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AMORF YARIMO'TKAZGICHLARNING FUNDAMENTAL YUTILISH SOHASI SPEKTRLARI

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Annotatsiya. *Maqolada amorf yarimo'tkazgichlarning fundamental yutilish sohasi optik yutilish koeffitsiyenti spektral xarakteristikalarini tahlil qilishda Kubo-Grinvud formulasidan foydalanish masalalari ko'rib chiqilgan. Devis–Mott yaqinlashishiga ko'ra formulani aniq integral ko'rinishiga keltirib , elektronlarning turli optik o'tishlari uchun partsial yutilish spektrlarining analitik ifodalarini keltirib chiqarilgan.*

Kalit so'zlar: *Amorf yarimo'tkazgichlar, Kubo-Grinvud formulasi , optik yutilish koeffitsiyenti , harakatchanlik tirqishi, elektron holatlar zichligi , valent zona dumi , partsial yutilish spektri , Devis-Mott yaqinlashishi.*

СПЕКТРЫ ФУНДАМЕНТАЛЬНОГО ПОГЛОЩЕНИЯ АМОРФНЫХ ПОЛУПРОВОДНИКОВ

Аннотация. *В статье рассмотрены вопросы применения формулы Кубо-Гринвуда для анализа спектральных характеристик коэффициента оптического поглощения в области фундаментального поглощения аморфных полупроводников. На основе приближения Дэвиса–Мотта формула приведена к виду определенного интеграла, и выведены аналитические выражения парциальных спектров поглощения для различных типов оптических переходов электронов.*

Ключевые слова: *Аморфные полупроводники, формула Кубо-Гринвуда, коэффициент оптического поглощения, щель подвижности, плотность электронных состояний, хвост валентной зоны, парциальный спектр поглощения, приближение Дэвиса-Мотта.*

FUNDAMENTAL ABSORPTION SPECTRA OF AMORPHOUS SEMICONDUCTORS

Abstract. *The paper investigates the application of the Kubo–Greenwood formula for analyzing the spectral characteristics of the optical absorption coefficient in the fundamental absorption region of amorphous semiconductors. Based on the Davis–Mott approximation, the formula is transformed into a definite integral form, and analytical expressions for the partial absorption spectra of various types of electronic optical transitions are derived.*

Keywords: *Amorphous semiconductors, Kubo–Greenwood formula, optical absorption coefficient, mobility gap, density of electronic states, valence band tail, partial absorption spectrum, Davis–Mott approximation.*

Amorf yarimutkazgichlarni optik yutilish koeffisienti spektral xarakteristikalarini $\alpha(\hbar\omega)$ analitik ifodasini aniqlash uchun odatda, Devis – Mott yaqinlashish usuliga kura Kubo-Grinvud formulasidan foydalaniladi. Bu formulani:

$$\alpha(\hbar\omega) = A\int g_V(\varepsilon)g_C(\varepsilon+\hbar\omega)\frac{d\varepsilon}{\hbar\omega} \quad (1)$$

yoki

$$\alpha(\hbar\omega) = A\int g_V(\varepsilon-\hbar\omega)g_C(\varepsilon)\frac{d\varepsilon}{\hbar\omega} \quad (2)$$

kurinishlarda yoziladi [1, 2]. Bu erda A – yutilgan fotonlarni energiyasiga ($\hbar\omega$) bog'liq bulmagan proporsianallik koeffisienti, $g_V(\varepsilon)$ - va $g_V(\varepsilon-\hbar\omega)$ – lar elektronlarni optik utishlaridan oldingi, $g_S(\varepsilon+\hbar\omega)$ – va $g_S(\varepsilon)$ – lar keyingi holatlari zichliklari.

(1) va (2) formulalardagi integrallar aniqmas bulganligi uchun ular umumiy echimni beradi. Shuning uchun [3] ishda Kubo-Grinvud formulasidan optik yutilish koeffisienti spektrlarini xususiy echimlarini olish maqsadida, undagi integralni aniq integral kurinishda yozish kerakligi kursatilgan. Malumki, elektronlarni optik utishlarini fundamental

sohasida yutilgan fotonlarni energiyasi amorf yarimutkazgichlarni harakatchanlik tirqishining energetik kengligidan ($E_g<\hbar\omega$) katta buladi. [4] ishda amorf yarimutkazgichlarda E_g dan katta energiyali fotonlar yutilganda, bir vaqtni uzida elektronlarni valent zona dumidan utkazuvchanlik zonasiga, valent zonadan utkazuvchanlik zonasiga va valent zonadan utkazuvchanlik zonasi dumiga optik utishlari kuzatilishi kursatilgan va shu utishlarga (1) formulani moslashtirilgan. Odatda, optik yutilish spektrlarni nazariy tadqiq qilishda, amorf yarimutkazgichlarning ruxsat etilgan zonalarni chegaralaridagi elektron holatlari zichliklari chiziqli yoki parabolik, ruxsat etilgan zonalarni dumlaridagi esa, eksponensial taqsimotlar bilan yoziladi [5, 6]. [7] ishda bu taqsimotlar uchun quyidagi empirik model taklif qilingan:

$$g_V(\varepsilon)=N(\varepsilon_V)\left(\frac{\varepsilon_C-\varepsilon}{E_g}\right)^{n_1},\quad n_1=1/2,1 \quad \text{va} \quad g_V(\varepsilon)=N(\varepsilon_V)\exp\left(-\beta_1(\varepsilon-\varepsilon_V)\right). \qquad (3)$$

$$g_C(\varepsilon)=N(\varepsilon_C)\left(\frac{\varepsilon-\varepsilon_V}{E_g}\right)^{n_2},\quad n_2=1/2,1 \quad \text{va} \quad g_C(\varepsilon)=N(\varepsilon_C)\exp\left(\beta_2(\varepsilon-\varepsilon_C)\right), \qquad (4)$$

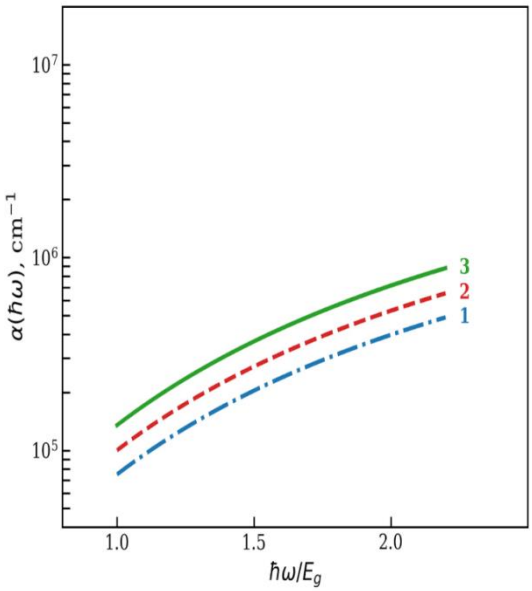
bu erda $N(\varepsilon_V)$ – valent zonadagi, $N(\varepsilon_S)$ – esa, utkazuvchanlik zonasidagi elektron holatlari zichligining effektiv qiymatlari.

Endi yuqoridagi usulda parsial yutilish koeffisienti spektrlarini (2) formuladan foydalanib hisoblash uchun, bu formuladagi integralni aniq integral kurinishida quyidagicha yozamiz:

$$\alpha(\hbar\omega)=A\int_{\varepsilon_0}^{\varepsilon_0+\hbar\omega} g_V(\varepsilon-\hbar\omega)g_C(\varepsilon)\frac{d\varepsilon}{\hbar\omega} \qquad (5)$$

(5) formulani elektronlarni optik utish turlariga moslashtirib, parsial yutilish spektrlariga ajratamiz:

$$\alpha(\hbar\omega)=A\int_{\varepsilon_0}^{\varepsilon_0+\hbar\omega} g_V(\varepsilon-\hbar\omega)g_C(\varepsilon)\frac{d\varepsilon}{\hbar\omega}=A\int_{\varepsilon_V+\hbar\omega}^{\varepsilon_0+\hbar\omega} g_V(\varepsilon-\hbar\omega)g_C(\varepsilon)\frac{d\varepsilon}{\hbar\omega}+$$
$$+A\int_{\varepsilon_C}^{\varepsilon_V+\hbar\omega} g_V(\varepsilon-\hbar\omega)g_C(\varepsilon)\frac{d\varepsilon}{\hbar\omega}+A\int_{\varepsilon_0}^{\varepsilon_C} g_V(\varepsilon-\hbar\omega)g_C(\varepsilon)\frac{d\varepsilon}{\hbar\omega}=\alpha_1(\hbar\omega)+\alpha_2(\hbar\omega)+\alpha_3(\hbar\omega) \qquad (6)$$



1 – rasm. Amorf yarimo‘tkazgichlarni 1 - n_1=n_2=1/2 bo‘lganda (7); 2 - n_1=n_2=1 bo‘lganda (8); 3 - n_1=1, n_2=1/2; yoki n_1=1/2, n_2=1 (9) formulalardan zonalararo partsial yutilish spektrlari.

bu erda ham, $\alpha_1(\hbar\omega)$– valent zona dumidan utkazuvchanlik zonasiga, $\alpha_2(\hbar\omega)$– valent zonadan utkazuvchanlik zonasiga (zonalararo yutilish spektri), $\alpha_3(\hbar\omega)$– valent zonadan utkazuvchanlik zonasi dumiga elektronlarni optik

utishlari bilan aniqlanadigan parsial yutilish koeffisienti spektrlari.(6) formuladagi zonalararo yutilish spektrlarini hisoblaymiz. n_1= n_2=1/2 ga teng bulganda, zonalararo yutilish spektri uchun

$$\alpha_2(\hbar\omega)=\frac{B}{4\hbar\omega E_g}\left[2(\hbar\omega-E_g)\sqrt{E_g\hbar\omega}-(E_g-\hbar\omega)^2\,arctg\left(\frac{E_g-\hbar\omega}{2\sqrt{E_g\hbar\omega}}\right)\right]. \qquad (7)$$

n_1= n_2=1 ga teng bulganda:

$$\alpha_2(\hbar\omega)=\frac{B}{6\hbar\omega E_g^2}(\hbar\omega-E_g)(E_g^2+4\hbar\omega E_g+(\hbar\omega)^2). \qquad (8)$$

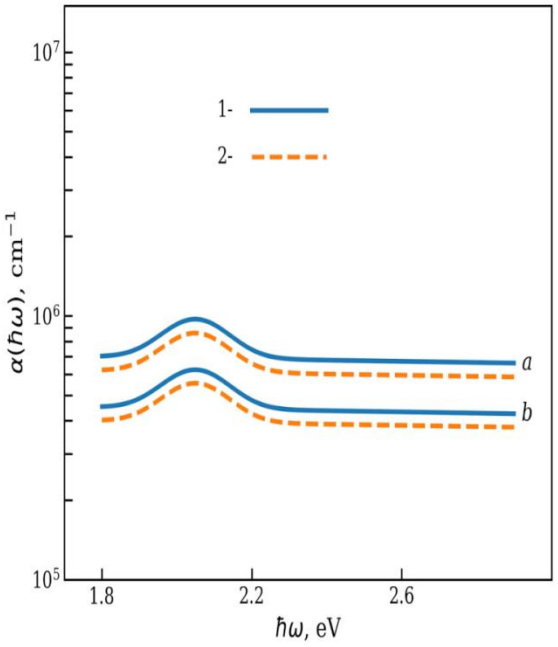
n_1=1, n_2=1/2 va n_1=1\2, n_2=1 bulganda esa:

$$\alpha_2(\hbar\omega)=\frac{2B}{15\hbar\omega\sqrt{E_g^3}}\left[5(\hbar\omega+E_g)\left(\sqrt{(\hbar\omega)^3}-\sqrt{E_g^3}\right)-3\left(\sqrt{(\hbar\omega)^5}-\sqrt{E_g^5}\right)\right]. \qquad (9)$$

ifodalar olindi. (7)-(9) formulalar [4] ishda olingan formulalardan umuman farq qilmasligini kurish mumkin, bu formulalardan olingan hisoblash natijalari 1- rasmda keltirilgan. Bulardan zonalararo yutilish spektrlarini analitik ifodalarini Kubo-Grinvud formulasidan aniqlashda, bu formulani (1) va (2) kurinishlaridan foydalanish mumkin ekanligi kelib chiqadi.

Xuddi shu usulda (6) formuladagi $\alpha_1(\hbar\omega)$ va $\alpha_3(\hbar\omega)$ larni hisoblashni qarab chiqamiz.

n_1=n_2=1/2 ga teng bulganda $\alpha_1(\hbar\omega)$ – valent zona dumidan utkazuvchanlik zonasiga, $\alpha_3(\hbar\omega)$ – valent zonadan utkazuvchanlik zonasi dumiga elektronlarni optik utishlari bilan aniqlanadigan parsial yutilish spektrlarini analitik ifodasini olishni imkoni bulmaganligi uchun, ularni taqribiy hisoblash usullaridan foydalanib aniqlandi.



2 – rasm. 1 - n_1=n_2=1 bo‘lganda (10) va (11) formulasidan hamda 1 - n_1=n_2=1/2 bo‘lganda taqribiy usullarda hisoblangan elektronlarni valent zona dumidan o‘tkazuvchanlik zonasiga (*a*), valent zonadan o‘tkazuvchanlik zonasiga (*b*) optik o‘tishlarining partsial spektrlari.

n_1=n_2=1 ga teng bulganda, valent zona dumidan utkazuvchanlik zonasiga va valent zonadan utkazuvchanlik zonasi dumiga elektronlarni optik utishlari bilan aniqlanadigan parsial yutilish spektrlarini analitik ifodalari:

$$\alpha_1(\hbar\omega)=\frac{B\exp(-\beta_1(\varepsilon_0-\varepsilon_V))}{E_g\hbar\omega\beta_1}\left[\left(\frac{1}{\beta_1}+\hbar\omega\right)\exp(\beta_1(\varepsilon_0-\varepsilon_V))-\left(\varepsilon_0-\varepsilon_V+\frac{1}{\beta_1}+\hbar\omega\right)\right], \qquad (10)$$

$$\alpha_3(\hbar\omega)=\frac{B\exp(\beta_2(\varepsilon_0-\varepsilon_C))}{E_g\hbar\omega\beta_2}\left[\left(\frac{1}{\beta_2}+\hbar\omega\right)\exp(\beta_2(\varepsilon_C-\varepsilon_0))-\left(\varepsilon_C-\varepsilon_0+\frac{1}{\beta_2}+\hbar\omega\right)\right]. \qquad (11)$$

kurinishlarda bulishi aniqlandi. (10)-(11) formulalardan kurish mumkinki, ular [4] ishda olingan formulalar bir xil bular ekan. (10) va (11) formulalardan olingan hisoblash natijalari 2-rasmda keltirilgan. Agar amorf yarimutkazgichlardagi elektron holatlari zichligi taqsimoti uchun tanlangan empirik model tug‘ri bulsa va Kubo-Grinvud formulasini elektronlarni optik utishlariga tug‘ri moslashtirilsa yutilish koeffisieti spektrlarini fundamental sohasidagi parsial spektrlarini (1) va (2) kurinishdagi Kubo-Grinvud formulasidan hisoblanganda bu formuladagi aniq integralni chegaralari tug‘ri olinsa. olinadigan natijalar bir xil bular ekan.

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