Resonant photoemission from $Cd_{1-x}Mn_xSe$: A probe of Mn 3*d* character and hybridization

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The Mn 3*d* contribution to the electronic density of states was analyzed for the wide-band-gap material $Cd_{1-x}Mn_xSe$ for $0 \le x \le 0.20$. Resonant photoemission at the Mn 3*p*-3*d* transition energy shows a new Mn-derived density-of-states feature 3.4 ± 0.1 eV below the valence-band maximum. Core photoemission data indicate that the presence of Mn atoms in the lattice yields a relatively small perturbation to the stability of the Cd—Se bond.

I. INTRODUCTION

Ternary diluted magnetic semiconductors (DMS) are receiving increasing attention because of the interesting new phenomena that they bring into the domain of semicon-ductor physics.^{1,2} The compounds obtained by replacing cations in the II-VI compound semiconductor lattice with magnetic Mn ions exhibit new magnetotransport and magneto-optical properties because of the spin-spin exchange interaction between the localized Mn 3d magnetic moments and the band and impurity states.^{3,4} In the presence of an external magnetic field, for example, such a semiconductor may exhibit large g factors, giant negative magnetoresistance, and large values for the Faraday rotation.5-7 Furthermore, all of these materials have composition-dependent transport and optical properties such as the nonmagnetic ternary semiconductor compounds involving II-VI and III-V elements. Good-quality samples with single-phase, single-crystal characteristics are now available over a wide range of composition so that a number of devices have been proposed that exploit the properties of these materials.^{1,7} The magnetic phase transitions in $Cd_{1-x}Mn_xSe$ have also been investigated.⁸ The compound is known to be paramagnetic at high temperatures and exhibits a paramagnetic to spin-glass phase transition at lower temperatures. This phase transition is apparently a consequence of frustration in a fcc lattice when magnetic ions interact antiferromagnetically.

Much interest has focussed on the character of the Mn 3d contribution to the density of states (DOS), that is crucial for any model of the magnetic, magnetotransport and magneto-optical properties of these materials. However, theoretical calculations for randomly substituted compounds involving localized 3d orbitals are complicated, especially in the limit of high-concentration compounds for which the localized-itinerant double aspect of the 3d states is bound to emerge.⁹ Photoemission spectroscopy is

an ideal experimental tool to investigate the electronic structure of these semiconductors, and we have recently presented a systematic study of the electronic properties and bonding of the narrow-band-gap ternary diluted magnetic semiconductors $Hg_{1-x}Mn_xSe^{.10}$ For the intermediate-band-gap semiconductors $Cd_{1-x}Mn_xSe$ and $Cd_{1-x}Mn_x$ Te, photoemission studies have yielded some controversies about the character of the Mn 3*d* level in these materials.

Earlier work on sputter-cleaned $Cd_{0.40}Mn_{0.60}Te$ samples identified a Mn 3d-derived feature 6.8 eV below the valence band maximum.¹¹ However, more recent work by Webb et al.¹² on sputter-cleaned samples (0 < x < 0.70)showed a Mn-derived nondispersive emission feature 3.5 eV below the Fermi level E_F . The deeper feature reported earlier¹¹ was interpreted as a shake-up satellite of the main Mn 3d feature. The results of Refs. 11 and 12 are somewhat in contrast with the conclusions of Oelhafen et al.¹³ who reported angle-resolved photoemission measurements of $Cd_{1-x}Mn_xTe$ (x =0.0, 0.3, and 0.6) crystals cleaved *in situ*. These authors conclude that there is no evidence in their data of localized 3d levels reported earlier, and that strong hybridization of the Mn d level with p-like states yields a valence band in which there is no "energetically sharp" 3d level. In contrast, Orlowski et al.¹⁴ recently reported angle-resolved photoemission results for $Cd_{1-x}Mn_x$ Se (x = 0, 0.4) that indicate a main Mn 3d-derived DOS feature 3.35 eV below the valenceband edge plus some degree of p-d hybridization in the low-binding-energy valence states. The samples were single crystals cleaved in air and then cleaned by sputtering and anneal in situ.

We have addressed this controversial subject with an approach that has been proved successful for $Hg_{1-x}Mn_xSe^{10}$ We used single crystals cleaved *in situ* to avoid preferential sputtering and segregation effects that may take place in semiconductor compounds upon

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sputtering and annealing.¹⁵ In addition, angle-integrated synchrotron radiation photoemission has been used to sample the whole Brillouin zone at vacuum-ultraviolet (vuv) and soft-x-ray energies. Furthermore, photoemission at the Mn 3p-3d resonance has been used to probe the elemental character and hybridization of the valence states. Our results indicate that a Mn-derived density of states feature is present 3.4 eV below the valence band maximum, that the corresponding electronic states have pure Mn 3d orbital character, and that there is no evidence of strong d-p hybridization. Analysis of the core binding energies in the compound suggests that the presence of Mn ions in the lattice perturbs only weakly the Cd-Se bond. The systematics of the Mn bonding for $Hg_{1-x}Mn_xSe$ and $Cd_{1-x}Mn_xSe$ indicate that important cation-dependent variation of the 3d ionization energy may occur in II-VI compound semiconductor series.

II. EXPERIMENTAL CONSIDERATIONS

Bulk single crystals of $Cd_{1-x}Mn_xSe$ were prepared through a modified Bridgmann method.¹⁶ The crystal structure is known to be a hexagonal wurtzite structure for x < 0.5.¹⁷ X-ray microprobe measurements versus calibrated standards on specimens obtained from sections of the boule in very close proximity to the samples used in this study revealed a Mn concentration of $x = 0.21 \pm 0.01$.¹⁸ This result should be compared with the nominal Mn concentration of 0.20 anticipated from the premixed weights used in the growth of this particular sample. As grown $Cd_{1-x}Mn_x$ Se crystals are expected to be n type, similar to what is found for CdSe, but this was not independently substantiated for the crystals used here. The experimental samples used in this study were obtained from crystals grown for Raman studies¹⁹ and, as a consequence, were lightly doped in the melt with $\sim 10^{17}$ Ga atoms/cm³ (for CdSe) and $\sim 10^{16}$ In atoms/cm³ (for $Cd_{1-x}Mn_xSe$).

The experiments were performed at the Synchrotron Radiation Center of the University of Wisconsin-Madison, with a "grasshopper" grazing-incidence monochromator in the photon energy range $40 \le h\nu \le 140$ eV. Radiation from a high-intensity tungsten lamp was focused on the sample surface through a quartz viewport to eliminate charging. Clean surfaces were obtained by fracturing the samples inside the photoelectron spectrometer which was operating at a pressure less than 1×10^{-10} Torr. All measurements were performed at room temperature. Energy analysis of the photoelectrons was performed with a double-pass cylindrical mirror analyzer, and the overall resolution (monochromator plus analyzer) ranged from 0.5 to 0.7 eV for valence studies at $h\nu < 110$ eV, 1.0–1.9 eV for valence-band results at hv=110 eV, and 1.0 eV for the Se 3d core level at hv = 140 eV. The results of this study are shown in Figs. 1 and 5 as photoelectron energy distribution curves (EDC's). The zero of the energy scale corresponds to the valence band maximum E_v as obtained through a linear extrapolation of the leading valence-band edge.²⁰

RESULTS

Representative EDC's for the valence band emission of CdSe and $Cd_{1-x}Mn_xSe$ (x = 0.21) are shown, respectively, in Figs. 1 and 2. Comparison with DOS calculations,^{13,21} allow us to identify in Fig. 1 a first Se *p*-derived DOS feature extending to about 3.5 eV below E_V , with an emission maximum at 1.2 ± 0.1 eV.²² A second hybrid metal s-Se *p* DOS feature is centered 4.5 eV below E_V . The Cd 4*d* core levels appear as a doublet barely resolved at hv=40 eV (with $4d_{5/2}$ component 9.7±0.1 eV below E_V) and unresolved at higher photo energies. The EDC's for Cd_{1-x}Mn_xSe in Fig. 2 are very similar to the one for CdSe at hv=40 eV, but show important differences at higher photon energies. Furthermore, the Cd 4*d* core levels appear shifted 0.22±0.10 eV to higher binding energy.

In Fig. 3 we compare details of the valence EDC's (after subtraction of the secondary background) for $Cd_{0.79}Mn_{0.21}Se$ (solid line) and CdSe (dashed line). The similarity of the spectra at $h\nu=40$ eV suggests a calcula-



FIG. 1. Valence-band emission for single crystals cleaved in situ. Binding energies are referred to the valence-band maximum E_V .



FIG. 2. Valence-band emission for $Cd_{0.79}Mn_{0.21}Se$ single crystals cleaved *in situ*.

tion of the difference curves to emphasize the spectral changes at higher photon energy. Such difference curves, obtained after normalization of the spectra to the main Se-derived valence feature are shown by a dot-dashed line in Fig. 3. While only a small difference is seen at $h\nu=40$ eV, spectra at $h\nu=70$, 90, and 110 eV emphasize the emergence of a new symmetric emission line centered some 3.4 eV below E_V .

A quantitative analysis of this feature is given in Fig. 4. In the topmost section a "raw" difference curve at $h_V=70$ eV shows the typical scattering of the experimental points before data processing. The binding energy E_B of the difference curve and its full width at half maximum (FWHM) are plotted as a function of photon energy in the midsection and bottom-most section, respectively, of Fig. 4. The data indicate that a well defined Mnderived symmetric line is present in all spectra 3.4 ± 0.1 eV below E_V . The data in Fig. 4 show that this feature is indeed a density of states feature. Its *intrinsic* FWHM can be calculated for Fig. 4 taking into account the experimental resolution, and is 0.4 ± 0.1 eV. The elemental and orbital character of the electron states corresponding to



FIG. 3. Detail of the valence-band emission for $Cd_{0.79}Mn_{0.1}Se$ (solid line) and CdSe (dashed line), after subtraction of the secondary background. The difference curve (dot-dashed line) emphasizes the Mn-derived emission in the 2–6 eV energy range.

this feature in our data can be determined by a study of the photon energy dependence of the photoemission cross section.

Mn 3*d* emission is expected first to be reduced (antiresonance) and then enhanced (resonance) when the photon energy is swept through the Mn 3p-3d transition energy. This effect, present both in atomic²³ and metallic Mn,²⁴ reflects the quantum-mechanical equivalence of different processes leading from the ground state to the same final state. One process is the direct excitation:

$$3p^63d^54s^2hv \rightarrow 3p^63d^44s^2\epsilon f$$
.

The other involves a 3p core excitation and a super-Coster-Kronig decay:

$$3p^63d^54s^2 + h\nu \rightarrow 3p^53d^64s^2 \rightarrow 3p^63d^44s^2\epsilon f$$
.

The interference of the two processes yields a characteristic Fano²⁵ line shape of the overall excitation cross section. In compounds, the strength of the resonant



FIG. 4. Top: difference curve at hv = 70 eV emphasizing the Mn-derived emission. No smoothing or data processing was performed. Center: binding energy E_B of the Mn-derived feature versus photon energy. Bottom: full width at half maximum (FWHM) as a function of photon energy. The Mn-derived 3*d* emission gives rise to a well-defined symmetric line centered 3.4 eV below E_V .

enhancement is related to the overlap of the p core hole and d valence states. If the d states become hybridized the overlap is reduced and the enhancement diminishes. Correspondingly, some resonant enhancement appears in the cross section of the extra-atomic states that gained dcharacter through hybridization.^{26,27} Resonant photoemission, therefore, can be used to probe the Mn 3d character and hybridization.

Direct emission from the Mn 3p core levels is visible in Fig. 5, where we show (a) the Se 3d emission and the Mn 3p emission before (b) and after (c) background subtraction for Cd_{0.79}Mn_{0.21}Se. The measured binding energy of 47.0 ± 0.1 eV is identical, within experimental uncertainty,



FIG. 5. Emission from the Se 3d core levels (a) and from the Mn 3p cores before (b) and after (c) background subtraction for Cd_{0.79}Mn_{0.21}Se at $h\nu = 130$ eV.



FIG. 6. Top: optical absorption coefficient of Mn metal from Ref. 29 in the energy range of the 3p-3d resonance. Bottom: partial photoionization cross section of the Mn 3d emission for Cd_{0.79}Mn_{0.21}Se (squares) and Hg_{0.85}Mn_{0.15}Se. The three-fold enhancement at resonance reflects the pure Mn 3d orbital character of the corresponding states.

to the one measured in Ref. 10 for Mn in $Hg_{1-x}Mn_xSe$ compounds.²⁸ We expect, therefore, an analogous resonant behavior for the Mn 3d level in $Cd_{1-x}Mn_xSe$, and this is indeed seen in Fig. 6. In the top section we show the optical absorption coefficient of Mn metal from Ref. 29. The sharp 3p-3d adsorption feature is consistent with a Fano resonance.²⁵ In the bottom-most section of Fig. 6 we plot the integrated intensity of the 3.4-eV DOS feature as a function of photon energy (squares), together with the analogous results for Mn in $Hg_{1-x}Mn_xSe$ (circles). The intensities have been normalized to the monochromator output and are directly proportional to the partial photoionization cross section of the electron states described in Fig. 4. The threefold enhancement observed for the 3.4-eV feature is analogous to the one observed in the top section of Fig. 6, demonstrates the Mn 3d elemental and orbital character of the corresponding electron states, and indicates that no major p-d hybridization takes place.

IV. CONCLUSIONS

The position of the Mn-induced spectral feature found in this study at 3.4 ± 0.1 eV below E_V is in agreement with the observation of Orlowski *et al.*,¹⁴ who report a similar feature at 3.35 eV below the valence-band edge in angular resolved photoemission spectra at hv=21.1 eV in $Cd_{0.6}Mn_{0.4}Se$. Recent calculations of the DOS for $Cd_{1-x}Mn_xSe$ also show a similar Mn derived feature at this energy.³⁰

Based on the results reported in this work, it can be

concluded that the main aspect of Mn—Se bonding in $Cd_{1-x}Mn_x$ Se is the coupling of the metal s states with Se p states. The hybrid s-p orbitals involving Mn are expected to give a relatively small contribution to the DOS feature observed 4.5 eV below the valence-band maximum. This can be contrasted to a series of related measurements on $Hg_{1-x}Cd_x$ Te where distinct Hg6s—Tep and Cd5s—Tep bonding features were observed, respectively, 5.4 and 4.6 eV below E_V^{31} These two features were distinguishable because of a difference in the binding energies between the Hg 6s and the Cd 5s states. As Cd is replaced by lighter elements (Z < 57) like Mn, the relative binding energies of the p and s orbitals are not expected to change appreciably. It follows that only one s-p bonding DOS feature should appear at 4.5 eV below E_F , a result consistent with our experimental findings.

Our measurements also indicate that the formation of Mn—Se chemical bond seems to have relatively little effect on the stability of the Cd—Se bond. If we compare the binding energy of the Cd 4*d* and Se 3*d* cores in CdSe and Cd_{0.79}Mn_{0.21}Se, we observe a 0.22 and a 0.1 eV increase, respectively, in binding energy upon going from the binary to the ternary semiconductor. The *relative* Cd-Se core binding energy difference decreases therefore of + 0.12 eV, a value only slightly larger of the experimental uncertainty (0.1 eV).

If such relative binding energy shifts can be used as an index of the metallization of the bonding through charge transfer as suggested by Spicer *et al.*³² for $Hg_{1-x}Cd_xTe$, one is lead to conclude that the introduction of Mn perturbed only very slightly the Cd—Se bond and, if anything, increased the stability of the bond in the compound. Therefore the inclusion of a relatively low electronegatively element such as Mn in these compounds produces an effect certainly small and possibly opposite to the one that could be expected on the basis of the model proposed in Ref. 32.

The binding energies of the Mn 3p and Mn 3d levels that are not directly involved in the chemical bond remain constant relative to the valence band maximum in the $Hg_{1-x}Mn_xSe-Cd_{1-x}Mn_xSe$ series.³³ This trend is not consistent with simplified models¹¹ and studies of $Zn_{1-x}Mn_xSe$ and $Cd_{1-x}Mn_xS$ compounds are now in

- ¹J. K. Furdyna, J. Appl. Phys. **53**, 7637 (1982), and J. Vac. Sci. Technol. **21**, 220 (1982).
- ²R. R. Galazka and J. Kossut, in Narrow Gap Semiconductors: Physics and Applications, No. 133 of Lecture Notes in Physics Series (Springer, Berlin, 1980).
- ³G. Bastard, C. Rigaux, Y. Guldner, J. Mycielski, and A. Mycielski, J. Phys. (Paris) **39**, 87 (1978); G. Bastard, C. Rigaux, and A. Mycielski, Phys. Status Solidi B **79**, 585 (1977).
- ⁴M. Jaczynski, J. Kossut, and R. R. Galazka, Phys. Status Solidi B 88, 73 (1978).
- ⁵T. Dietl, Solid State Sci. 24, 344 (1981).
- ⁶R. Reifenberger and D. A. Schwarzkopt, Phys. Rev. Lett. 50, 907 (1983).
- ⁷A. E. Turner, R. L. Gunshor, and S. Datta, Appl. Opt. 22, 3152 (1983); J. K. Furdyna, Proc. Int. Soc. Opt. Eng. 409, 43 (1983).

progress in order to further investigate the systematics of the binding energies of these Mn levels.

Finally, it should also be noted that the identification of a Mn 3d level at 3.4 eV below E_V in $Cd_{1-x}Mn_x$ Se supports the interpretation of recent photoluminescence data reported by Moriwaki, et al.³⁴ They have performed a study of Mn-induced transitions in $Cd_{1-x}Mn_x$ Se with $x \sim 0.45$. Significant features in both the absorption and emission were observed for hv near 2.4 eV and were interpreted in terms of intra-ion transitions. The placement in energy of the final state probed by their measurements is not a priori known, but can be inferred when the ground state of the Mn^{2+} ion has been established. In particular, the position of the Mn 3d states at 3.4 eV below the valence-band edge would indicate that the final states probed in Ref. 34 lie in the valence band continuum.³⁵

In summary, resonant photoemission studies of $Cd_{1-x}Mn_xSe$ compounds show well defined Mn 3d states and no evidence of strong d-p hybridization. This result points out the need for similar studies in $Cd_{1-x}Mn_xTe$, which remains the only ternary semimagnetic semiconductor for which extensive d-p hybridization has been reported.¹²

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⁸C. D. Amarasekara, R. R. Galazka, Y. Q. Yang, and P. H. Keeson, Phys. Rev. B 27, 2868 (1983).

- ⁹K. C. Haas and H. Ehrenreich, J. Vac. Sci. Technol. A 1, 1678 (1983).
- ¹⁰A. Franciosi, R. Reifenberger, and J. K. Furdyna, J. Sci. Technol. A 3, 124 (1985); A. Franciosi, C. Caprile, and R. Reifenberger, Phys. Rev. B 31, 8061 (1985).
- ¹¹B. A. Orlowski, Phys. Status Solidi B 95, K31 (1979).
- ¹²C. Webb, M. Kaminska, M. Lichtensteiger, and J. Lagowski, Solid State Commun. **40**, 609 (1981).
- ¹³P. Oelhafen, M. P. Vecchi, J. L. Freeouf, and V. L. Moruzzi, Solid State Commun. **50**, 749 (1984).
- ¹⁴B. A. Orlowski, K. Kopalko, and W. Chab, Solid State Commun. 50, 749 (1984).
- ¹⁵See, for example, Y. Chabal, J. E. Rowe, J. M. Poate, A. Franciosi, and J. H. Weaver, Phys. Rev. B 26, 2748 (1982), and

references therein.

- ¹⁶M. R. Lorenz, in *Physics and Chemistry of II-VI Compounds*, edited by M. Aven and J. S. Prener (North-Holland, New York, 1967), pp. 75–113; A. G. Fisher, in *Crystal Growth*, 2nd ed., edited by B. R. Pampline (Pergamon, New York, 1980), pp. 357–393.
- ¹⁷A. Pajaczkowska, Prog. Cryst. Growth Charact. 1, 289 (1978).
- ¹⁸Electron Microprobe Analysis, edited by S. J. B. Reed (Cambridge University Press, Cambridge, 1975), and Electron Probe Microanalysis, edited by A. J. Tousimis and L. Marton (Academic, New York, 1969).
- ¹⁹D. L. Peterson, Ph.D. thesis, Purdue University, 1984 (unpublished).
- ²⁰This method gives results in agreement, within experimental uncertainty, with transport data. For our *n*-type CdSe, for example, we find $E_V - E_F = 1.7 \pm 0.1$ eV, to be compared with an energy gap $E_G = 1.74 \pm 0.05$ eV. The position of the Fermi level E_F was obtained by evaporating 50-Å aluminum films *in* situ onto the cleaved surface and directly measuring the Fermi cutoff.
- ²¹N. J. Shevchik, J. Tejeda, M. Cardona, and D. W. Langer, Phys. Status Solidi B 59, 87 (1973).
- ²²This feature seems to disperse slightly to higher binding energy $(1.5\pm0.1 \text{ eV})$ with increasing photon energy. However, part of this effect could be due to the varying experimental resolution.
- ²³J. P. Connerade, M. W. D. Mansfield, and M. A. P. Martin, Proc. R. Soc. London Ser. A 350, 405 (1976).
- ²⁴L. C. Davis and L. A. Feldkamp, Solid State Commun. 19, 413 (1976); Phys. Rev. A 17, 2012 (1978).
- ²⁵U. Fano, Phys. Rev. 124, 1866 (1961).
- ²⁶A. Franciosi and J. H. Weaver, Phys. Rev. B 27, 3554 (1983);
 J. H. Weaver, A. Franciosi, and V. L. Moruzzi, *ibid.* 29, 3292 (1984).

- ²⁷A. Franciosi, J. H. Weaver, N. Martensson, and M. Croft, Phys. Rev. B 24, 3651 (1981); M. Croft, A. Franciosi, J. H. Weaver, and A. Jayaraman, *ibid.* 24, 544 (1981).
- ²⁸In Ref. 10 we gave a value of 47.6±0.15 eV for the Mn 3*p* binding energy relative to the Fermi level E_F . It was also $E_F E_V \sim 0.6 \pm 1$ eV, so that the binding energy relative to the valence-band maximum E_V is 47.0 eV.
- ²⁹B. Sonntag, R. Haensel, and C. Kunz, Solid State Commun. 7, 597 (1969).
- ³⁰B. Velicky and J. Masek, in Proceedings of the International Conference on Deep Level Impurities, Lund Conference, Budapest, 1983 (unpublished). See Ref. 14 for a plot of the theoretical calculations.
- ³¹J. A. Silberman, P. Morgen, I. Lindau, W. E. Spicer, and J. A. Wilson, J. Vac. Sci. Technol. 21, 142 (1982); W. E. Spicer, J. A. Silberman, J. Morgan, I. Lindau, J. A. Wilson, An-Ban Chen, and A. Sher, Phys. Rev. Lett. 49, 948 (1982).
- ³²W. E. Spicer, J. A. Silberman, I. Lindau, A. B. Chen, A. Sher, and J. A. Wilson, J. Vac. Sci. Technol. A 1, 1735 (1983).
- ³³In Ref. 10 the binding energies (E_B) were measured with respect to the Fermi level. The results where E_B (3d)=4.1eV, E_B (3p)=47.6 eV. Since $E_F-E_V\sim0.6$ eV, the binding energies referred to E_V , are respectively, 3.5 ± 0.1 eV and 47.0 ± 0.15 eV.
- ³⁴M. M. Moriwaki, R. Y. Tao, R. R. Galazka, W. M. Becker, and J. W. Richardson, Proceedings of the 16th International Conference on the Physics of Semiconductors [Physica 117&118B, 467 (1983)].
- ³⁵It should be realized that binding energies determined for localized states by photoemission techniques may, however, be influenced by different correlation effects than those appropriate for photoluminescence measurements. This is a consequence of the different final states that result for these two different experimental techniques.