.

![Figure 3. EL spectra of the superlattice structure with 2 nm layers ($T = 77$ K) at different excitation currents. Dependence of the electroluminescence intensity on the supplied current (inset).](image)

4. Summary
The experiments have shown the possibility of growing a heterostructure with a strained Type-II InAs/GaSb superlattice by MOCVD. The research will be continued in order to minimize the thickness of transition layers at the boundaries in superlattices grown using atomic layer epitaxy. The maximum in the electroluminescence spectra is observed at about 0.25 eV. There is a five-fold luminescence increase when the current is doubled.

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References
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