Impurity Levels in Gallium Antimonide

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Gallium antimonide is one of the most interesting III–V compounds because its physical properties are generally similar to those of germanium and some of these properties (the ratio of the electron and hole mobilities, the predominance of the negative over the positive absorption, and the conditions for the energy pumping to the electron system) are superior to those of germanium.

In view of the interest in gallium antimonide and because of the well-known influence of impurities on physical properties, it would be desirable to know the energy positions of impurity levels in this compound. An analysis of the results reported by other workers and of our own results yields the following scheme of impurity levels in the forbidden band of GaSb (Fig. 1).

According to van Maaren[1] the Li-doped GaSb has only one acceptor level with an ionization energy of 0.01 eV. We studied[2] the photoluminescence of uniaxially compressed silicon-doped GaSb and found an acceptor level of silicon lying at 0.011 eV. Elsewhere[3,4] it was reported that GaSb crystals grown without an excess of Sb (from a solution in gallium) exhibit only one acceptor level at the 0.022 eV, which has been attributed to gallium. The levels at 0.034 and 0.056 eV, observed in pure or Sb-doped GaSb crystals[5,6] should be attributed to acceptors in the form of excess antimony atoms. Welker[7] reported an acceptor level of zinc (0.037 eV) for zinc-doped GaSb crystals.

An analysis[3] of the temperature dependence of the Hall coefficient of copper-doped GaSb (up to $1.8 \cdot 10^{18}\,cm^{-3}$) shows that copper forms four acceptor levels in GaSb:[8] 0.01, 0.03-0.04, 0.12-0.17, and 0.24-0.30 eV.

Magnetic spectroscopy of tunnel diodes prepared by alloying with Sn + 3%Te + 1% has indicated the presence of Fe acceptor levels at 0.16 and 0.36 eV from the bottom of the conduction band.[9]

Fundamental investigations of the behavior of group VI donors in GaSb were carried out by Shmartsev et al.[10,11] These experimental and theoretical investigations have made it possible to classify the impurity states of the group VI donors in GaSb on the basis of a model according to which each VI atoms replacing Sb gives rise to three groups of weakly interacting impurity states, in accordance with three groups of inequivalent conduction-band minima. In the light of these investigations the donor states of tellurium in GaSb can be described satisfactorily by the hydrogenic model. The binding energies calculated in accordance with this model are in agreement with the experimental values and at 320°K these energies are $(E_{Te})_{\Gamma_1} = 0.003$, $(E_{Te})_{L_1} = 0.02$, $(E_{Te})_{L_1} < (E_{Te})_{X_1} < 0.08$ eV.

The energy positions of selenium and sulfur impurity levels in GaSb are affected by the deviation from the hydrogenic model along the Te → Se → S series and by the corresponding increase in the binding energy. The energies given in ref. 11 and by other workers are: $(E_{Se})_{L_1} =$ 0.06-0.08 eV at 77°K; $(E_{Se})_{X_1} = 0.2$ eV at 290°K; $(E_S)_{L_1} =$ 0.14-0.15 eV at 290°K.

The energy spectrum of gallium antimonide given in Fig. 1 shows that the physical properties of GaSb can be controlled within a wide range, which may be useful in practical applications. The results indicate that GaSb is one of the most promising industrial semiconductors.

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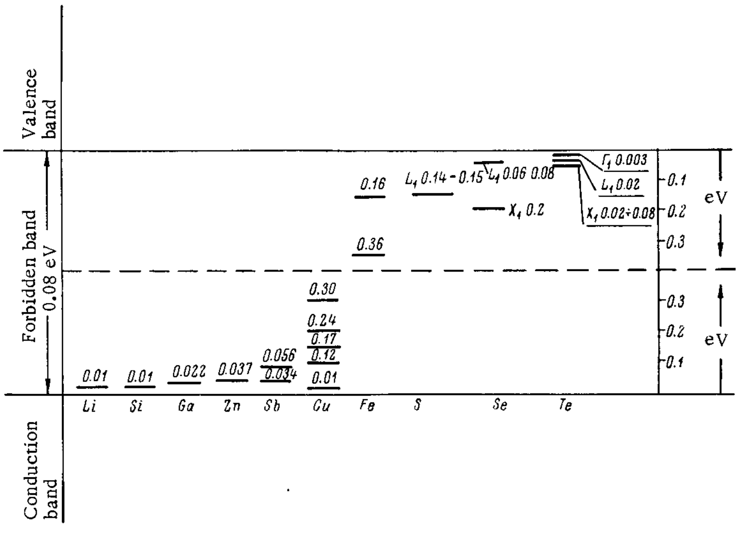

Fig. 1. Positions of impurity levels in the forbidden-band of gallium antimonide.

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