Auger photoelectron coincidence studies of the intrinsic and extrinsic processes in the Ga $L_{23}M_{45}M_{45}$ Auger line of GaAs

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Auger photoelectron coincidence spectroscopy has been used to study the intrinsic and extrinsic satellite contributions to the Ga $L_{23}M_{45}M_{45}$ Auger line of GaAs. Data have been collected for the Ga $L_{23}M_{45}M_{45}$ Auger line in coincidence with the $2p_{3/2}$ and $2p_{1/2}$ photoelectron lines from GaAs. The Ga $2p_{3/2}$ photoelectron line has also been collected in coincidence with the satellite on the lower kinetic-energy side of the Ga $L_{23}M_{45}M_{45}$ Auger line. The relative contributions of the intrinsic loss processes is shown to be negligible, as expected, whereas the extrinsic loss function is shown to be a significant consideration when using these lines in quantitative analysis. No evidence is seen for a difference in the response of the Ga $L_{23}M_{45}M_{45}$ final-state terms to the presence of a $3d$ hole at the surface and at the bulk as has been reported in the literature for the As $M_{45}VV$ line.

INTRODUCTION

The low-energy tail of Auger and photoelectron lines has contributions from both intrinsic processes (those that effect the emission of the electron from the atom), and extrinsic loss processes (those that effect the electron as it makes its way out of the solid). In order to model the shape of such lines, a necessary part of quantitative analysis, it is essential to know the intrinsic shape of the main emission line. There are a number of effects that occur in the Auger spectra of the $3d$ metals which complicate the intrinsic emission and are reflected in the final line shape. The first of these is the change of the spectra from bandlike to atomiclike with increasing atomic number. In the $3d$ series the bandlike materials are those whose atomic number is less than 29, while the atomlike spectra are those heavier than this. This effect was explained by Cini[1] and Sawatzky,[2] independently, in 1977. The second effect that is apparent is that the L_2VV component of the $L_{23}VV$ spectrum increases in intensity relative to the L_3VV component with increasing atomic number. This was explained by Roberts, Weightman, and Johnson,[3] in terms of a Coster-Kronig (CK) transition that takes place between the L_2 and L_3 shells. In these effects, the shape of the Auger line is influenced by the width of the valence band,[4] the separation of the core levels,[4] and the position of the Fermi level.[5]

We have previously published Auger photoelectron coincidence spectroscopy (APECS) studies of the $L_{23}VV$ Auger spectra of a number of $3d$ transition metals, including Cu, Ni, and Co.[4,6] From these studies we have shown that as well as the intrinsic (or true) line shape and extrinsic inelastic loss contributions there is considerable intensity in the low-energy tail due to intrinsic processes. These three- and four-hole states have been shown by Martensson, Nyholm, and Johansson[7] and Whitfield *et al.*[8] to be due to initial state shake-up–shake-off processes and CK cascade processes. It was shown[6] how these processes must be considered when using Auger lines from the $3d$ transition-metal elements for quantitative analysis.

Ga having a $3d^{10}4s^24p^1$ electron configuration is classed as being outside the $3d$ transition series. For Ga the final-state hole-hole interaction energy (U_{eff}) is much greater than the valence-band width (Γ), that is $U_{\text{eff}}/\Gamma \gg 1$, and the $L_{23}M_{45}M_{45}$ spectrum has been shown to be atomiclike.[9] GaAs has a relatively intense and well-separated satellite in both the $L_{23}M_{45}M_{45}$ Auger and $2p_{3/2}$ photoelectron spectra at 16.3 eV below the main lines. Antonides, Janse, and Sawatzky[10] have shown that there is very little probability of CK processes occurring[10] in Ga and there appears to be no evidence of three- or four-hole states.[9] Antonides and colleagues[9] have fitted the Ga $L_{23}M_{45}M_{45}$ spectra with the five final-state terms ^1S, ^1G, ^3P, ^1D, and ^3F and the $L_3M_{45}M_{45}$ line shape is well described by the atomic terms. Little is known of the shake-up–shake-off processes in Ga but the analysis of Antonides, Janse, and Sawatzky[9] appears to show that they do not appear to be important in the $L_{23}M_{45}M_{45}$ Auger spectrum. Electron energy loss spectroscopy (EELS) (Refs. 11–13) and x-ray photon spectroscopy[14] (XPS)[14] spectra have shown GaAs to have a bulk plasmon loss at 16.3 eV below the main line, and depending on the energy of the initial primary electrons and the particular surface (i.e., crystal face and which reconstruction is present), the surface plasmon has been known to vary from 10.0 to 11.5 eV below the main line.[11–13] Ludeke and Koma[13] have shown that at 400-eV primary energy on a GaAs (111) face there is a surface plasmon loss at the theoretical energy predicted by theory ($\omega_s = \omega_b/\sqrt{2}$) of 11.5 eV.

Bartynski *et al.*[15] have used APECS to study the Ga and As $M_{45}VV$ Auger spectra of GaAs (110) using synchrotron radiation at $\hbar\omega = 90$ eV. Because of the energies involved their results are very surface sensitive. Their singles and coincidence spectra for the As $M_{45}VV$ line exhibited three main features, a large peak at 29 eV, a second smaller peak at 20 eV, and a third weak feature

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at 15 eV. The two lower-energy peaks were assigned[15] to part of the self-convoluted densities of states (DOS). After subtracting a smooth monotonic polynomial function for the background, their singles and coincidence data were scaled so that the low-kinetic-energy features in both coincidence and singles spectra had approximately the same intensity. They then found that the main peak (assigned to the *pp* part of the DOS) from the singles and coincidence spectra did not have the same intensity. They explain this apparent reduction in the *pp* component of the As Auger coincidence spectrum as being due to a difference in the response of the various angular momentum components of the As valence band to the presence of a 3*d* core hole at the surface and in the bulk. Good agreement was found between their coincidence Ga $M_{45}VV$ Auger spectrum and a self convolution of the *p*-DOS, in part because only the *pp* component was measured.

In this current work we present data for APECS studies of the relative contributions of intrinsic and extrinsic processes to the Ga $L_{23}M_{45}M_{45}$ Auger and $2p_{3/2}$ photoelectron line shapes. Although confirming the absence of complications due to intrinsic processes, the results show that care must still be taken when using the Ga $L_{23}M_{45}M_{45}$ Auger lines for quantitative analysis. The extrinsic loss features, which vary with inelastic mean free path (IMFP), are shown to make a significant contribution to the Auger lines. There also appears to be no evidence for a difference in the response of the Ga $L_{23}M_{45}M_{45}$ final-state terms to the presence of a 3*d* core hole at the surface and in the bulk.

EXPERIMENT

The apparatus used to make these measurements has been described previously.[16] Briefly it consists of two 127° cylindrical deflecting analyzers that have been constructed with a view to having very good timing resolution together with appropriate coincidence electronics. These are housed in a conventional UHV chamber with a base pressure of 2×10^{-10} Torr. Excitation was achieved using Mg $K\alpha$ radiation from a conventional, unmonochromated, x-ray tube with a resolution of 700 meV. The GaAs sample was a *p*-type single crystal ingot obtained from the University of Western Australia and cleaved along the (110) plane. It was initially cleaned by *in situ* cycles of ion bombardment and heating to $\sim350\,^{\circ}\mathrm{C}$ for three min until the O 1*s* photoelectron line was below detection. After this the sample was repeatedly ion bombarded with 1-keV Ar^+ ions and heat (to 350 °C) treated every 12 h. Auger peak height ratios (MVV Auger lines) were consistent with a near to stoichiometric surface. We expect that the surface may still be slightly Ga enriched, making the surface a little more Ga like. After 12 h of data collection no evidence of oxygen or carbon contamination was found.

In our coincidence experiment one analyzer was set on the maximum of the photoelectron peak while the other analyzer scanned the Auger line over the required energy range. The analyzers were operated in constant pass energy mode with a resolution of ≈2.6 eV. We collected spectra that showed the difference in time between electrons arriving in each analyzer for each setting of the scanning analyzer. These time-to-amplitude spectra were then analyzed by summing the counts in a time window that corresponded to the difference in time between electrons from the same event being detected in each analyzer. This gave the Auger coincidence spectrum. The error bars shown in the experimental data reflect the statistical error in the true count, (i.e., true-to-accidental rate) as well as the error in the background estimation. A more detailed description of the method for obtaining coincidence spectra from the accidental background has been described previously.[17]

The singles spectra were obtained by summing all points in the time-to-amplitude spectra collected at each energy setting, regardless of what the time interval was between the count in the Auger channel and the count in the photoelectron channel. Hence the same set of data produced both the coincidence data and the singles data free from any distortion due to instrumental changes. The spectrometer that was scanning was repeatedly swept through the energy range of interest a number of times during the data acquisition period in order to insure that any artifacts due to contamination were reduced. Photoelectron coincidence spectra could be collected in the same way by setting one analyzer on the maximum of the Auger peak and scanning the other analyzer over the energy range of the photoelectron spectrum. On average, each spectrum took four weeks to acquire.

RESULTS AND DISCUSSION

We have taken APECS measurements of the Ga $L_{23}M_{45}M_{45}$ Auger and $2p_{3/2}$ photoelectron lines in GaAs. The Ga $L_{23}M_{45}M_{45}$ Auger line in coincidence with the $2p_{3/2}$ and $2p_{1/2}$ photoelectrons for GaAs are shown in Figs. 1 and 2. Each of the coincidence spectra have been fitted with a model spectrum which is the sum of three Gaussians and this is shown as the dashed line while the solid line is the singles data obtained at the same time. The main, atomiclike component of each line (e.g., 1068 eV for $L_3M_{45}M_{45}$) was fitted with a single Gaussian as the analyzer resolution (≈2.6 eV) did not allow differentiation between the component atomic-term contributions. A good fit between the model and the experimental coincidence data was only achieved by fitting two Gaussians at multiples of 11.5 eV below the main peak and these values for the energy positions were fixed throughout the analysis. The peak intensities and full width at half maximum were then optimized using the Simplex algorithm, as used in the fitting of XPS line shapes by Thurgate and Erickson.[18] A good fit was determined on the basis of a point by point-least-squares comparison between the model curve and the coincidence data. A simple smoothly varying background function, to approximate the extrinsic loss function, has also been added to the sum of the component curves to give the total, fitted curve.

The singles Ga $L_{23}M_{45}M_{45}$ Auger spectra show two features for both the $L_3M_{45}M_{45}$ and $L_2M_{45}M_{45}$ components, the main emission and a satellite at ~16 eV

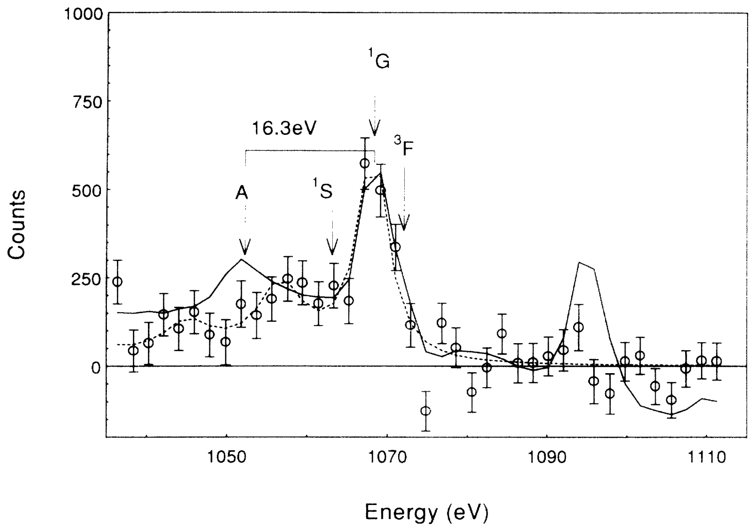

FIG. 1. $L_{23}M_{45}M_{45}$ Auger spectrum of Ga (in GaAs) in coincidence with the $2p_{3/2}$ photoelectron line. The coincidence spectrum has been fitted with a model spectrum which is the sum of three Gaussians, as described in the text, and this is shown as the dotted line, while the solid line is the singles data. The energy positions of each of the atomic term contributions to the main Ga DOS are marked as given by Antonides, Janse, and Sawatzky (Ref. 9). The line marked A shows the position of the fixed (Auger) analyzer when studying the nature of the satellite 16.3 eV below the mainline in the Ga $2p_{3/2}$ photoelectron spectrum as described in the text.

below the main peak. This latter peak has previously been assigned[11–14] to a bulk plasmon peak. Coincidence Auger spectra for both the $2p_{3/2}$ and $2p_{1/2}$ lines show a main emission followed by two or more smaller peaks at multiples of 11.5 eV below the main peak. The main Auger singles peak for both the $L_3M_{45}M_{45}$ and $L_2M_{45}M_{45}$ structures are well described by the main coincidence spectrum, especially on the low-kinetic-energy side (e.g., between 1068 and 1062 eV for the $L_3M_{45}M_{45}$) component where three- and four-hole satellites would be expected. This was not the case for previous studies[6] of Co, Ni, and Cu. It can be seen, however, by comparison with the singles data derived from the same data, that there are substantial differences between the singles and coincidence data in the region of the satellite at 16.3 eV below the main peaks. These differences are due to either an intrinsic feature or extrinsic loss feature that is included in the singles spectra, but is absent from the coincidence spectra. We were able to distinguish between these possibilities by the following experiments and analysis.

(i) The positions of the atomic terms in the Ga DOS, as given in the work of Antonides, Janse, and Sawatzky,[9] are marked in Figs. 1 and 2. As observed above there is good agreement between the singles and coincidence spectrum in the region of the main peak at 1068 eV for the $L_3M_{45}M_{45}$ Auger spectrum. Therefore it is clear that none of the two-hole DOS terms contribute to the peak seen in the coincidence spectrum at 11.5 eV below the main peak or the satellite seen at 16.3 eV below the main peak in the singles spectrum.

(ii) There is no component of the $L_{23}M_{45}M_{45}$ spectrum in coincidence with the $2p_{1/2}$ photoelectron line (Fig. 2) close to, but on the low-kinetic-energy side of, the $L_3M_{45}M_{45}$ peak where the three-hole CK state would be expected. This three-hole peak was clearly evident on all the Co, Ni, and Cu samples studied previously.[6] Therefore, as expected, there is no evidence of a CK process in Ga and the satellite cannot be due to any of the processes initiated by a CK process.

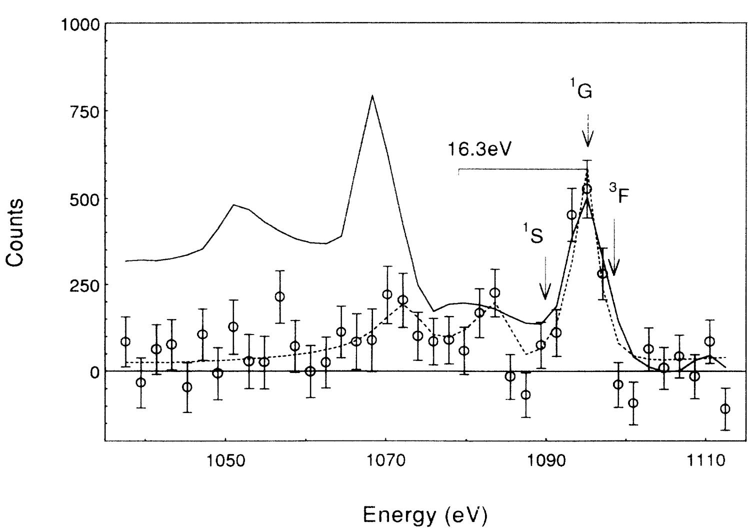

FIG. 2. $L_{23}M_{45}M_{45}$ Auger spectrum of Ga (in GaAs) in coincidence with the $2p_{1/2}$ photoelectron line. The coincidence spectrum has been fitted with a model spectrum which is the sum of three Gaussians, as described in the text, and this is shown as the dotted line, while the solid line is the singles data. The energy positions of each of the atomic term contributions to the main Ga DOS are marked as given by Antonides, Janse, and Sawatzky (Ref. 9).

(iii) By fixing the photoelectron analyzer on the satellite at 16.3 eV below the main peak in the $2p_{3/2}$ photoelectron line (shown as A in Fig. 3) and scanning the $L_3M_{45}M_{45}$ Auger line and corresponding satellite, no significant coincidence could be found. Haak[19] has performed a similar experiment for Ni, where a clear shake-up–shake-off satellite is known. He was able to show that by fixing one analyzer on the Ni photoelectron shake-up–shake-off satellite and scanning the Ni $L_{23}VV$ line that a clear coincidence peak was obtained close to, but on the low-kinetic-energy side of, the L_3VV peak where the three-hole state was known to be. The fact that no coincidence was obtained for the GaAs clearly suggests that the 16.3-eV satellite in the $2p_{3/2}$ photoelectron spectrum is not is a shake-up–shake-off satellite.

(iv) Measurements were then made by scanning the $2p_{3/2}$ photoelectron line in coincidence with the satellite on the low-energy side of the Ga $L_3M_{45}M_{45}$ Auger spectrum (marked as A in Fig. 1) and these are shown in Fig. 3. This spectrum is not significantly different from the $2p_{3/2}$ singles photoelectron line. The implication is that this Auger satellite has no preferred origin in the photoelectron spectrum, and so is an extrinsic loss feature and that it is not a shake-up–shake-off satellite similar to that seen in Ni.[19]

From this we can only conclude that the 16.3-eV satellite in the Auger spectrum is predominantly extrinsic in nature. The results confirm that the $L_{23}M_{45}M_{45}$ spectrum has few of the complicating affects that effect the shape of the $L_{23}VV$ spectra of the previously reported $3d$ materials due to intrinsic processes. We are unable to detect if there was any contribution to the low-energy tail from a final-state shake-up–shake-off event. Such an event implies the simultaneous emission of an electron with the Auger electron and so would not be distinguishable from an extrinsic event in the coincidence experiment.[6]

In contrast to the work of Bartynski *et al.*[15] for the As $M_{45}VV$ line the main atomiclike emission in the Ga $L_3M_{45}M_{45}$ and $L_2M_{45}M_{45}$ singles lines (1068 and 1095 eV, respectively) are in very good agreement with the corresponding $L_3M_{45}M_{45}$ and $L_2M_{45}M_{45}$ emissions in coincidence with the $2p_{3/2}$ and $2p_{1/2}$ core holes, respectively. There appears to be no evidence for a difference in the response of the Ga $L_{23}M_{45}M_{45}$ final-state terms to the presence of a $3d$ core hole at the surface and in the bulk. The only difference appears in the low-energy satellite at 16.3 eV below the main peak. As discussed above the differences seen between the features of the singles and coincidence spectra in the region of the satellites at 16.3 eV below the main emission can only be explained by differences in the extrinsic loss processes. In particular we attribute these differences to differences in the contribution of the surface and bulk plasmons.

Based on our coincidence results for GaAs discussed above, the work of Antonides, Janse, and Sawatzky[9] for the Ga Auger line and the EELS spectra of GaAs,[11–14] we assign the low-energy satellite at ≈ 16 eV below the main peak in both our Ga $L_2M_{45}M_{45}$ and $L_3M_{45}M_{45}$ singles lines to a combination of the surface and bulk plasmons and not part of the DOS. Differences between the singles and coincidence spectra for the $L_{23}M_{45}M_{45}$ spectrum in coincidence with the $2p_{3/2}$ and $2p_{1/2}$ photoelectron lines can be explained solely by the differences in IMFP for electrons of different energy. The singles spectrum is at an energy of ~ 1100 eV, which corresponds to an IMFP (Ref. 20) of 23.7 Å and therefore it will show largely bulk loss features and some contribution from surface loss features. The effective coincidence IMFP is given by[21]

$$\frac{1}{\lambda_{\text{eff}}} = \frac{1}{\lambda_A} + \frac{1}{\lambda_{\text{PE}}} , \tag{1}$$

where λ_{eff} is the effective IMFP, λ_A is the IMFP of the Auger electron, and λ_{PE} is the IMFP of the photoelectron. From this it can be seen that the coincidence line will have an IMFP close to that of the photoelectron line of 4.06 Å (Ref. 20) and therefore comes from much closer to the surface than the singles Auger line. The coincidence Auger line is therefore likely to be described predominantly by a surface loss function. In this case the plasmon contribution can be expected to remain con-

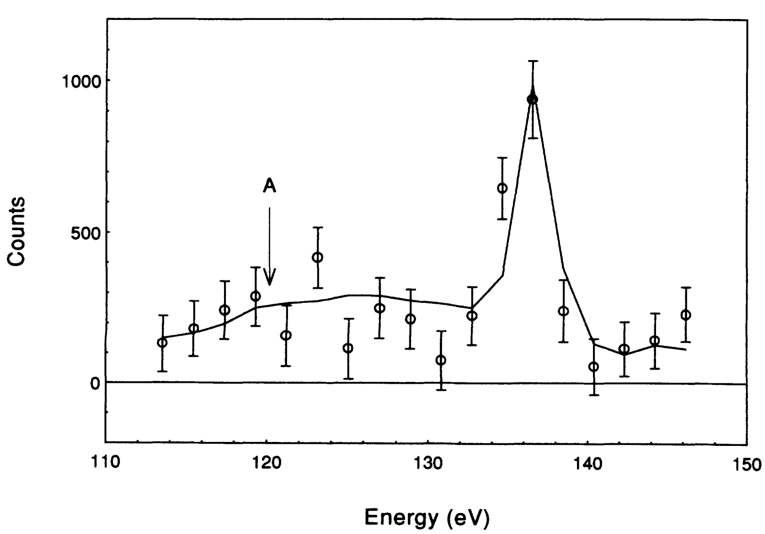

FIG. 3. Ga $2p_{3/2}$ photoelectron line in coincidence with the satellite 16.3 eV below the main line in the $L_3M_{45}M_{45}$ Auger spectrum. The solid line is the singles data. The line marked A is the position of the fixed (photoelectron) analyzer when studying the nature of the satellite 16.3 eV below the mainline in the Ga $L_{23}M_{45}M_{45}$ Auger spectrum as described in the text.

stant, while that of the bulk plasmon will decrease or disappear from the spectrum entirely. This difference in IMFP distance, 19.6 Å, for two energies differing by ~1000 eV is useful for showing the bulk and surface effects more clearly than conventional photoemission experiments. APECS has the advantage that this is achieved for the same surface from the same set of data at one time.

Figures 1 and 2 show exactly the result expected in light of the previous discussion. The singles Auger spectra have a large satellite at ~16.3 eV corresponding to the bulk plasmon, with a small shoulder at ~11.5 eV corresponding to the surface plasmon. On the other hand, the coincidence spectra have only multiples of peaks separated by 11.5 eV corresponding to the surface plasmon with only a small intensity, if any, at 16.3 eV corresponding to the bulk plasmon. Both coincidence spectra (Figs. 1 and 2) confirm that the high-energy shoulder on the plasmon satellite in the singles spectrum is due to the surface plasmon.

Similar results for the wide band, nearly-free-electron metal Al have been reported by Jensen *et al.*[22] Their Al $2p_{3/2}$ photoelectron line taken in coincidence with the main part of the Al $L_{23}VV$ Auger line showed that the bulk plasmon peak was noticeably attenuated compared to the corresponding singles spectrum. Their surface plasmon peak was not significantly attenuated in the coincidence spectrum compared to the singles because the relative probability of producing a surface loss is not affected by the enhanced surface sensitivity. This behavior was also evident when comparing their singles $L_{23}VV$ Auger spectrum with that of their $L_{23}VV$ Auger in coincidence with the $2p_{3/2}$ photoelectric line but it is not as clear due to significant differences in the background in this region.

Yubero *et al.*[23] have recently applied a proposed model for quantitative analysis of reflection energy-loss spectra to evaluate the dielectric loss function of Si and SiO_2 in the 4–100-eV energy range, and to determine inelastic scattering properties for these materials for low-energy electrons (500–10 000 eV). Their calculations of the effective inelastic scattering cross sections as a function of the path traveled by the electron for different primary energies clearly show how the surface effects are enhanced at low primary electron energies. Slow electrons (e.g., 500 eV) reach depths of a few nanometers, and correspondingly excite more efficiently the surface plasmons rather than bulk plasmons. More energetic electrons excite a larger number of bulk plasmons.

Although confirming the absence of complications due to intrinsic processes our coincidence results show that care must still be taken when using the Ga $L_{23}M_{45}M_{45}$ Auger lines for quantitative analysis. Extrinsic loss processes and, in particular, second-order bulk and surface plasmons from the $L_2M_{45}M_{45}$ line can be seen to make a significant contribution to the $L_3M_{45}M_{45}$ line that must be accounted for. The same is also true for the effect of the $2p_{3/2}$ photoelectron line on the $2p_{1/2}$ line. Figure 4 shows the singles spectrum for the $L_{23}M_{45}M_{45}$ Auger spectrum together with both the $L_{23}M_{45}M_{45}$ in coincidence with the $2p_{3/2}$ and the $L_{23}M_{45}M_{45}$, with the $2p_{1/2}$ coincidence spectra overlaid for comparison. It can be seen from this figure that the second-order surface plasmon loss peak from the $L_2M_{45}M_{45}$ line still has significant intensity and appears on the high-kinetic-energy side (1068 to 1072 eV) of the $L_3M_{45}M_{45}$ peak. This is one reason why the main component of the $L_3M_{45}M_{45}$ peak in coincidence with the $2p_{3/2}$ is less intense than the singles peak on the high-kinetic-energy side. From the results of Fig. 4 the second-order surface plasmon is of the order of 15% of the $L_3M_{45}M_{45}$ peak and will therefore significantly effect the quantitative results obtained using this peak if not correctly accounted for by an appropriate and correct background subtraction.

The plasmon positions (surface and bulk) have been shown[14] in EELS measurements to change in position and intensity for the other Ga-based III-V materials such as GaP and GaSb as well as the intrinsic semiconductors such as Ge. This will change the relative contribution of the plasmon peaks to the intensity of the $L_3M_{45}M_{45}$

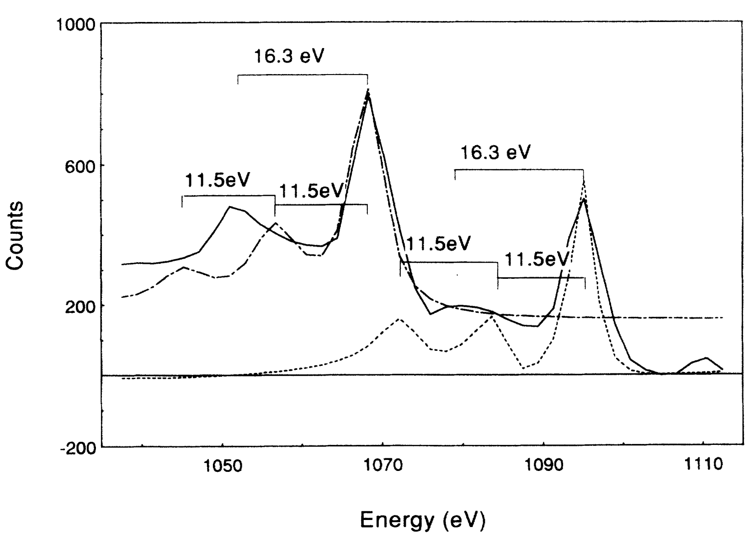

FIG. 4. $L_{23}M_{45}M_{45}$ Auger line of Ga (in GaAs) in coincidence with the $2p_{3/2}$ (dashed and dotted line) and $2p_{1/2}$ (dashed line) photoelectron lines. The solid line is the singles spectrum from the $2p_{3/2}$ data and the coincidence lines are the model "fits" to the coincidence data as described in the text. The fitted line from the $2p_{1/2}$ coincidence data has been scaled to the same height as the L_2 peak of the singles spectrum. The expected positions of the first- and second-order bulk (16.3 eV) and surface (11.5 eV) plasmons below the main $L_3M_{45}M_{45}$ and $L_2M_{45}M_{45}$ lines are marked.

Auger and $2p_{1/2}$ photoelectron lines in a way that is not evident from the singles spectra themselves. From these studies it is evident that the area under both the Ga $L_2M_{45}M_{45}$ and $L_3M_{45}M_{45}$ lines must be taken when using the $L_{23}M_{45}M_{45}$ Auger lines for quantitative analysis and the area under the low-energy tail must be accounted for for some distance down on the low-kinetic-energy side. If using either an experimental EELS measurement,[11–13] or a calculated theoretical loss function,[20,23] to model the background in semiconductor compounds (including Ga), the energy of the primary emission line must be taken into account. The coincidence data and the work of Yubero *et al.*[23] clearly show that the loss function can change quite significantly with a change in IMFP.

CONCLUSIONS

APECS experiments have confirmed the relative contributions of the intrinsic loss processes to be negligible in the Ga $L_{23}M_{45}M_{45}$ line of GaAs. The main emission is shown to be well fitted by the atomic terms with no evidence of three- or four-hole states or CK transitions. No evidence is seen for a difference in the response of the Ga $L_{23}M_{45}M_{45}$ final-state terms to the presence of a $3d$ hole at the surface and in the bulk. Differences between the singles and coincidence spectra can be explained purely in terms of differences in the extrinsic loss function due to different inelastic mean free paths. The satellite peak in the singles spectrum at 16.3 eV is shown to be predominantly extrinsic in nature and is made up mainly of contributions from the bulk plasmon with some surface plasmon contribution. On the other hand, the coincidence Auger spectra, due to their lower inelastic mean free-path were found to predominantly contain contributions from the surface plasmons. The extrinsic loss function was shown to significantly effect the intensity under the Ga $L_3M_{45}M_{45}$ Auger and $2p_{1/2}$ photoelectron lines and that it changes with IMFP. In particular, the second-order plasmon from the $L_2M_{45}M_{45}$ Auger line lies under, and contributes significantly to, the $L_3M_{45}M_{45}$ line. The ratio of the surface to bulk plasmon changes with IMFP. An energy-dependent loss function that correctly accounts for the IMFP of the main emission must be used for background subtraction. Both the $L_2M_{45}M_{45}$ and $L_3M_{45}M_{45}$ lines must be taken when using the $L_{23}M_{45}M_{45}$ Auger lines for quantitative analysis and the area under the low-energy tail must be accounted for some distance down on the low-energy side.

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