

Nonmagnetic-semimagnetic semiconductor heterostructures: Ge-Cd_{1-x}Mn_xTe(110)

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Synchrotron-radiation photoemission studies of heterovalent heterojunctions involving Ge and Cd_{1-x}Mn_xTe alloys ($x=0, 0.35$, and 0.60) were performed on interfaces prepared *in situ* by Ge deposition on cleaved (110) semimagnetic semiconductor surfaces. The valence-band offsets ΔE_v were obtained with consistent results through a nonlinear least-squares fit of the interface valence-band emission in terms of a superposition of valence-band spectra for the individual semiconductors, and with a more conventional method utilizing the Te 4*d* and Ge 3*d* core-level emission. We find valence-band offsets $\Delta E_v=0.80\text{--}0.83$ eV largely independent of semimagnetic composition and band gap. In the framework of the linear models of semiconductor heterojunction behavior, this result would indicate that CdTe-Cd_{1-x}Mn_xTe heterojunctions will follow the common anion rule.

INTRODUCTION

Semiconductor heterostructures involving ternary semimagnetic semiconductors such as Cd_{1-x}Mn_xTe have been attracting increasing attention since the original idea of a spin superlattice.¹ Quantum wells where a semimagnetic semiconductor is coupled with a nonmagnetic counterpart of similar energy gap and conduction-band electron effective mass will exhibit strong modification of the electronic properties in a magnetic field due to the large difference in the electronic *g* factors of the two materials.^{2,3} For example, the spin splitting of electronic states in semimagnetic semiconductors may be two orders of magnitude greater than in the adjacent nonmagnetic layer^{2,4} and comparable to the ionization energy of shallow impurities. The consequent tunability of the depth of the quantum wells by the magnetic field may give rise to phenomena such as enhancement of electronic *g* factors in shallow nonmagnetic wells surrounded by semimagnetic barriers, magnetically induced transitions from type-I to type-II superlattice,⁵ boil-off and freeze-out of electrons to and from quantum wells, and selective spin tunneling across the barriers.^{2,3}

Observation of the magnetic effects described above is crucially dependent on the presence of heterojunction band discontinuities of suitable magnitude. For most nonmagnetic-semimagnetic (NM-SM) heterojunctions, however, no information is available at present about conduction- and valence-band offsets. Even for the most studied NM-SM heterojunction system, CdTe-Cd_{1-x}Mn_xTe, the situation is somewhat unclear. Photoluminescence results in external magnetic fields have been interpreted⁶ as indicating a valence-band discontinuity $\Delta E_v=25$ meV (for $x=0.24$, 0.6% lattice mismatch), corresponding to a conduction- to valence-band offset ratio $\Delta E_c/\Delta E_v$ of about 14:1 or $\Delta E_v=6.7\%$ of the band-gap energy difference ΔE_g . This would imply that the valence-band discontinuity for a hypothetical strain-free case is virtually zero.^{6,7} However, a magnetic-field-

induced type-I to type-II transition in CdTe-Cd_{0.93}Mn_{0.07}Te superlattices (0.2% strain) has been recently interpreted in terms of a valence band offset of up to 20% of the band-gap energy difference.⁵

A study of NM-SM heterojunction band offsets by means of photoemission spectroscopy seems therefore timely. Photoemission spectroscopy has clarified in the past many of the systematic trends in heterojunction behavior⁸ and can in favorable cases directly visualize the band offset in the valence-band spectra.^{9,10} We selected as a first test case the Ge-Cd_{1-x}Mn_xTe system for a number of reasons. Systematic studies exist of Ge deposition on a variety of semiconductors,¹¹ including CdTe.¹² Amorphous layers can be easily obtained through deposition at room temperature, so that the overlayer is unstrained.¹¹ At the same time, epitaxial Ge-Cd_{1-x}Mn_xTe structures are likely to be the first NM-SM heterostructure involving a group-IV material to be synthesized, since epitaxial CdTe layers have been successfully grown with both (100) and (111) orientation^{13,14} on GaAs(100), which is lattice-matched to Ge. The Ge-CdTe valence-band offset is also known to be large,¹² so that direct visualization of the offset by photoemission may be possible.

Photoemission measurements of the valence-band offset for Ge-Cd_{1-x}Mn_xTe interfaces prepared *in situ* with $x=0, 0.35$, and 0.60 were conducted using two different methods. We used the initial (Ge coverage $\theta=0$) and final ($\theta>20$ Å) positions of the valence-band maximum, together with the variation in Ge 3*d* and Te 4*d* core separation as a function of coverage to obtain ΔE_v . We also used a new fitting procedure to visualize ΔE_v directly from the interface valence-band emission. The valence-band offset was found to be independent of the semimagnetic ternary composition within experimental uncertainty. Given a maximum change in the valence-band offset in the Ge-Cd_{1-x}Mn_xTe series of only 0.03 eV, application of the transitivity rule of heterojunction behavior would yield an upper limit of only 6.5% of the band-gap energy difference for ΔE_v in CdTe-Cd_{1-x}Mn_xTe.

EXPERIMENTAL DETAILS

The $\text{Cd}_{1-x}\text{Mn}_x\text{Te}$ crystals used in the present studies were grown at Purdue University through a modified Bridgmann method, and characterized through x-ray diffraction and x-ray microprobe analysis as to crystallographic phase and composition. The same samples were used in studies of the bulk electronic structure of $\text{Cd}_{1-x}\text{Mn}_x\text{Te}$ semiconductors (Refs. 15 and 16) and metastable $\text{Cd}_{1-x}\text{Mn}_x\text{Te}$ alloy formation through Mn-CdTe thin-film reaction.¹⁷ All results presented here were obtained on single-phase single crystals ($x=0, 0.35,$ and 0.60) cleaved *in situ* in a photoelectron spectrometer. Operating pressure was $< 5 \times 10^{-11}$ Torr. Heterojunctions were synthesized by depositing Ge *in situ* from a tungsten basket evaporator onto mirrorlike cleavage surfaces kept at room temperature. In these conditions amorphous Ge overlayers are known to form.¹² The Ge coverage θ (in Å) was monitored by means of a quartz microbalance. The pressure during deposition never exceeded 5×10^{-10} Torr.

Angle-integrated photoemission measurements were performed as a function of Ge overlayer thickness in the 1–20-Å range. Synchrotron radiation from the 1-GeV electron storage ring Aladdin at the Synchrotron Radiation Center of the University of Wisconsin–Madison was monochromatized by means of a 3-m toroidal grating monochromator and focused onto the samples. Photoelectrons were collected at an average emission angle of 45° by means of a commercial hemispherical energy analyzer. Angle-integrated photoelectron energy distribution curves (EDC's) were recorded with an overall energy resolution (electrons and photons) ranging from 0.2 to 0.3 eV in the photon-energy range from 45 to 110 eV, as determined from the width of the Fermi cutoff in spectra from metallic standards deposited *in situ* onto the sample.

RESULTS AND DISCUSSION

In Fig. 1 we show representative EDC's for the valence-band emission from Ge-CdTe(110), Ge- $\text{Cd}_{0.65}\text{Mn}_{0.35}\text{Te}$ (110), and Ge- $\text{Cd}_{0.40}\text{Mn}_{0.60}\text{Te}$ (110) interfaces for Ge coverages θ (shown to the right of each spectrum) in the 1–5-Å range, at a photon energy of 80 eV. The bottom-most spectrum of each series shows the valence-band emission from the cleaved substrate surface prior to Ge deposition. The zero of the binding-energy scale was taken at the position of the substrate valence-band maximum E_v , as estimated from a linear extrapolation of the leading valence-band edge.

A word of caution is required when measuring the valence-band offset between an amorphous and a crystalline semiconductor. Electronic-structure calculations have shown that several characteristics of the electron-energy spectrum of semiconductors are sensitive to topological disorder.¹⁸ In particular, it is possible to define a valence and a conduction band for amorphous semiconductors, but the corresponding density of states (DOS) may differ substantially from those of the corresponding

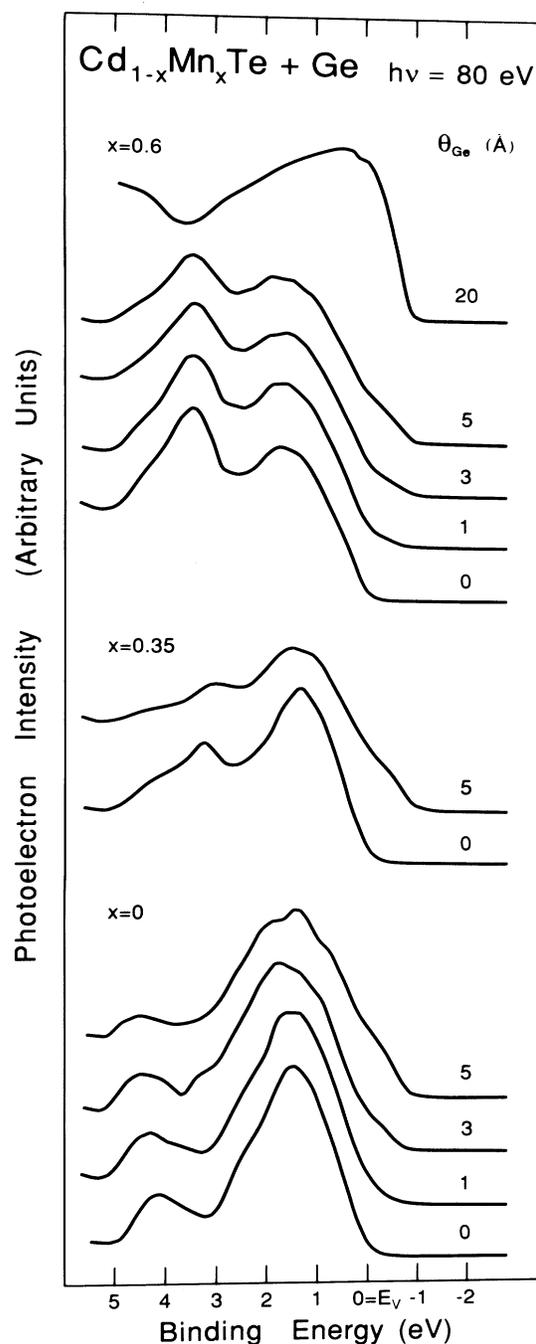


FIG. 1. Photoelectron energy distribution curves for the valence-band emission from Ge- $\text{Cd}_{1-x}\text{Mn}_x\text{Te}$ (110) interfaces for $x=0$ (bottom), 0.35 (midsection), and 0.60 (top) at a photon energy of 80 eV. Ge coverages θ in Å are shown to the right of each spectrum. The bottom-most spectrum of each series shows the valence-band emission from the cleaved substrate surface prior to Ge deposition. The zero of the binding-energy scale was taken at the position of the substrate valence-band maximum E_v , as estimated from a linear extrapolation of the leading valence-band edge. The topmost EDC (20-Å coverage) is representative of the bulk amorphous Ge valence-band emission.

crystalline semiconductors. The general trend, as observed by photoemission spectroscopy, is a smearing of the DOS structure,¹⁸ for the valence band of amorphous Ge (and similarly for amorphous Si and C), this results mainly in a broadening of the double structure occurring some 7–10 eV below the top of the valence-band maximum of crystalline Ge (Refs. 19 and 20) and associated with the six-membered rings in the diamond structure.²⁰ In addition, it is difficult to define unequivocally a band gap in the amorphous material, because of the existence of states in the gap that above a characteristic energy are increasingly delocalized in r space.¹⁸ Finally, photoemission measurements have shown that the electron density of states of amorphous Ge depends on the growth conditions, such as the substrate temperature²¹ and the angle between the source and the sample normal.²² Therefore, the magnitude of the band gap is not a well-defined physical constant. From a phenomenological point of view, photoelectron spectroscopy allows one to locate a valence-band edge,¹² but determination of the corresponding band-gap discontinuity and conduction-band offset remains difficult. In what follows we will discuss the systematics of the valence band offsets in Ge-Cd_{1-x}Mn_xTe interfaces by using the photoemission-determined phenomenological position of the valence-band maximum.

The Ge coverage range in Fig. 1 was selected to emphasize emission from both substrate and overlayer features. At higher coverages the valence-band emission converges rapidly to a bulklike amorphous Ge emission. This is illustrated by the topmost EDC in Fig. 1, obtained upon deposition of 20 Å of Ge on Cd_{0.40}Mn_{0.60}Te and representative of elemental Ge.^{12,23}

The valence-band emission from CdTe(110) (the bottom-most EDC) reflects the major Te p -derived density-of-states feature in the 0–3-eV binding-energy range, and the smaller DOS feature with mixed Cd s -Te p character in the 3–5-eV range. Upon Ge deposition, Ge-related states give rise to a shoulder on the low-binding-energy side of the main DOS feature. By $\theta=5$ Å, a new Ge-derived leading valence-band edge is clearly visible below the original CdTe valence-band edge. Analogous results are shown in the midsection of Fig. 1 for Ge-Cd_{0.65}Mn_{0.35}Te(110). The spectrum for the ternary semimagnetic substrate prior to Ge deposition shows the emergence of a new emission feature located some 3.5 eV below E_v relative to CdTe.^{15,24,25} This structure becomes the dominant valence-band feature in Cd_{0.40}Mn_{0.60}Te and is primarily due to the $3d$ emission from substitutional Mn atoms in the spin-polarized d^5sp configuration.^{15,17} All of the spectra for $\theta=5$ Å in Fig. 1, irrespective of the substrate, exhibit a second Ge-induced valence-band edge below the original substrate DOS.

The qualitative trends in Fig. 1 suggest that the valence-band emission from the interface is, to a first approximation, simply a superposition of substrate-related and overlayer-related valence-band spectra. The exponential attenuation observed for all substrate core features as a function of Ge coverage (not shown) also argues against interface reactions and the formation of new mixed phases. We therefore attempted to fit the experi-

mental interface spectra in Fig. 1 to a superposition of substrate and elemental Ge emission. The results are shown in Fig. 2 for the three interfaces at a Ge coverage of 5 Å. EDC's prior to Ge deposition (dashed line) were selected for each interface to represent the substrate emission. EDC's at Ge coverages $\theta > 20$ Å were selected to represent the bulk Ge emission (dotted line). The experimental data in the region of the leading valence-band edge (solid circle) were fitted to a superposition of substrate and overlayer spectra. A nonlinear least-squares fit, implementing a modified Levenberg-Marquardt algorithm,²⁶ was performed as a function of two parameters, namely, the relative amplitude and energy offset of substrate and overlayer EDC's. The result of the best fit is

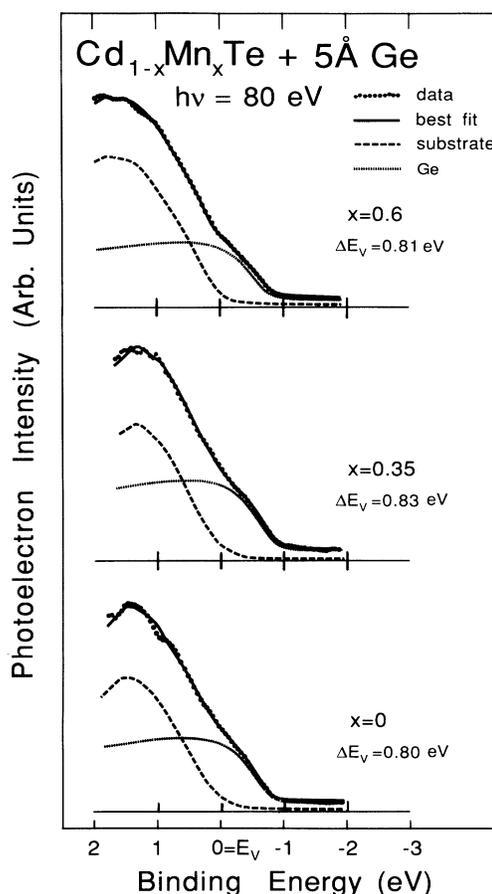


FIG. 2. Fit of selected experimental interface spectra from Fig. 1 (solid circles) in terms of a superposition of Cd_{1-x}Mn_xTe (dashed line) and elemental Ge (dotted line) valence-band spectra. A nonlinear least-squares fit was performed as a function of the relative amplitude and energy offset of substrate and overlayer EDC's. The result of the best fit is shown by the solid line superimposed on the experimental data for each interface. The resulting offset between the linearly extrapolated values of the valence-band maxima for substrate and overlayer spectra was found to be 0.80 eV for Ge-CdTe, 0.83 eV for Ge-Cd_{0.65}Mn_{0.35}Te, and 0.81 eV for Ge-Cd_{0.40}Mn_{0.60}Te. The uncertainty of the systematic variation of the offset in the series is 0.03 eV; on each individual value it is 0.07 eV.

also shown in Fig. 2 as the solid line superimposed on the data.

The best fits in Fig. 2 were obtained for similar values of the relative amplitude and shift. In particular, the offset between the linearly extrapolated values of E_v for substrate and overlayer spectra was found to be 0.80 eV for Ge-CdTe, 0.83 eV for Ge-Cd_{0.65}Mn_{0.35}Te, and 0.81 eV for Ge-Cd_{0.40}Mn_{0.60}Te. The reliability of the results is demonstrated by the consistent value of the offset obtained for each sample at different Ge coverages.²⁷ The reliability of the procedure is also supported by the values of the Ge-substrate relative intensity obtained from the fit, which closely matched (within $\pm 5\%$) the values expected from the observed Ge 3d–Cd 4d and Ge 3d–Te 4d integrated core intensity ratios (not shown).

The experimental uncertainty of the valence-band offsets determined through the above procedure has two components. First, there is the uncertainty deriving from the fitting procedure, which is of the order of the smallest variation in parameter space which gives comparable total least-squares differences. This was estimated at ± 0.02 eV, and affects the *systematic variation* of the valence-band offset in the Ge-CdTe, Ge-Cd_{0.65}Mn_{0.35}Te, and Ge-Cd_{0.40}Mn_{0.60}Te series. The measured valence-band offset is therefore quantitatively consistent in the series within experimental uncertainty. In addition, there is a substantial experimental uncertainty which derives from the determination of the position of E_v through a linear extrapolation of the leading valence-band edge of substrate and overlayer spectra. We estimate the corresponding combined uncertainty at ± 0.07 eV (Ref. 16). Such a higher uncertainty affects the numerical value of each single offset, but does not affect the variation of the offset in the series, because of the cancellation of possible systematic errors due to the linear-extrapolation method.

Since the procedure explored in Fig. 2 is new, we elected to compare its results with those of a more conventional method to evaluate band offsets. Conventional photoemission determinations of the valence-band offset would rely on the measured position of a characteristic substrate core level $E_{cl}(\text{CdTe})$ relative to the valence-band maximum E_v prior to Ge deposition, the position of a Ge core level $E_{cl}(\text{Ge})$ relative to the valence-band maximum in thick overlayers, and the energy difference ΔE_{cl} of the Cd and Ge core levels at the interface obtained following deposition of thin overlayers onto the substrate:^{8,28,29}

$$\Delta E_v = [E_{cl}(\text{Ge}) - E_v(\text{Ge})] - [E_{cl}(\text{CdTe}) - E_v(\text{CdTe})] - \Delta E_{cl} \quad (1)$$

Since in this picture the core levels are used as markers of the position of the bulk electronic states and to monitor band bending, care must be taken to select core levels which are not modified by chemical bonding at the interface and reflect the bulk environment. In Fig. 3 we show representative EDC's for the Te 4d emission and the Ge 3d core emission (solid circles) from Ge-CdTe(110) at a photon energy of 57 eV as a function of Ge coverage. It

can be seen that while the Te 4d line shape remains unchanged in Fig. 3 and exhibits only a rigid shift of 0.13 eV (from $\theta=0$ to 5 Å) to higher kinetic energies (lower binding energies), the Ge 3d line shape changes dramatically with increasing coverage, suggesting that a portion of the Ge atoms is affected by the interface environment. The Cd 4d line shape (not shown) exhibits only minor changes in the same coverage range, with a rigid shift to lower binding energies consistent with that of the Te 4d cores. However, at higher coverages evidence of small amounts of segregated or alloyed Cd is found. We associate the rigid shift of the substrate core levels to a Ge-induced change in band bending, and elect to use the Te 4d core levels to evaluate ΔE_v through Eq. (1).

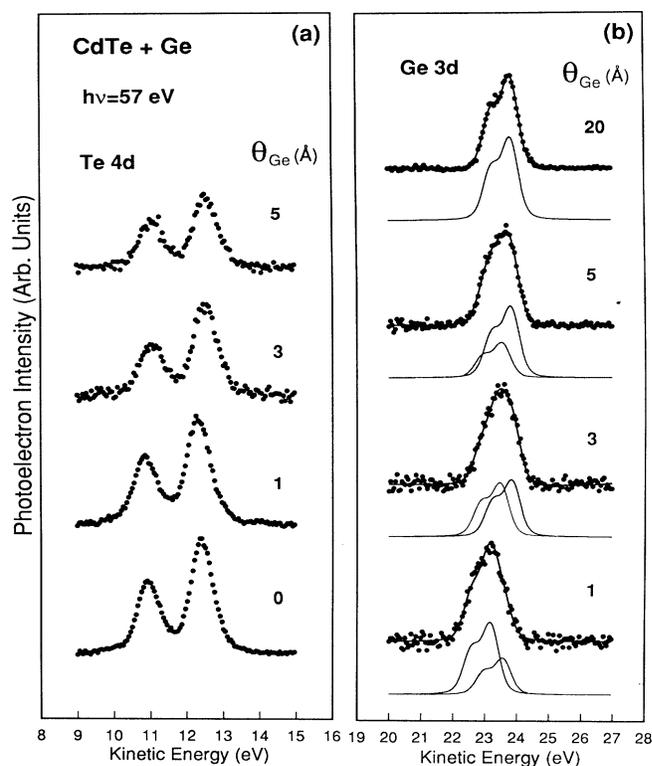


FIG. 3. EDC's for the Te 4d emission and the Ge 3d core emission (solid circles) from Ge-CdTe(110) at a photon energy of 57 eV as a function of Ge coverage. The Te 4d line shape remains unchanged, and exhibits only a band-bending-related rigid shift to higher kinetic energies (lower binding energies), in agreement with an analogous behavior of the Cd 4d core levels (not shown). The Ge 3d line shape changes with increasing coverage. We obtained good fits of the Ge 3d line shape (solid line) in terms of interface-related and bulk-related 3d doublets. The individual doublets resulting from the fit are also shown, shifted downward for clarity. From the coverage-dependent core-level position and the initial ($\theta=0$) and final positions ($\theta=20$ Å) of the valence-band maxima, we determined a valence-band offset of 0.81 ± 0.07 eV for Ge-CdTe(110). With an analogous procedure, we obtained offsets of 0.85 ± 0.07 eV for Ge-Cd_{0.65}Mn_{0.35}Te(110), and 0.85 ± 0.07 eV for Ge-Cd_{0.40}Mn_{0.60}Te(110).

A coverage-dependent change in the Ge $3d$ line shape has been observed during Ge deposition on III-V semiconductors.³⁰ A deconvolution of the Ge $3d$ core emission in terms of interface-related and bulk-related contributions proved necessary to obtain reliable Ge-III-V valence-band offsets.²⁹ Along the same lines, we obtained good fits of the overall Ge $3d$ line shape in terms of two spin-orbit split $3d$ doublets. Each doublet comprised Gaussian-convoluted Lorentzian functions. Position, intensity, branching ratio, and spin-orbit splitting of each doublet, together with the Gaussian and Lorentzian width of each core level, were treated as fitting parameters and determined through a least-squares minimization.^{31,32} The result of the fit is shown in Fig. 3 by the solid line superimposed on the experimental points. The individual doublets resulting from the fit are also shown, shifted downward for clarity.

At a Ge coverage of 1 Å, the dominant contribution to the Ge $3d$ emission comes from Ge atoms directly bound to the CdTe surface. A second, smaller Ge $3d$ doublet shifted by 0.36 eV to lower binding energies reflects the development of the bulk Ge band structure and becomes dominant at coverages $\theta > 3$ Å. With increasing Ge coverage, the two Ge $3d$ doublets shift rigidly to lower binding energy by 0.29 eV (from $\theta = 1$ to 20 Å), while maintaining a constant separation. We associate the rigid shift of Te $4d$, Cd $4d$, and Ge $3d$ features to a Ge-induced band-bending variation. We used the position of the bulk-related Ge $3d$ doublet in Fig. 3 to determine the core-level separation ΔE_{cl} in Eq. (1). With this procedure we calculated $\Delta E_v = 0.81 \pm 0.07$ eV for Ge-CdTe(110).

Results analogous to those depicted in Fig. 3 were obtained for Ge-Cd_{0.65}Mn_{0.35}Te and Ge-Cd_{0.40}Mn_{0.60}Te interfaces. Through a line-shape analysis of the Ge $3d$ line shape, we obtained $\Delta E_v = 0.85 \pm 0.07$ eV for Ge-Cd_{0.65}Mn_{0.35}Te(110), and $\Delta E_v = 0.85 \pm 0.07$ eV for Ge-Cd_{0.40}Mn_{0.60}Te(110). The two methods to determine the valence-band offsets yield, therefore, quite similar results, with a maximum discrepancy of 0.04 eV for Ge-Cd_{0.40}Mn_{0.60}Te(110). There is good agreement between the value of the offset obtained here for Ge-CdTe (0.81 ± 0.07 eV) and that reported earlier by Katnani and Margaritondo¹² (0.85 ± 0.10 eV).

Any determination of ΔE_v through Eq. (1) may in principle require corrections when residual strains are present in the overlayer. Tersoff and Van de Walle pointed out³³ that the effect of strain on the position of the core levels relative to the valence-band maximum should be carefully evaluated. The position of the core levels in the overlayer will change due to hydrostatic and uniaxial effects. The separation between the core levels and the centroid of the valence bands at Γ in the Brillouin zone is only influenced by hydrostatic strain. Conversely, uniaxial strain removes the valence-band degeneracy at Γ and modifies the position of the spin-split band, but does not shift the centroid.³⁴ The resulting required correction to the core position might be quite large. For example, Schwartz *et al.*³⁴ estimated a strain-related correction between 0.39 and 0.52 eV for Si-Ge(100) (4.0% in-plane strain), and we obtained³⁵ corrections of 0.44 and 0.45 eV

for Si-GaAs(100) and Si-AlAs(100), respectively (4.1% and 4.2% in-plane strain), based on an extrapolation of the results of Yu *et al.*³⁶

The method of valence-band-offset determination illustrated in Fig. 2 is, instead, far less affected by possible residual strains in the overlayer.³⁷ For the Ge-Cd_{1-x}Mn_xTe interface series examined, we obtained consistent results with the two methods, and this supports the presence of complete strain relaxation in the Ge overlayer as a result of the amorphous nature of the overlayer.¹² We emphasize that the large lattice mismatch between Ge and Cd_{1-x}Mn_xTe (> 14%) also promotes complete strain relaxation at the lowest coverages explored, in analogy to what has been found for CdTe(100)-GaAs(100).^{13,14}

The existence of a common value of the valence-band offset for the Ge-Cd_{1-x}Mn_xTe heterojunctions examined is especially interesting, since the band-gap energy difference ΔE_g varies widely in the series, because of the increase of the band gap of Cd_{1-x}Mn_xTe with x . The band gap of the alloy is 1.47, 1.93, and 2.13 eV for the three compositions ($x = 0, 0.35$, and 0.60) examined. As a consequence, the Ge-Cd_{1-x}Mn_xTe systems must exhibit large variations in the valence-band percentile contribution to the band-gap difference, a behavior that is relatively uncommon in semiconductor heterostructures.⁸

The observed systematics of the band offset in Ge-Cd_{1-x}Mn_xTe can be used to infer the behavior of the band offset in the CdTe-Cd_{1-x}Mn_xTe system. Using the transitivity rule of heterojunction behavior, the CdTe-Cd_{1-x}Mn_xTe band offset can be inferred from the variation of the Ge-Cd_{1-x}Mn_xTe band offset. The transitivity rule states that, given two semiconductors A and B and a third semiconductor C , the valence-band offset satisfies the relation

$$\Delta E_v(A, B) = \Delta E_v(A, C) - \Delta E_v(B, C) . \quad (2)$$

This transitivity has been experimentally verified for a number of semiconductors, within an accuracy of 0.1–0.15 eV.¹¹ If we use Eq. (2) to infer the CdTe-Cd_{1-x}Mn_xTe band offsets from the Ge-Cd_{1-x}Mn_xTe experimental results, we find $\Delta E_v(\text{CdTe}, \text{Cd}_{0.65}\text{Mn}_{0.35}\text{Te}) = \Delta E_v(\text{CdTe}, \text{Ge}) - \Delta E_v(\text{Ge}, \text{Cd}_{0.65}\text{Mn}_{0.35}\text{Te}) = 0.03$ eV in modulus, and, similarly,

$$\Delta E_v(\text{CdTe}, \text{Cd}_{0.40}\text{Mn}_{0.60}\text{Te}) = 0.01 \text{ eV} .$$

This suggests that, unlike most of the binary-ternary alloy heterojunctions studied to date, this system may follow closely the common anion rule of heterojunction behavior.⁸ We can derive an upper limit for the valence-band contribution to the band-gap difference in CdTe-Cd_{1-x}Mn_xTe as

$$0.03 / (1.93 - 1.47) = 6.5\% .$$

Such an estimate is in good agreement with those proposed by Chang *et al.*⁶ and Nurmiikko⁷ and somewhat at variance with that proposed by Deleporte *et al.*⁵

CONCLUSIONS

The band discontinuities in nonmagnetic-semimagnetic Ge-Cd_{1-x}Mn_xTe(110) semiconductor heterojunctions involving amorphous relaxed overlayers were determined by means of high-resolution synchrotron-radiation photoemission spectroscopy for different values of the Mn concentration x . The two different analysis methods employed point both to a valence-band offset largely independent of semimagnetic composition and band gap in the series. Consequently, because of the 0.66-eV variation in the Cd_{1-x}Mn_xTe band gap with increasing x from 0 to 0.6, the valence- and conduction-band contributions to the band-gap difference ΔE_g for Ge-Cd_{1-x}Mn_xTe vary considerably with x .

The observed independence of the Ge-Cd_{1-x}Mn_xTe valence-band offset on x suggests the CdTe-Cd_{1-x}Mn_xTe heterojunctions may follow the common anion rule of heterojunction behavior. This is somewhat surprising, since the rule does not appear to work for other common

anion heterojunctions with good lattice matching, such as GaAs-AlAs and HgTe-CdTe. Based on our results, we estimated an upper limit of 6.5% of the band-gap difference for the valence-band offset in CdTe-Cd_{1-x}Mn_xTe heterojunctions.

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