PLASMON SATELLITES OF X-RAY EXCITED AUGER ELECTRON SPECTRA OF POLAR SEMICONDUCTORS

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Abstract : Plasmon satellites in solids theory has been used to calculate the energy separation and relative intensity of low and high energy Plasmon satellites of $L_2M_{4.5}M_{4.5}$ and $L_3M_{4.5}$ $M_{4.5}$ main X-ray excited Auger electron spectral line of polar semiconductors. The calculated values of energy separation and relative intensities are studied with theoretical methods which match the values of Kleiman et al.

IndexTerms - Auger Electron Spectra, Plasmon satellites, Polar Semiconductors.

INTRODUCTION

Ferrell [1],Noziers and Pines [2], Houston and Park [3], and Mahan[4] have pointed out that interpretation of X-rays emission, absorption and Auger spectra etc. must take into account the contribution of the interaction between the suddenly created or annihilated core holes to the collective modes of the conduction electrons. This interaction produces a structure which is displaced from the principal structure by an energy $\hbar\omega_p$ (known as Plasmon energy). It has also been pointed out by Brouers[5] that Plasmon excitation during x-ray emission process is the collective counterpart of the usual Auger effect, in which the primary x-ray transition excites a secondary electron.

In case of x-ray absorption process, the Plasmon excitation will give rise to the fine structure in the absorption spectra[6] while in the case of x-ray emission or Auger spectra, this process will rise to low and high energy Plasmon satellites[7,8]. Low energy x-ray Plasmon satellites are obtained when a valence electron, before filling a core vacancy in the inner shell, excites a Plasmon. The energy of the emitted x-ray photon will be less by an amount $\hbar\omega_p$ (ω_p is the Plasmon frequency), which has been used up in exciting the Plasmon. It has also been pointed out by Shmidt [9] that Plasmon can transfer its energy, on decay, to a conduction electron which subsequently fills the core vacancy, with the emission of x-ray photon. This x-ray emission line, due to Plasmon gain, will have higher energy by an amount $\hbar\omega_p$ than the parent line. This structure can be observed on the higher energy side of the main x-ray emission line and is known as high energy Plasmon satellites. Such satellites have been extensively studied both experimentally and theoretically by several workers [7-10].

Kleiman et.al.[11] have observed several structures along with Plasmon loss structures on the high and low energy sides of $L_{2.3}$ $M_{4.5}$ $M_{4.5}$, L_2 $M_{4.5}$ $M_{4.5}$ and L3M4.5 M4.5 Auger spectral lines of In, Sn and Sb. They found above structures by properly choosing the experimental energy ranges and subtracting the background energy with excluded the Plasmon loss structures. But we know [1-5] that Plasmon loss structures cannot be avoided from any characteristics x-ray or Auger spectra when the excitation energy of the spectra is of the order of keV. Thus, in spite of Kleiman et al [11], Plasmon loss structures can be avoided by subtracting the background whose intensities are very weak. Therefore, it was thought of great interest to explore the possibility, whether Plasmon loss structures are satellites whose intensities are not weak, are present along with multiple structures.

Low and high energy satellite peaks in 4d transition metal (Zr, Nb , Mo, Ru, Rh, Pd, Ag and Cd) have been calculated [17-19]. The Plasmon theory has been used to explain energy satellite and relative intensity of high energy X-ray satellites $L_{\alpha 3}$, $L_{\alpha 4}$ & $L_{\alpha 5}$ with respect of $L_{\alpha 1}$ parent line in 4d Transition metal and estimated values are calculated [20].

If Plasmon loss structures or satellites are present in the spectra, it should be observed at an energy distance of $\Delta E = \hbar\omega_p$, 2 $\hbar\omega_p$ or $\hbar\omega_s$, $2\hbar\omega_s$ or its multiple (where $\hbar\omega_p$ is Plasmon energy and $\hbar\omega_s$ is surface Plasmon energy) from the main x-ray or Auger lines L_2 $M_{4.5}$ $M_{4.5}$ $L_3M_{4.5}$ $M_{4.5}$ and $L_{2.3}$ $M_{4.5}$ $M_{4.5}$

Theoretical Study

Plasmon and surface Plasmon energies of In, Sn and Sb can be calculated by using the formula given by Marton et. al.[12] as

$$\hbar\omega_p = 28.8(Z\sigma/W)^{1/2}\ \text{eV}$$
$$\text{And} \quad \hbar\omega_s = \hbar\omega_p/\sqrt{2} \qquad (1)$$

Where Z is the effective number of electrons taking part in Plasmon oscillations, σ is the specific gravity and W is the molecular weight.

The Plasmon and surface Plasmon energies of In, Sn and Sb are given in Table 1. The authors have also giventhe energy separation of those structures on the high and low energy side whose energy separation are equal to Plasmon or surface Plasmon energy.

From the table it appears that the energy separation of $^3F_2$ and $^3F_4$ peaks, under IC coupling of L_2 $M_{4.5}$ $M_{4.5}$ $L_3M_{4.5}M_{4.5}$ and ^3F peaks under LS coupling as given by Kleiman et al [11] are fairly close to Plasmon and double surface Plasmon energy respectively. For the low energy side, the energy separation of the first peak from the main $L_{2.3}$ $M_{4.5}$ $M_{4.5}$, L_2 $M_{4.5}$ $M_{4.5}$ and $L_3M_{4.5}M_{4.5}$ Auger emission lines has been estimated. This also agrees fairly well with the Plasmon energy.

Thus, in order to confirm whether $^3F_2$, $^3F_4$ and ^3F structures on the high energy side of L_2 $M_{4.5}$ $M_{4.5}$, $L_3M_{4.5}M_{4.5}$ and $L_{2.3}$ $M_{4.5}$ $M_{4.5}$ lines and the first peak on the low energy side are due to Plasmon satellite or not , one should calculate the relative intensity of these Plasmon satellites also.

Relative intensity of Plasmon Peaks

Langreth [13] and Chang and Langreth [14] have developed a general theory to explain the factors on which the relative intensity of Plasmon satellite depends. It is an intrinsic process. Bradshaw et al [15] have further divided the intrinsic process into two categories (i) when the number of slow electrons are conserved. The Plasmon satellites will be weak and (ii) when the numbers of slow electrons are not conserved, the Plasmon satellites will be strong. Relative intensities of Plasmon satellites are calculated as under

(i) When the number of slow electrons are conserved:

For this process [7] have derived the formula for the relative intensity of high Plasmon satellites as

$$I = \alpha[1-(3/2).(\sqrt{2}/\beta).\tan^{-1}\sqrt{\beta/2}+1/(2+\beta)] \quad \text{........(2)}$$

Where α and β are defined [16] as

$$\alpha = 0.16r_s$$
$$\beta = 0.47\sqrt{r_s} \quad \text{...... (3)}$$

Where r_s is a dimensionless parameter [17] given by

$$r_s = \{(47.11)/(\hbar\omega_p)\}^{2/3} = [47.11)/\Delta E]^{2/3} \quad \text{.......(4)}$$

where $\hbar\omega_p$ is equivalent to the energy separation (ΔE) of the Plasmon satellite line from the main x-rays emission line. Using the eq.(2), the relative intensities of Plasmon satellites have been calculated for In, Sn and Sb and are given in Table II. The calculated values are in fairly good agreement with the $^3F_2$ structure on the high energy side of $L_2 M_{4.5} M_{4.5}$ spectra under I-C coupling [11] in Table II.

(ii) When the slow electrons are not conserved:

Langreth[13] has given the formula for the relative intensity of the first Plasmon satellites as

$$I = I_1/I_0 = \alpha = 0.16r_s \quad \text{.......... (5)}$$

Where α, the coupling parameter [13] is given by

$$\alpha = e^2q_{max}/\hbar\omega_p = 0.16r_s \quad \text{.......... (6)}$$

(a) <u>Intensity of high energy Plasmon satellites:</u>

Thus eq. (5) has been used to calculate ^3F peaks on the high energy side of $L_3 M_{4.5} M_{4.5}$ (under I.C coupling) and $L_{2.3} M_{4.5} M_{4.5}$ (under LS coupling) lines and are given in Table III and IV which agrees fairly well with the values observed [11].

(b) <u>Low energy Plasmon satellites:</u>

Equation (5) has been used to calculate the relative intensity of the first peak on the low energy side of $L_2 M_{4.5}M_{4.5}$, $L_3M_{4.5}M_{4.5}$ and $L_{2.3} M_{4.5} M_{4.5}$ Auger spectral lines are given in Table V, which agrees fairly well with the values estimated from [11] curve.

Thus $^3F_2$, $^3F_4$ and ^3F structures on the high energy side and the first peak on the low energy side may be due to Plasmon satellites.

Conclusion

The Plasmon energy of In, Sn and Sb has been calculated which agrees fairly well with the energy separation of $^3F_2$, $^3F_4$ and ^3F structures on the high energy side and the first peak on the low energy side as given by Kleiman et al [11]. It is also calculated the relative intensities of low and high energy Plasmon satellites which also agree fairly well with intensities of $^3F_2$, $^3F_4$ and ^3F structures on the high energy side as given Kleiman et al [11] and also the intensity of the first peak on the low energy side. Thus one can conclude that the structures may be due to Plasmon excitation, while the explanation [11] may also be true.

Table I - Plasmon energy and energy separation of high energy and low energy Plasmon satellites for In, Sb and Sb elements.

Elements	Z	Calculated		Estimated	Observed by Kleiman et al[11]		
		$\Delta E = \hbar\omega_p$ eV	$\Delta E = \hbar\omega_s$ eV Double Surface Plasmon energy	Low energy side ΔE(eV)	High Energy		
					Peak	ΔE(L.S.)	$\Delta E = \hbar\omega_s$ (I.C.)
In	2	10.27	14.6	10.64	$^3F_2$ ^3F $^3F_4$	9.94	10.72 15.68
Sn	2	10.10	14.4	11.06	$^3F_2$ ^3F $^3F_4$	10.2	11.57 16.72
Sb	3	11.70	16.6	11.06	$^3F_2$ ^3F $^3F_4$	10.3	12.52 17.83

Table II -Relative intensity of High energy Plasmon satellite $^3F_2$ peak of $L_2M_{4.5}M_{4.5}$ Auger spectra under IC coupling.

Elements	**$r_s=\{47.11/(\hbar\omega_p)\}^{2/3}$**	**i_{cal} Author's value**	**i Kleiman et al[4] value**	**Peak**
In	2.76	.01	.01	$^3F_2$
Sn	2.81	.01	.01	$^3F_2$
Sb	2.54	.01	.02	$^3F_2$

Table III - Relative intensity of high energy Plasmon satellite ^3F structure under LS coupling of $L_{2.3}$ $M_{4.5}$ $M_{4.5}$ Auger spectra of In, Sn, Sb elements.

Elements	**$r_s=\{47.11/(\hbar\omega_p)\}^{2/3}$**	**i_{cal}**	**i Kleiman et al [11] value**	**Peak $L_{2.3}$ $M_{4.5}$ $M_{4.5}$**
In	2.76	0.44	0.38	^3F
Sn	2.81	0.44	0.38	^3F
Sb	2.54	0.40	0.38	^3F

Table IV - Relative intensity of high energy surface double Plasmon satellite of $^3F_4$ structure under I.C. coupling of L_3 $M_{4.5}$ $M_{4.5}$ Auger spectra of In, Sn, Sb elements.

Elements	**$r_s=\{47.11/\hbar\omega_p)\}^{2/3}$**	**When number of slow electron are not conserved i= .16r_s**	**Peak**	**(IC)Relative Intensities observed by Kleiman (et al) L_3 $M_{4.5}$ $M_{4.5}$**
In	2.19	.35	$^3F_4$(I)	.33
Sn	2.20	.35	$^3F_4$(I)	.34
Sb	2.01	.32	$^3F_4$(I)	.33

Table V- Relative intensity of low energy Plasmon satellite of In, Sn and Sb elements.

Elements	**$r_s=\{47.11/(\hbar\omega_p)\}^{2/3}$**	**i_{cal} Author's value**	**i estimated from Kleiman Curve et al[11] value**
In	2.76	0.44	0.42
Sn	2.81	0.44	0.42
Sb	2.54	0.40	0.38

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