Summary Abstract: HgTe–CdTe superlattices

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In their seminal paper on superlattices, Esaki and Tsu[1] indicated that superlattices involving II–VI compounds and their alloys, could be of interest along with superlattices involving group IV and III–V semiconductors. Independently, Schulman and McGill[2] identified the HgTe–CdTe superlattice as an interesting case to study. HgTe and CdTe have the same crystal structure and lattice constant to 0.3%.[3] CdTe is a conventional zinc blende semiconductor with a band gap of about 1.6 eV; HgTe is a zero band gap semiconductor.[3] Hence, HgTe–CdTe superlattices are expected to span a wide range of properties.

Schumlan and McGill[2,4] carried out extensive theoretical studies of this superlattice and concluded that this superlattice could have significant application in infrared devices. For fixed Hg to Cd ratio, they found that the band gap of the superlattice could be adjusted from zero in the limit of thick HgTe layers to a value that is approximately that of the corresponding alloy for thin HgTe layers. This band gap variation should be contrasted with that of the alloy where a single value is obtained for fixed Hg to Cd ratio. One could also make superlattices from alloys $Hg_{(1-x)}Cd_xTe$–$Hg_{(1-y)}Cd_yTe$. Hence, one could vary both the thickness of the two layers and x and y. These four independent parametes can be used to control the materials properties.

An important question is the value of the offset between the valence band in the two materials. This parameter is particularly important in governing the properties of the superlattices. Classical arguments based on the electron affinity differences,[5] the common anion rule,[6] and Harrison's model[7] suggest that valence band offsets should be small. Schulman and McGill[8] found that if they took the band offset between the valence bands of the HgTe and CdTe to be zero, then the decay of the wave function near the valence band and conduction band edges into the CdTe was slow. Therefore, transport normal to the layers was possible even for rather thick layers of CdTe in the superlattice. Hence, the material would behave as a true three-dimensional material, in that transport normal to the layers would take on a reasonable value. Experimentally, the value of the band offsets for this structure has not been determined unequivocally. However, the results of experiments by Kuech and McCaldin[9] suggest that the band offsets for the valence band may indeed be small.

In a recent paper, Smith, McGill, and Schulman[10] have presented a number of reasons for considering HgTe–CdTe superlattices for application in the infrared. Using a much improved calculation of the band gap of the superlattice as a function of the layer thickness, they find that interesting cutoff wavelengths (8–12 μm) can be reached by working with superlattices with thickness as great as 55–75 Å. Furthermore, they find that the band gap of the superlattice can be determined with less fractional precison in the layer thickness than the fractional precision in composition required for the alloy. This makes it easier to reach a given cutoff wavelength with the superlattice than with the alloy.

They also find that the CdTe layers in the superlattice tend to confine the electronic wave functions for energies in the forbidden gap better than in the alloy. To illustrate this point, we have plotted the complex band structure for $Hg_{(1-x)}Cd_xTe$ alloys in Fig. 1 and that for HgTe–CdTe superlattices with the same band gaps. The important point to be noted here is the much larger value of the k_I for the superlattice as compared to the alloy with the same band gap. This difference in the imaginary part suggests significantly reduced tunneling in junctions formed in the superlattice as compared to those in alloys. Hence, the HgTe–CdTe superlattice has a number of properties that could make it interesting in comparison to the alloy for infrared applications.

The fabrication of these structures is difficult owing to the high Hg vapor pressure. A number of groups have been attempting to fabricate HgTe–CdTe superlattices. Very recently Faurie and co-workers[11] have reported the first growth of these structures. Using molecular beam epitaxy, this group has succeeded in fabricating as many as 100 layers. The thickness of the HgTe layers ranged from 180–1600 Å, and the thickness of the CdTe layers ranged from 44–600 Å. While these experimental results are very preliminary, they indicate that HgTe–CdTe superlattices can, in fact, be

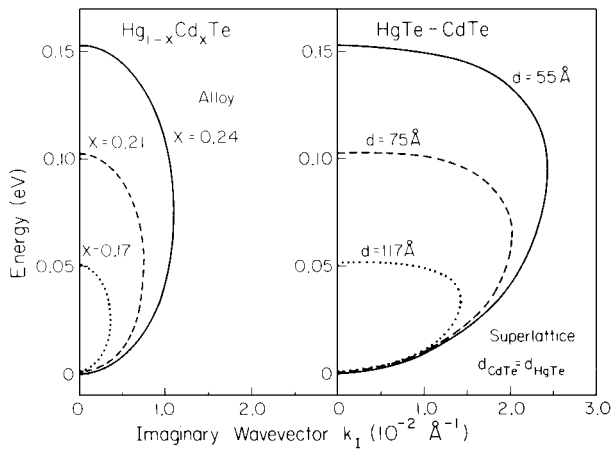

FIG. 1. Complex band structure of the $Hg_{(1-x)}Cd_xTe$ alloy and the HgTe–CdTe superlattice. The abscissa is the imaginary part of the wave vector which governs the decay of the wave function in the forbidden energy range which is given on the ordinate. The results for a number of different alloy compositions x are given. To make comparison possible, the results are also given for the superlattice with equal amounts of CdTe and HgTe, with the thickness of the layers adjusted to give the same value for the band gap as for the alloy.

grown. Only future experiments will show whether or not they have the desired properties.

In summary, HgTe–CdTe superlattices are extremely interesting materials, whose properties are only beginning to be explored.

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